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Vekariya PR
Ph.D. Scholar, B. A. College of
Agriculture, Anand Agricultural
University, Anand, Gujarat, India

Darji VB
Retd. Professor, B. A. College of
Agriculture, Anand Agricultural
University, Anand, Gujarat, India

Pandya MM
Assistant Research Scientist, Main
Vegetable Research Station, Anand
Agricultural University, Anand,
Gujarat, India

Corresponding Author:
Vekariya PR
Ph.D. Scholar, B. A. College of
Agriculture, Anand Agricultural
University, Anand, Gujarat, India

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Relative efficiency of Variance Balanced Design (VBD) and Alpha Lattice Design (ALD) in diallel crosses of brinjal

Vekariya PR, Darji VB and Pandya MM

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Abstract

Field experiments are critical in agricultural research, enabling the study of treatments under real-world conditions. A common issue in such experiments is soil heterogeneity, which introduces variability into results. This study compared Randomized Complete Block Design (RCBD) with two Incomplete Block Designs (IBD); Alpha Lattice Design (ALD) and Variance Balanced Design (VBD) in evaluating F_1 populations of brinjal crosses. The analysis showed that VBD significantly improved experimental accuracy, with average gains over RCBD of 107.5% in Error Mean Square (EMS), 50.95% in Standard Error of Mean (S.E.m), 55.05% in Coefficient of Variation (CV%), and 18.75% in F estimates, averaging a 58.06% efficiency gain. ALD also demonstrated notable gains with 47.64% in EMS, 21.55% in S.E.m, 21.54% in CV%, and 32.22% in F estimates, averaging 30.74%. The reduced error variances in VBD and ALD underscore their superiority over RCBD. These findings suggest that VBD, in particular, is the most efficient design for improving precision in field experiments involving brinjal crosses. Consequently, adopting VBD and ALD can significantly enhance the accuracy and reliability of crosses effect estimates in agricultural research. The study concludes that IBDs, especially VBD, should replace RCBD in such experiments, as they are straightforward to construct and analyze, offering a robust solution for managing soil heterogeneity and improving experimental outcomes.

Keywords: Alpha lattice design, variance balanced design, error mean square, standard error of mean, coefficient of variation, efficiency

Introduction

Field experiments play a crucial role in agricultural research, allowing scientists to study the effects of various treatments or measures under actual growing situations. While designing field experiments, researchers often encounter the need to allocate treatments efficiently to minimize bias and maximize the precision of the estimates (Johnston & Poulton, 2018) [6]. Agricultural field experimenters are experiencing the problem of soil heterogeneity which is one of the major causes of variability in experimental data/results.

A survey carried out under the “Statistical evaluation of experimental variability for improving the efficiency of field experimentation” project on the use of experimental designs by Research Scientists in Gujarat state revealed that more than 95% of the field experiments are being conducted in the RCBD (Anon., 2016) [1]. The accuracy of this design depends on the control of heterogeneity within blocks (replications). But the use of RCBD is inefficient and unsuitable when the number of genotypes (treatments) is as large as sixteen in a single block (Yang *et al.*, 2004) [13] because of failure to adequately minimize the effect of soil heterogeneity (Lentner and Bishop, 1993) [7]. There are certain trade-offs between the two designs, though. CBD requires a greater number of blocks than IBD since each treatment must be present in every block. When the experimental area is small or achieving block homogeneity is difficult, this requirement can be a restriction. In such circumstances, IBD is a more appealing option making it more viable and cost-effective (Dean *et al.*, 1981) [3].

The practical utility of comparing complete block design vs incomplete block design is that it allows researchers to make conclusion regarding which design is best suited for their investigations. Good field designs help to ensure efficient/precise estimates of treatment effects.

For effective control of experimental error due to soil heterogeneity relatively small blocks are a must. Incomplete Block Designs (IBD) and Balanced Incomplete Block Designs (BIBD) help in achieving this goal through the concept of local control (one of the basic requirements of field experimentation). The treatments/entries/genotypes are grouped theoretically and allotted into small blocks within replication. Consequently, there is a gain in precision in the experimental results. The gain in efficiency / precision of one design over another design is measured by Relative Efficiency (RE).

The advantage of alpha lattice design is that it is easy to construct and can be constructed in cases where balanced incomplete block designs and lattice designs don't exist. In the early phase/stage of introduction of alpha lattice design the aim was to control variation down the columns of plots in the field. This is often adequate when plots are long and narrow. Patterson and Hunter (1983) [8] have demonstrated the value of alpha designs in terms of gain in efficiency. Yau (1997) [14] reported the use of alpha lattice design in 714 international yield trials of barley, durum wheat and bread wheat from 1990-91 to 1992-93 and found average efficiency 18% higher than the RCBD. Though IBD and its forms are relatively more efficient (resource-saving) than RCBD, these designs are not in use on all Crop Research Stations/Centres functioning in the Gujarat state. Scientists accept theory and results on the basis of the "seeing is believing" concept. Many researchers observed that alpha lattice design is more efficient than RCBD and has the potential to replace RCBD (Patterson and Silvey, 1980; Patterson *et al.*, 1978; Patterson and Hunter, 1983; Pilarczyk, 1991; Yau, 1997; Campbell and Bauer, 2007) [9, 10, 8, 11, 14, 2].

Materials and Methods

Experimental Site

Crossing of genotypes was carried out to generate F₁ populations in *Late Kharif*, 2021 at the Main Vegetable Research Station, AAU, Anand. Further the generated material was evaluated in

Late Kharif, 2022 at the Agronomy Farm, AAU, Anand. Anand is located in Agro Climatic Zone-III (Middle Gujarat) of Gujarat State. Geographically, Anand is situated at 22° 58' N latitude and 72° 92' E longitude with an elevation of 45.1 meters above the mean sea level. The soil of the experimental site is sandy loam, the typical "Goradu" soil of the "Charotar" tract, which has less organic matter content with 8.1 to 8.3 soil pH and 0.20 to 0.25 EC. It is very deep, well-drained and fairly moisture retentive. The climatic condition of the area represents the tropical condition with a semi-arid climate. Anand is the head quarter of the Anand Agricultural University.

Experimental Material

Ten brinjal genotypes (Table 1) were used as parents to make diallel crosses. The seeds of parents were sown in nursery and transplanted into field after 30 days to form crossing block in *Late Kharif*, 2022. Crossing was carried out in all possible combinations excluding reciprocal crosses in crossing block for making 45 hybrids (Table 2) among all the parents. The diallel crosses were made as per Griffing's Method IV (Griffing, 1956) [5].

Table 1: Details of the parents used in the study

Notation	Genotype (Parents)	Source
P ₁	AB 15-06	Main Vegetable Research Station, AAU, Anand
P ₂	AB 20-09	Main Vegetable Research Station, AAU, Anand
P ₃	AB 15-08	Main Vegetable Research Station, AAU, Anand
P ₄	AB 15-18	Main Vegetable Research Station, AAU, Anand
P ₅	AB 20-07	Main Vegetable Research Station, AAU, Anand
P ₆	ABSR 2	Main Vegetable Research Station, AAU, Anand
P ₇	AB 20-13	Main Vegetable Research Station, AAU, Anand
P ₈	GP BRJ 224	Main Vegetable Research Station, AAU, Anand
P ₉	GP BRJ 309	Main Vegetable Research Station, AAU, Anand
P ₁₀	AB 20-03	Main Vegetable Research Station, AAU, Anand

Table 2: List of F₁ population (crosses) of diallel crosses used in study

Notation	Crosses	Notation	Crosses
C ₁	AB 15-06 × AB 20-09	C ₂₄	AB 15-08 × AB 20-03
C ₂	AB 15-06 × AB 15-08	C ₂₅	AB 15-18 × AB 20-07
C ₃	AB 15-06 × AB 15-18	C ₂₆	AB 15-18 × ABSR 2
C ₄	AB 15-06 × AB 20-07	C ₂₇	AB 15-18 × AB 20-13
C ₅	AB 15-06 × ABSR 2	C ₂₈	AB 15-18 × GP BRJ 224
C ₆	AB 15-06 × AB 20-13	C ₂₉	AB 15-18 × GP BRJ 309
C ₇	AB 15-06 × GP BRJ 224	C ₃₀	AB 15-18 × AB 20-03
C ₈	AB 15-06 × GP BRJ 309	C ₃₁	AB 20-07 × ABSR 2
C ₉	AB 15-06 × AB 20-03	C ₃₂	AB 20-07 × AB 20-13
C ₁₀	AB 20-09 × AB 15-08	C ₃₃	AB 20-07 × GP BRJ 224
C ₁₁	AB 20-09 × AB 15-18	C ₃₄	AB 20-07 × GP BRJ 309
C ₁₂	AB 20-09 × AB 20-07	C ₃₅	AB 20-07 × AB 20-03
C ₁₃	AB 20-09 × ABSR 2	C ₃₆	ABSR 2 × AB 20-13
C ₁₄	AB 20-09 × AB 20-13	C ₃₇	ABSR 2 × GP BRJ 224
C ₁₅	AB 20-09 × GP BRJ 224	C ₃₈	ABSR 2 × GP BRJ 309
C ₁₆	AB 20-09 × GP BRJ 309	C ₃₉	ABSR 2 × AB 20-03
C ₁₇	AB 20-09 × AB 20-03	C ₄₀	AB 20-13 × GP BRJ 224
C ₁₈	AB 15-08 × AB 15-18	C ₄₁	AB 20-13 × GP BRJ 309
C ₁₉	AB 15-08 × AB 20-07	C ₄₂	AB 20-13 × AB 20-03
C ₂₀	AB 15-08 × ABSR 2	C ₄₃	GP BRJ 224 × GP BRJ 309
C ₂₁	AB 15-08 × AB 20-13	C ₄₄	GP BRJ 224 × AB 20-03
C ₂₂	AB 15-08 × GP BRJ 224	C ₄₅	GP BRJ 309 × AB 20-03
C ₂₃	AB 15-08 × GP BRJ 309		

Experimental Details

Three environmental designs *i.e.*, Randomized Complete Block Design (here after RCBD), Alpha Lattice Design (here after ALD) and Variance Balanced Design (here after VBD) to evaluate the F_1 populations (here after crosses) of diallel crosses. Each plot consisted of three rows each of eight plants with spacing of 90 cm × 60 cm (Inter row × Intra row). RCBD consists two replications whereas ALD consists of 5 × 9 blocks *i.e.*, five blocks, each containing nine crosses, with two replications. The parameters for the VBD include 10 blocks, two replications, and a block size of nine.

For recording fruit yield, five plants were randomly selected before flowering start per crosses. Picking-wise number of fruits (NF) and fruit weights (FY) were recorded. The total fruit yield was derived by summing up the picking-wise (all) fruit weight. Similarly, picking-wise number of fruits harvested were summed up to obtain total number of fruits. The average values of five plants were used in analysis.

Statistical analysis

Data were subjected to statistical tools to compare efficiency of the experimental designs *viz.*, ALD, VBD and RCBD using error mean square (EMS), coefficient of variation (CV%), standard error of mean (SEm) and F-estimate of the experiments. The variance components were computed using the Analysis of Variance (ANOVA) approach. For the analysis, different statistical models were used as described below.

RCBD

$$Y_{ij} = \mu + r_j + t_i + \varepsilon_{ij}$$

ALD

$$Y_{ijk} = \mu + t_i + r_j + b_{jk} + e_{ijk}$$

VBD

$$Y = \mu 1 + X\tau + D\beta + \varepsilon$$

Relative efficiency by error mean square

To calculate RE of ALD over RCBD, following equation was used:

$$RE\% = \frac{\hat{\sigma}_{eRCBD}^2}{\hat{\sigma}_{eALD}^2} \times 100$$

$\hat{\sigma}_{eRCBD}^2$ and $\hat{\sigma}_{eALD}^2$ are error mean squares of respective designs.

Ghosh and Ahuja (2017)^[4] suggested the formula for calculating relative efficiency (RE) for comparing randomized complete block design (RCBD) and variance balanced design (VBD) as mentioned below:

$$RE\% = \frac{V(\hat{t}_i - \hat{t}_j)_{RCBD}}{V(\hat{t}_i - \hat{t}_j)_{VBD}} \times 100$$

Where,	
$V(\hat{t}_i - \hat{t}_j)_{RCBD}$	$\frac{2}{r} \hat{\sigma}_{RCBD}^2$
$V(\hat{t}_i - \hat{t}_j)_{VBD}$	$\frac{2}{\theta} \hat{\sigma}_{VBD}^2$
r	Number of replications in RCBD
$\hat{\sigma}_{RCBD}^2$	Error mean square of RCBD
$\hat{\sigma}_{VBD}^2$	Error mean square of VBD
θ	$\frac{n-b}{v-1}$ [n = number of observations, v = number of crosses, b = blocks]
(Note: Relative efficiency is expressed in per cent)	

Relative efficiency by SEm and CV%

Relative Efficiency using SEm and CV was calculated by taking ratio of SEm and CV as

$$RE\% = \frac{SEm_{RCBD}}{SEm_{ALD \text{ (or VBD)}}} \times 100$$

$$RE\% = \frac{CV_{RCBD}}{CV_{ALD \text{ (or VBD)}}} \times 100$$

If the value is greater than 100, VBD and ALD would be considered efficient in comparison to RCBD.

The gain in efficiency was computed using formula:

$$\text{Gain in efficiency} = RE\% - 100$$

Relative efficiency by calculated F value

Relative Efficiency using F value was calculated by taking ratio of F value as

$$R_f = \frac{\text{Cal. F}_{RCBD}}{\text{Cal. F}_{ALD \text{ (or VBD)}}} \times 100$$

If the value is lower than 100, VBD and ALD would be considered efficient in comparison to RCBD.

The gain in efficiency was computed using formula:

$$\text{Gain in efficiency} = 100 - RE\%$$

Result and Discussion

The replication effect (Table 3) was found significant or highly significant in brinjal experiment conducted in RCBD and ALD for both traits studied. The block effects in VBD were highly significant for both traits leading to error reduction and yielding more accurate estimates compared to RCBD.

Experimental analysis of RCBD and ALD (Table 3) revealed similar mean square estimates for replication effect and crosses effect (barring estimates obtained in VBD analysis). The error

variance ($\hat{\sigma}_e^2$) exhibited a consistent trend across both traits studied, with RCBD having a higher value compared to VBD followed by ALD. The observed error variances suggested that the IB (ALD and VBD) designs, increased the precision of the estimates in comparison to RCBD.

Table 3: Analysis of variance (ANOVA) for experiment conducted on brinjal

Trait	Source	RCBD		ALD		VBD	
		df	MS	df	MS	df	MS
FY	Rep / Block [@]	1	3.57*	1	3.57**	9 [@]	4.64**
	Crosses	44	4.35**	44	4.35**	44	2.10**
	Block (*Rep)	-	-	8	1.34**	-	-
	Error	44	0.57	36	0.40	36	0.22
NF	Rep / Block [@]	1	399.02*	1	399.02*	9 [@]	2470.82**
	Crosses	44	1620.61**	44	1620.61**	44	993.32**
	Block (*Rep)	-	-	8	212.45 **	-	-
	Error	44	83.67	36	55.06	36	41.99

*Rep: Replication

*, ** significant at $p \leq 0.05$ and $p \leq 0.01$, respectively**Table 4:** Gain in efficiency by various measures

Parameters	Traits	Over RCBD						Over ALD	
		RCBD		ALD		VBD		VBD	
EMS	FY	0.57	100 (0.00)	0.40	143.29 (43.29)	0.22	233.88 (133.88)	0.22	163.22 (63.22)
	NF	83.67	100 (0.00)	55.06	151.98 (51.98)	41.99	181.11 (81.11)	41.99	119.18 (19.18)
S.Em	FY	0.53	100 (0.00)	0.44	119.82 (19.82)	0.33	160.73 (60.73)	0.33	134.14 (34.14)
	NF	6.47	100 (0.00)	5.25	123.27 (23.27)	4.58	141.16 (41.16)	4.58	114.51 (14.51)
CV%	FY	14.75	100 (0.00)	12.32	119.72 (19.72)	8.91	165.54 (65.54)	8.91	138.27 (38.27)
	NF	12.36	100 (0.00)	10.02	123.35 (23.35)	8.55	144.56 (44.56)	8.55	117.19 (17.19)
R estimate	FY	7.69	100 (0.00)	11.02	69.78 (30.22)	9.54	80.61 (19.39)	9.54	115.51 (-15.51)
	NF	19.37	100 (0.00)	29.44	65.79 (34.21)	23.65	81.90 (18.10)	23.65	124.48 (-24.48)

Table 5: Average gain in efficiency by designs studied (%)

Over RCBD	Gain in efficiency by				Average
	EMS	S.Em	CV%	F	
In ALD	47.64	21.55	21.54	32.22	30.74
In VBD	107.5	50.95	55.05	18.75	58.06

The relative efficiency of the VBD compared to the RCBD based on the EMS was 133.88% for fruit yield and 81.11% for the number of fruits in brinjal (Table 4). VBD showed a gain of 63.22% in fruit yield and 19.18% in the number of fruits over the ALD, while ALD exhibited a gain of 43.29% and 51.98% over RCBD, respectively.

Based on the S.Em, VBD's relative efficiency compared to RCBD was 60.73% for fruit yield and 41.16% for the number of fruits (Table 4). The efficiency gain of VBD over ALD was 34.14% for fruit yield and 14.51% for the number of fruits, whereas ALD's efficiency gain over RCBD was 19.82% and 23.27%, respectively.

In terms of the CV%, VBD's relative efficiency compared to RCBD was 65.54% for fruit yield and 44.56% for the number of fruits (Table 4). VBD's efficiency gain over ALD was 38.27% for fruit yield and 17.19% for the number of fruits. ALD demonstrated higher efficiency compared to RCBD.

Regarding the F estimate, VBD's relative efficiency compared to RCBD was 19.39% for fruit yield and 18.10% for the number of fruits in brinjal (Table 4). The relative efficiency gain of VBD over ALD was -15.51% for fruit yield and -24.48% for the number of fruits, indicating that ALD had higher efficiency compared to RCBD.

VBD demonstrated substantial improvements over RCBD with average gains of 107.5% in EMS, 50.95% in S.Em, 55.05% in CV% and 18.75% in F estimate, averaging 58.06%. ALD also showed notable efficiency gains over RCBD with 47.64% in EMS, 21.55% in S.Em, 21.54% in CV%, and 32.22% in F estimate, averaging 30.74%. These findings highlight the superior performance of VBD in optimizing experimental accuracy and reliability.

Overall, the results emphasize the significance of VBD and

ALD, both being incomplete block designs, over RCBD. VBD emerged as the preferred choice from an efficiency viewpoint for evaluating F_1 populations of crosses in the brinjal crop. Similar results were reported by Popat (2021) [12].

Experiment conducted in VBD on the F_1 generation of brinjal produced through a diallel mating design, yielded more precised results compared to ALD and RCBD. Blocking within replication (VBD) played a significant role in reducing experimental error. Thus, it can be inferred that VBD was more effective and the estimates obtained from VBD were more precise compared to ALD and RCBD. When compared the estimates of RCBD with ALD (Table 3), ALD was better choice than RCBD for field experiments on brinjal crosses.

Conclusion

From the present investigation it can be concluded that the incomplete block designs viz., Variance Balanced Design (VBD) and Alpha Lattice Design (RCD) are efficient in differentiating performances of crosses than Randomized Complete Block

Design (RCBD). The trend of error variance ($\hat{\sigma}_e^2$) $\hat{\sigma}_{eRCBD}^2 > \hat{\sigma}_{eALD}^2 > \hat{\sigma}_{eVBD}^2$ proved effectiveness of VBD and ALD. The present study encompasses experiments with larger sets of crosses, providing valuable insights into the efficacy of experimental designs. In general, IBD (ALD & VBD) provided smaller EMS, SEm, CV% and larger F values compared to RCBD increasing efficiency in comparing crosses. Therefore, plant breeders are advocated to use VBD and ALD in place of RCBD for evaluating breeding materials.

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