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Triallel cross designs for comparing a set of test lines with a control line

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Abstract

Partial triallel cross (PTC) designs are suitable for developing crosses between inbred lines to study the genetic nature of quantitative traits in crops, which in turn help identify the strategy and methods of selection essential for breeding. PTCs are useful to compare test lines versus control line with more precision. In this paper, a method for constructing a class of PTC designs for comparing a set of test lines with a control line has been described. The proposed class of designs are variance balanced for estimating the contrasts pertaining to general combining ability effects of half as well as full parents. The suggested construction method doesn't demand deep knowledge in statistics and therefore, the breeders can easily obtain small and efficient triallel cross plans for test lines vs. control line comparisons for their breeding trial.

Key words: Combining ability, variance balance, partial triallel, test *vs*. control comparisons

Introduction

Quite often breeding programmes are planned for hybridization of plants/animals that involves several lines/individuals and are extended to various generations. The major objective of any breeding programme is to improve the genetic potential of the individuals. Even though several differences exist in techniques and strategies involved in plant and animal breeding, the experimental designing aspect remains same. There may be different types of suitable mating designs available for plant and animal breeding experiments but the basic idea behind them is that the phenotypic expression of an individual is much affected by the blocking (environment) of crosses/ treatments. Thus in order to evaluate the inherited traits, selection of a suitable mating-environmental design (crosses arranged in blocks) becomes important. Moreover, breeders may be interested in opting suitable methods for evaluation of the combining abilities of lines so that potential lines can be chosen for making crosses. A series of methods is available for making crosses like diallel, triallel, tetra-allele, but triallel is most suitable as it is intermediate of the other two methods from the view point of both resource utilization and information on combining ability effects.

There are many crops like maize and corn where three-way crosses are commonly used to develop commercial hybrids. Weatherspoon (1970) recommended the use of three-way crosses as they are more uniform, high yielding and stable than the single cross hybrids. However, the number of crosses in a complete three-way cross plan increases manifold and becomes unmanageable with increase in the number of lines. This situation forces the investigator to take a sample of complete triallel crosses, known as partial triallel crosses (PTC). Under PTC, a sample has to be drawn in a systematic manner such that a minimum loss of information regarding combining ability effects may occur.

Hinkelmann (1965) introduced the term PTC and defined it as a set of crosses involving n lines if, (i) each line occurs exactly r_H times as half-parent and r_F times as full-parent and (ii) each cross (ixj)xk occurs either once or not at all. Here, the condition (ii) doesn't exclude the simultaneous occurrence of (ixj)xk, (ixk)xj and (jxk)xi in order to ensure the structural symmetric property (SSP) of the PTC. The total number of crosses is nr_F. Since each line is equally often represented as half-parent it follows immediately that $r_H = 2r_F$.

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Suitable mating-environmental designs are to be chosen for the selection of crosses and their arrangement in blocks. This is equally important as the selection of appropriate parental lines is essential for a successful breeding programme. A series of PTC plans using Trojan square design, generalized incomplete Trojan type designs and mutually orthogonal Latin squares have been obtained by Dharmalingam (2002), Varghese and Jaggi (2011) and Sharma et al. (2012). Choi et al. (2004) obtained diallel cross plans for comparing test lines with a control line. Hsu and Ting (2005) investigated A-optimality of diallel cross experiments for comparing two or three test lines with a control line. A series of partial diallel cross designs for test vs. control comparisons are given in Srivastava et al. (2013). Some methods of constructing variance balanced mating-environmental row-column designs for test lines vs. control comparisons are developed by Varghese and Varghese (2015). In all these studies, designs are obtained such that all pair-wise comparisons among general combining ability effects pertaining to half as well as full parents are given equal importance. However, in most of the breeding trials the breeder may be interested in making crosses of new lines/test lines with an established control line and thus making a comparative study to find out the new lines worth for use in breeding programmes. The aim of the present study was to construct variance balanced PTC designs that may be suitable for comparing several test lines with a control line.

Materials and methods

Model

Let there be n number of lines. One can obtain $N = n(n-1)(n-2)/2$ three-way crosses from n lines. Consider three-way crosses (ignoring reciprocal effects) of the form $i \times j \times k$ (i, j, k = 1,2,…,n and $i \neq j \neq k$) arranged in b blocks of size k and each cross replicated r times. The model for mating experiments can be expressed in the form

$$y_{lm} = \mu + \tau_{(ijk)l} + \beta_m + e_{lm} \qquad (1)$$

where y_{lm} is the response from the l^{th} cross (l =1,2,…,N) belonging to the m^{th} (m = 1,2,…,b) block, μ is the grand mean, $\tau_{(ijk)l}$ the effect of the l^{th} triallel cross and e_{lm} is *i.i.d.* following a normal distribution with 0 mean and constant variance σ^2.

Method of Construction of three-way cross plans with crosses arranged in blocks (PTC Design 1) for test vs. control comparisons

Let n represents the number of test lines, which is a prime number (>5, but not a prime power). Various steps involved in the construction are:

- Obtain (n-1) initial columns of size 3 each starting with line 1 by successively adding 1 to each preceding entry in the first initial column, 2 to each preceding entry in the second initial column and so on, adding (n-1) to each preceding entry in the $(n-1)^{th}$ initial column, modulus n.
- Develop (n-1) more columns from each initial column by successively adding 1 to each element in the previous column, modulus n. Thus, (n-1) arrays, each of size 3 x n is obtained.
- Now, replace the third row of any (n-1)/2 arrays by the control line (denoted by 0).
- Making all possible distinct three-way crosses within each column of each array, a family of complete/partial three-way cross plans can be obtained. To ensure SSP, crosses of types (ixk)xj and (jxk)xi are considered along with each cross (ixj)xk in each block.

The nature of plan varies from complete to partial triallel cross with increasing n, *i.e*., the plan becomes complete triallel cross for n < 7 and otherwise, it is a partial triallel cross. The parameters of this class of designs are, total number of crosses (N) = 3n(n-1), number of blocks (b) = (n-1), block size (k) = 3n and degree of fractionation (f) = 6/(n+1).

Method of Construction of three-way cross plans with crosses arranged in blocks (PTC Design 2) for test vs. control comparisons

From PTC Design1, another class of PTC designs for n test lines (n is a prime number >5) can be obtained as a particular case. Various steps in the construction procedure are: (i) Obtain (n-1)/2 initial columns of size two starting with 1 by adding 1 to first, 2 to second and so on (n-1)/2 to $(n-1)/2^{th}$ initial column, mod n. (ii) Develop (n-1) more columns from each initial column by adding successively 1 to each element in the preceding column (mod n). Thus, (n-1)/2 arrays, each of size 2 ´ n is obtained. (iii) Now, append a third row consisting of the control line (represented by 0) to each array resulting in (n-1)/2 arrays of size 3 x n. Thus, (n-1)/2 blocks each consisting 3n crosses (crosses of types (ixk)xj and (jxk)xi are to be considered along with each cross (ixj)xk in each block in order to ensure

SSP of the plan) can be obtained easily by making all possible crosses within each column of each array. The parameters of this particular class of designs are: $N = 3n(n-1)/2$, $b = (n-1)/2$, $k = 3n$ crosses and $f = 3/(n+1)$. These parameters are listed in Table 1 for n = 25.

A program was written in PROC IML of SAS software (available with the authors) to compute ($1/\sigma^2$) times the variances of contrasts pertaining to estimated gca effects for test vs. test and test vs. control lines of half parents ($V_{h_{ii'}}$ and $V_{h_{i0}}$) as well as full parents ($V_{g_{ii'}}$ and $V_{g_{i0}}$), where, 0 denotes the control line and $i \neq i' = 1, 2, ..., n$.

Results and discussion

Designs under PTC Design1 are constructed for different values of n. As an example, for n = 7, the following design is constructed based on the methodology described under materials and methods.

1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
2	3	4	5	6	7	1	3	4	5	6	7	1	2	4	5	6	7	1	2	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
5	6	7	1	2	3	4	6	7	1	2	3	4	5	7	1	2	3	4	5	6
2	3	4	5	6	7	1	4	5	6	7	1	2	3	6	7	1	2	3	4	5

The crosses are obtained by making all the possible distinct three-way crosses within each column of each array as follows:

Block I	Block II	Block III	Block IV	Block V	Block VI
(1×2)×0	(1×3)×0	(1×4)×0	(1×5)×2	(1×6)×4	(1×7)×6
(2×3)×0	(2×4)×0	(2×5)×0	(2×6)×3	(2×7)×5	(2×1)×7
(3×4)×0	(3×5)×0	(3×6)×0	(3×7)×4	(3×1)×6	(3×2)×1
(4×5)×0	(4×6)×0	(4×7)×0	(4×1)×5	(4×2)×7	(4×3)×2
(5×6)×0	(5×7)×0	(5×1)×0	(5×2)×6	(5×3)×1	(5×4)×3
(6×7)×0	(6×1)×0	(6×2)×0	(6×3)×7	(6×4)×2	(6×5)×4
(7×1)×0	(7×2)×0	(7×3)×0	(7×4)×1	(7×5)×3	(7×6)×5

Crosses of types (ixk)xj and (jxk)xi are considered along with each cross (ixj)xk in each block to ensure SSP. The parameters of the design are: N = 126, b = 6, k = 21 and f = 6/8. The ($1/\sigma^2$) times of the variances for test vs. test and test vs. control comparisons, pertaining to the estimated gca effects of half parents and full parents are computed as $V_{h_{ii'}}$ =0.0802, $V_{h_{i0}}$ =0.0344, $V_{g_{ii'}}$ = 0.1390 and $V_{g_{i0}}$ 0.0596 where $i \neq i' = 1, 2, ..., n$. For other values of n, designs are constructed as explained above (not reported). The parameters of the designs obtained have been listed for $n \leq 25$ in Table 1 along with the computed variances. The variance of contrasts pertaining to the estimated general combining ability effects of full parents as well as half parents are computed for test vs. test lines and test vs. control lines and it was found that test lines vs. control line comparisons are made with more precision. For test vs. test line comparisons, contrasts pertaining to general combining ability effects of full parents as well as half parents are estimated with a constant variance indicating that the designs obtained are variance balanced.

Designs under PTC Design 2 for different values of n are constructed. To illustrate the method of construction, PTC design with n = 7 lines is given below:

1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
2	3	4	5	6	7	1	3	4	5	6	7	1	2	4	5	6	7	1	2	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The crosses thus obtained in each of the 21 columns are given as follows:

Block I	Block II	Block III
(1×2)×0	(1×3)×0	(1×4)×0
(2×3)×0	(2×4)×0	(2×5)×0
(3×4)×0	(3×5)×0	(3×6)×0
(4×5)×0	(4×6)×0	(4×7)×0
(5×6)×0	(5×7)×0	(5×1)×0
(6×7)×0	(6×1)×0	(6×2)×0
(7×1)×0	(7×2)×0	(7×3)×0

The parameters of the designs after ensuring SSP are: N = 63, b = 3, k = 21, and f = 6/8. ($1/\sigma^2$) times the variances for test versus test and test versus control, pertaining to the estimated gca effects of half parents and full parents is given as $V_{h_{ii'}}$ =0.0802, $V_{h_{i0}}$ =0.0344, $V_{g_{ii'}}$ = 0.1390 and $V_{g_{i0}}$ 0.0596 where 0 is the control line and In a similar way, for other values of n the PTC designs are constructed (not reported).

Table 1. Triallel cross plans for comparing *n* test lines with a control line

S.No.	*n*	Type of design	*N*	*b*	*k*	*f*	$V_{h_{ii0}}$	$V_{h_{ii'}}$	$V_{h_{ii0}}$	$V_{g_{ii'}}$
1	5*	D_1	60	4	15	1	0.2262	0.5654	0.0905	0.2262
2	5*	D_2	30	2	15	3/6	0.4741	1.1852	0.2074	0.5185
3	7	D_1	126	6	21	6/8	0.1375	0.3209	0.0596	0.1390
4	7	D_2	63	3	21	3/8	0.3165	0.7385	0.1451	0.3385
5	11	D_1	330	10	33	6/12	0.0802	0.1764	0.0369	0.0811
6	11	D_2	165	5	33	3/12	0.1924	0.4233	0.0914	0.2011
7	13	D_1	468	12	39	6/14	0.0666	0.1442	0.0311	0.0673
8	13	D_2	234	6	39	3/14	0.1612	0.3491	0.0772	0.1673
9	17	D_1	816	16	51	6/18	0.0498	0.1058	0.0237	0.0503
10	17	D_2	408	8	51	3/18	0.1217	0.2586	0.0589	0.1253
11	19	D_1	1026	18	57	6/20	0.0442	0.0934	0.0211	0.0446
12	19	D_2	513	9	57	3/20	0.1084	0.2289	0.0527	0.1113
13	23	D_1	1518	22	69	6/24	0.0362	0.0757	0.0174	0.0365
14	23	D_2	759	11	69	3/24	0.0891	0.1862	0.0435	0.0910

*These are CTC plans

It can be deduced from the results that through the suggested methods, breeders can obtain small and efficient triallel cross plans with comfortable knowledge in statistics. By using these designs, they can optimize the resource utilization and reduce the heterogeneity present in the experimental field, simultaneously. As the lines are being selected using triallel plans, uniformity, yield and stability of the selected ones are also ensured.

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