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Relative effectiveness of alpha lattice design and randomized complete block design in oats breeding experiment

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Abstract

To decrease errors and increase the precision and efficacy of crop improvement programmes, a quality experimental design is required in addition to breeding methods. In this study, ninety-six oat genotypes used to examine the relative efficiency of randomized complete block design (RCBD) and alpha lattice design (ALD). Effectiveness of ALD over RCBD was determined for green forage yield per plant and seed yield per plant. Genotypes were sown in three replications during two consecutive years 2019-20 and 2020-21. The results of each year of experiment showed >1.0 relative efficiency for ALD while in pooled environment of each trait relative efficiency changed drastically might be due to high and significant genotype X environment interaction for studied traits. Multi-environment trials are the major concerned for evaluation of entries for economic traits. So as a consequence RCBD should be substituted by ALD in crop field experiments.

Keywords: Alpha lattice design, Randomized complete block design, Relative efficiency, Crop improvement, Oats

1. Introduction

One of the basic principles in experimental design is that of reduction of experimental error. In the last 50 years or more, there has been a phenomenal increase in the creation and introduction of new experimental designs, owing in large part to an ever-expanding area of applications as well as the mathematical beauty and challenge that some of these designs bring. While many designs originated in agricultural field experiments, it is now clear that these designs, as well as changes, expansions, and scientific breakthroughs, were stimulated by applications in almost every sort of experimental study (Hinkelmann and Kempthorne, 2005). For example, in field research, randomized complete block design (RCBD) is being used frequently. This approach incorporates all three principles of experimentation: randomization, replication, and local control. The experimental units are divided into groups (referred to as blocks) in these designs so that the experimental units within each block are as homogenous as feasible. A Randomized Full Block (RCB) design is a complete block in the sense that each block is a complete replication, as the name indicates (Gupta *et al.*, 2016). Scientists in developed countries objurgate the capability of RCBD while dealing with major field experiments. One of the disadvantages of RCBD is that it is only acceptable for genotypes ranging twenty-five to thirty in a single block due to heterogeneity in experimental units within blocks. RCBD has indeed been replaced with a resolvable incomplete block designs developed (Patterson and Williams, 1976; William and Talbot, 1993).

The approach of creating some forms of resolvable incomplete block designs, such as balanced incomplete block (BIB) or partially balanced incomplete block (PBIB) designs is known as lattice design. BIB designs often require a high number of replications and are not accessible for all parameter combinations. Lattice designs were first created for large-scale agricultural trials (Yates, 1936), when a large number of genotypes need to be compared with greater accuracy. When the number of genotypes (g) or block size (k) does not fulfill the precise requirements for one of the lattice designs, we can use alpha designs to create resolvable incomplete block designs (Sharma and Das, 1985). Alpha designs are resolvable incomplete block designs with a block size that is a multiple of the number of entries/treatments or genotypes (Patterson and Williams, 1976; John and Williams, 1995). Despite the fact that these designs cannot attain balance, they are widely employed in plant breeding because they are quite flexible in terms of the number of entries to be assessed and the suitable size of incomplete block, as well as providing sufficient error control. Furthermore, by eliminating treatments from an alpha design with a greater number of treatments, these designs may easily be modified to situations where the number of entries is not an exact multiple of block size. In any crop improvement porgramme, multi-environmental replicated trials for evaluation of large number of entries or genotypes is the most crucial step for the identification of best entries which exploit environmental and standard error in very limited extent (Kumar *et. al.,* 2019a). So that entries can show their actual phenotypic effect and improve the precision level. The goal of this study was to examine the relative efficiency of alpha lattice design (ALD) vs. randomized complete block design (RCBD) in terms of economic traits such as green forage yield and seed yield of oat genotypes.

2. Materials and methods

2.1 Experimental materials

Since the main objective of present experiment was to explore the benefits of sub-blocks within super block in ALD over RCBD. Therefore, diagnostic study of experiments on oat crop was conducted in the Fodder experimental farm, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India in alpha lattice design (ALD) with 3 replications, 96 genotypes and 12 blocks (*k*) during, 2019-20 and 2020-21. Data were recorded for two economic traits as green forage yield per plant (g) and seed yield per plant (g). The collected data on yield was analyzed in randomized complete block design and alpha lattice design using statistical software PROC GLM SAS (Statistical Analysis Software, 2013).

2.2 Randomized complete block design

All of the treatments in the experiment appear once in each block in this design. Therefore, the number of treatments is equal to the block size furthermore, because each block is a complete replication, the number of blocks equals the number of treatments replicated. The linear mathematical model in randomized complete block design is: $y_{ij}=\mu+\tau_i+\beta_j+e_{ij}$ Where y_{ij} is the response of variable; μ is the general mean effect; τ_i is the effect of the i^{th} treatment (fixed); β_j is the effect of the j^{th} block (fixed); e_{ij} is random error associated with response.

2.3 Alpha lattice design

The emphasis was on RCB designs feature full blocks in the sense that all treatments occur exactly once in each block. However, it is impossible to build blocks that contain as many experimental units without affecting by soil factors and maintain homogeneity when genotypes or treatments size is big. As a result, resolvable block designs (lattice, augmented designs) are performed in entire replications is an intriguing aspect and alpha lattice one of them to minimize soil heterogeneity and adjust mean performance of each treatment involves in experiment within block. This design resembles as randomized complete block designs however, there are blocks inside replications and the treatments are randomized within blocks within each replication. It allows the investigator to eliminate some of the variability between blocks within replications. The linear mathematical model in alpha lattice design is: Where y_{iju} is the response of variable; μ is the general mean effect; τ_i is the effect of the i^{th} treatment; β_j is the effect of the j^{th} block; e_{iju} are uncorrelated random error components with response. The impact of Alpha Lattice design over RCBD was assessed by relative efficiency in term of the size of the experimental error and improvement in precision or efficiency manner. An estimated relative efficiency (ERE) less than 1 indicates that an ALD over RCBD is not efficient, while value greater than 1 suggests that ALD is more efficient design than RCBD.

3. Results and Discussion

3.1 Analysis of variance (randomized complete block design) of economic traits in oats

Analysis of variance (RCBD) for both the years and pooled analysis of economic traits are presented in (Tables 1 and 2). Mean square of the replications had high significant differences for seed yield per plant, non-significant for green forage yield per plant in both the years. Mean square of year in the pooled data had highly significantly differences seed yield per plant and green forage yield per plant. Interaction between replication × years was non-significant for both seed yield per plant and green forage yield per plant. The highly significant genotypic differences observed among both seed yield per plant and green forage yield per plant in both years and pooled data indicate that the germplasm pool used in this study could be a rich source of genetic diversity for breeding purposes. Thus the germplasm can be used to identify genotypes with high levels of green forage and grain yield potentiality.

Table 1. Analysis of variance (RCBD) for studied traits in oats during two consecutive years

Sources of variation	df	2019-20		2020-21	
		Seed yield per plant	Green forage yield per plant	Seed yield per plant	Green forage yield per plant
Replications	2	17.18**	12.61	8.67**	10.95
Genotypes	95	66.66**	736.79**	9.23**	842.40**
Error	190	1.34	27.79	2.23	53.75

**Significant at 1% level; *significant at 5% probability level

Table 2. Pooled analysis of variance (RCBD) for studied traits in oats

Sources of variation	df	Seed yield per plant	Green forage yield per plant
Replications	2	10.39	2.37
Years	1	81.87**	38702.90**
Replication x year	2	15.47	21.19
Genotypes	95	35.38**	885.98**
Pooled error	475	9.53	171.25

**Significant at 1% level; *significant at 5% probability level

3.2 Analysis of variance (alpha lattice design) of economic traits in oats

Analysis of variance (alpha lattice design) for both the years and pooled of economic traits are presented in (Tables 3 and 4). Mean square of the blocks had non-significant differences for both seed yield per plant and green forage yield per plant in both the years and pooled data. Similar as RCBD, mean square of the replications had highly significant differences for seed yield per plant, non-significant for green forage yield per plant in both the years. Interaction between replication × years was found to be significant for the trait seed yield per plant. Mean square of the year in the pooled data had highly significantly differences for both the traits in pooled. The highly significant genotype × year interaction was observed for both seed yield per plant and green forage yield per plant indicate that wide range of variations between genotypes and between years and that different reacted differently to varying environment. This information shows that oat genotypes responded to G × E interaction over the environments. The highly significant genotypic differences observed for both seed yield per plant and green forage yield per plant in both years and pooled data indicate that the germplasm pool used in this study could be a rich source of genetic diversity therefore, can be used to identify genotypes with high levels of green forage and grain yield potentiality.

Table 3. Analysis of variance (alpha lattice design) for studied traits in oats during two consecutive years

Sources of variation	df	2019-20		2020-21	
		Seed yield per plant	Green forage yield per plant	Seed yield per plant	Green forage yield per plant
Replications	2	17.18**	12.61	8.67**	10.94
Blocks (unadjusted)	33	1.52	27.00	2.48	60.01
Genotypes	95	57.46**	658.64**	8.45**	756.41**
Error	157	1.30	27.95	2.18	52.43

**Significant at 1% level; *significant at 5% probability level

Table 4. Pooled analysis of variance (alpha lattice design) for studied traits in oats

Sources of variation	df	Seed yield per plant	Green forage yield per plant
Genotypes	95	34.28**	874.17**
Years	1	81.87**	38702.90**
Replication x year	4	12.93**	11.78
Blocks	11	1.77	43.82
Genotype x year	95	40.20**	690.89**
Pooled error	369	1.78	40.67

**Significant at 1% level; *significant at 5% probability level

Relative efficiency of ALD versus RCBD

Coefficient of determination (R^2) is a measure of the goodness of fit of a model. In present study, the alpha lattice design in year 2019-20, 2020-21 and pooled showed coefficient of determination more than 0.90 except seed yield per plant in 2020-21 (0.74). Hence, can be considered as very high and fall under the accepted range. The relative efficiency less than one indicate that the alpha lattice design is less efficient than the RCBD. In this case the experiment is analyzed as RCBD and means are not adjusted for block effects. Relative efficiency of alpha lattice design for error mean square (EMS) was higher for seed yield per plant (1.03) as compared to RCBD during 2019–20 (Table 5). Coefficient of variation (CV) was also higher for seed yield per plant (1.01) whereas equal in green forage yield per plant (1.00). Relative efficiency of alpha lattice design (Table 5) during 2020–21 for error mean square (EMS) was higher (1.02) for both the traits and for coefficient of variation (CV) was reported also higher for green forage yield per plant (1.01) and seed yield per plant (1.01). Relative efficiency of alpha lattice design (Table 5) of pooled analysis for error mean square (EMS) was much higher for seed yield per plant (5.34) and green forage yield per plant (4.21) drastic improvement in relative efficiency based on error mean square is could be due to high standard error of differences and significant differences among genotypic mean performance, high significant replication difference and qualitative (crossover) genotype × environment interaction. Whereas for relative efficiency based on coefficient of variation (CV) was reported much higher for seed yield per plant (2.31) and green forage yield per plant (2.05) which indicate that analysis in alpha lattice design resulted in reducing the experimental error and thus enhancing the capability of the researcher to detect significant differences among the ninety-six oat genotypes.

Table 5. Relative efficiency of alpha lattice design *vs* RCBD for studied traits in oat during two consecutive years and pooled environments

Parameters		Seed yield per plant	Green fodder yield per plant
2019-20	EMS (RCBD)	1.34	27.79
	R^2	0.96	0.93
	EMS (Alpha lattice)	1.30	27.95
	R^2	0.97	0.94
	Relative efficiency	1.03	0.99
	CV (RCBD)	10.50	9.36
	CV (Alpha lattice)	10.35	9.39
	Relative efficiency	1.01	1.00
2020-21	EMS (RCBD)	2.23	53.74
	R^2	0.68	0.89
	EMS (Alpha lattice)	2.18	52.43
	R^2	0.74	0.91
	Relative efficiency	1.02	1.02
	CV (RCBD)	12.68	10.08
	CV (Alpha lattice)	12.53	9.96
	Relative efficiency	1.01	1.01
Pooled	EMS (RCBD)	9.53	171.25
	R^2	0.43	0.60
	EMS (Alpha lattice)	1.78	40.67
	R^2	0.92	0.93
	Relative efficiency	5.34	4.21
	CV (RCBD)	27.08	20.28
	CV (Alpha lattice)	11.72	9.89
	Relative efficiency	2.31	2.05

Many studies had investigated alpha lattice design in field experiments (Masood et al. 2008; Kashif et al. 2011; Abd El-Mohsen and Abo-Hegazy 2013; Masood et al. 2018; Anwaar et al. 2019 and Kumar et al. 2020). They came to the conclusion that alpha lattice design is more efficient than RCBD and might be used to replace it in regional and international trials. Masood et al. (2006 and 2007) compared alpha lattice design efficiency and found that alpha lattice design enhanced efficiency by 9 and 14 percent when compared to RCBD. Abd El-Mohsen and Abo-Hegazy (2013) performed research in wheat during the 2010-11 and 2011-12 growing seasons and came to the conclusion that RCBD should be replaced by alpha lattice in agricultural field trials when the numbers of genotypes are more than ten and error mean square is much higher. Masood et al. (2018) reported 6-8 % high relative efficiency of alpha lattice design against randomized complete block design in wheat field trials. In wheat trial experiments it was also concluded that the relative efficiency of ALD was more efficient than RCB design (Kumar *et al.,* 2019b; Kumar *et al.,* 2020).

This study demonstrated that employing alternate designs can result in considerable gains in managing inconsistency or variability when large numbers of genotypes are involved. According to the statistical analysis of the yield data from all of the tests, utilizing RCBD did not increase experimental accuracy, since it was less successful than alpha lattice design. In the examination of oat genotypes, the alpha lattice design generated superior results than the randomized complete block design. In comparison to the conventional design of randomized entire blocks, the experimental designs employed reduced total number of experimental plots. CV based relative efficiency in pooled data increase precision more than 100 % for both green forage yield per plant and seed yield per plant. This is especially beneficial in terms of improved experiment management. Findings of this study suggested that alpha lattice design better suited to the field trials than the traditional RCBD in agricultural research.

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Author's contribution

Designed and performed the experiments (SKS); supervised (VKS) and wrote as well revised the manuscript (SKS, SK and GS).

Compliance with ethical standards

NA

Conflict of interest

No

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