



Research article

Effectiveness of different alpha lattice designs in the evaluation of maize (*Zea mays* L.) genotypes in a rainforest agro-ecologyRichard Olutayo Akinwale^{a,*}, Love Kayode Odunlami^a, Chinedu Emmanuel Eze^b, Atanda Samuel Oladejo^a^a Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria^b Department of Agronomy, Michael Okpara University of Agriculture Umudike, Nigeria

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ABSTRACT

Plant breeding experiments require the use of appropriate experimental designs that will efficiently block variation due to wide heterogeneity nature of tropical soils. The primary objective of this study was to assess the effectiveness of eight different alpha-lattice designs relative to randomized complete block design for evaluating 108 genotypes of maize under rainforest agro-ecology. The maize genotypes were field-tested using three replications at two locations. Data were collected on grain yield and other agronomic traits. Data collected were subjected to analysis of variance (ANOVA) assuming randomized complete block design (RCBD) and eight alpha-lattice designs. Pearson's correlation and stepwise multiple regression analyses were used to analyze relationship among different designs and efficiency of the lattice designs over RCBD was computed. Result showed that all the alpha lattice designs except 27×4 were effective in evaluating the genotypes for plant height. There was significant difference ($p < 0.001$) among genotypes for grain yield only when data were analyzed based on 9×12 alpha lattice design. In addition, results showed that the proportion of variation due to blocking and R-square values of the model increased with increase in the number of blocks for grain yield. In contrast, coefficient of variation decreased with increase in the number of blocks. The result showed an increase in efficiency of the alpha lattice designs as the number of blocks increased. It could then be concluded that the more the number of blocks within replicate, the proportion of total variation due to blocking increased, the coefficient of variation (CV) reduced, coefficient of determination (R-square) increased and thus, effectiveness increased. Appropriateness of designs was trait dependent. The 9×12 alpha lattice design was identified to be the best in the evaluation of grain yield for the maize genotypes.

1. Introduction

The agricultural origin of experimental design was first reported by R. A. Fisher and his co-workers between 1918 – 1940s in which he developed three basic principles of design; randomization, replication and local control. An experimental design is the way and manner by which treatments are allocated to the experimental units (plots) of which its importance is to reduce bias and better estimate effects of interest. Experimental designs are applicable to experimental research where effects of treatments imposed in a study are examined. The major import of experimental designs in the conduct of an experiment is to capture variations that are not due to the treatment under study, which can invariably bias decision about accepting or rejecting the null hypothesis. In other words, experimental design helps an experimenter to avoid

committing any of the statistical errors, that is, Type I error or Type II error when making decision on the hypothesis of the experiment during data analysis and interpretation. The use of analysis of variance (ANOVA), a very important inferential statistics in the field of agriculture and biological sciences, is premised on appropriate choice of experimental design for its results to be considered valid.

There are different types of experimental designs used in agricultural research. The choice of appropriate design to use depends on a number of factors including the objective of the experiment, types of experiment, size of treatment, number of factors to study, availability of facilities for the experiment, and slope and shape of land to be used. Commonly used experimental designs in agricultural science can be grouped into complete block designs and incomplete block designs [1]. Complete block designs include completely randomized design (CRD), randomized

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complete block design, latin square design, as well as split plot and strip plot designs for factorial experiments. Incomplete block designs are grouped into balanced lattice design and partially balanced (or alpha-lattice) designs. Completely randomized design assumes only one source of variation, which is due to the treatment under study. It is employed mainly in laboratory experiments where other factors that can infer variation are well controlled. In other words, there is uniformity in all conditions around where the experiment is carried out except for the treatment applied. This design is grossly inappropriate for field experiments since there are other sources of variation that can compound the treatment effects such as soil heterogeneity, plant-to-plant competition and climatic elements. Randomized complete block design (RCBD) is the most commonly used design for field experiments especially when the treatment size is not too large and soil fertility gradient is unidirectional [1]. In principle, the design partitions the entire experimental area into blocks or replicates such that variation within block is minimized and all levels of treatment under study are represented within each block. Latin square design (LS) design is also used for field experiments with small treatment size but the experimental area has two fertility gradients running perpendicular to each other, or has a unidirectional fertility gradient but with residual effects from previous trials [1]. This design is not as popular as RCBD in biological and agricultural research especially in the rainforest region because of the peculiarity of the soil fertility gradient. However as the size of treatment becomes enlarged, efficiency of RCBD in ensuring relative uniformity within a block/replicate becomes poorer and poorer. This is typical of plant breeding and genetics experiments, which usually test large number of progenies in genetic analysis. This is the justification for the use of randomized incomplete block design or lattice design. By principle, lattice design further partitions a replicate into smaller blocks within each replicate to take into account variation that may exist within a replicate that can bias genotypic effect. Of the two types of lattice design (i.e., balanced and partially balanced lattice), partially balanced lattice design has been more commonly used because of its practicability, flexibility and versatility. The balanced lattice, on the other hand, is guided by strict principles and guidelines that make it less practicable in terms of land availability, high quantity of seeds use for evaluation and high high cost of evaluation. For instance, some of the principles include the following: the total number of genotypes to be evaluated must be a perfect square such as 25, 36, 49, 64 and so on; the number of replicates must be number of block plus 1, for example, if 64 genotypes are to be evaluated using 8×8 balanced lattice (8 entries in 8 blocks in one replicate), the number of replicates must be $8 + 1 = 9$ replicates [1]. These conditions make balanced lattice less popular since it is not every time that the number of genotypes to be evaluated is a perfect square and most times, limited land availability makes it practically impossible to consider large number of replicates especially for large sized breeding experiments. For alpha lattice design, any number of replicates can be used [2] and number of genotypes does not necessarily be a perfect square. Patterson and Williams [2] referred to this design as resolvable incomplete block design and Singh and Bhatia [3] considered the design as the most appropriate for any typical breeding experiments. More addition, Kharif et al [4] reported in his study on rice that randomized complete block designs (RCBD) should be replaced with alpha lattice in any agricultural field experiments when the number of varieties to be tested increases beyond ten. Considering its flexibility in terms of the number of small blocks a replicate can be subdivided, however, alpha lattice poses the challenge of determining how many blocks is appropriate for evaluation of a specific number of maize genotypes? For instance, to evaluate 80 genotypes, 8 alpha lattice options can be applied viz: 2×40 , 4×20 , 5×16 , 8×10 , 10×8 , 16×5 , 20×4 , and 40×2 where the first number in each pair implies the number of blocks and the second, the number of entries per block. There is dearth of information on the number of blocks within replicate appropriate for evaluating such a large number of maize genotypes considering the peculiar wide heterogeneous nature of soils in tropical rainforest agro-ecology. In addition, it is a routine practice in any

agronomic experiment that data are collected on several traits of a set of genotypes evaluated using the same experimental design without considering sensitivity of different traits of maize to different designs. These traits do not follow the same biological pattern; some are morphological while other phenological. Some are more affected by edaphic factors because they are underground traits while some are above ground traits. Determination of appropriate experimental design is very crucial in carrying out genetic analysis simply because genetic effect is deduced from data taken on phenotypic expression. Phenotype is a sum total of genotype and environment. Thus, if environment component especially edaphic factor of the phenotype is not well captured, results from analysis of the genetic component will be grossly erroneous, and by extension, there might not be any appreciable progress made from genetic improvement of a trait in any breeding programme. Previous studies had reported relative efficiencies of different experimental designs for other crops such as sunflower (*Helianthus annuus* L.) [5], wheat (*Avena sativum* L.) [6] and indian mustard (*Brassica juncea* L.) [7]. but there has been dearth of information on the relative efficiency of randomized incomplete block design over RCBD in evaluating yield and other agronomic traits of relatively large number of maize genotypes under rainforest soil conditions.

The objectives of this study were to i) analyze data on grain yield and other traits of 108 maize genotypes assuming eight alpha lattice designs relative to randomized complete block design; and ii) compare results of the analyses based on the different designs and determine efficiencies of the alpha lattice designs relative to RCBD.

2. Materials and methods

2.1. Location of the study

The study was carried out at the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria ($7^{\circ}28' N$, $4^{\circ}33' E$, rainfall 1150 mm, altitude 224 m above sea level). The experiment was conducted for two cropping seasons between 2018 and 2019. The soil classification is ultisol, a highly weathered sandy loam belonging to Iwo series.

2.2. Plant materials and field layout

One hundred and eight maize genotypes (which constitute of fourteen parents from which diallel crosses were made to give ninety one hybrids, and in addition were two conventional checks (drought tolerant) and one local check). The experimental field was ploughed twice, and harrowed two weeks after before layout and planting was done. Randomized complete block design with three replications was used for the evaluation of the genetic materials in the location, with each plot consisting of two rows, each row was 5 m long. Spacing between rows was 0.75 m and within row spacing was 0.5 m.

The planting was done manually, seeds of each genotype were treated with Apronplus®, a fungicide containing carboxin, furathocarb and metalaxyl as active ingredients against downey mildew disease and sowed at three seeds per stand. Caterpillar force®, an insecticide containing cypermethrin as the active ingredient was applied to combat armyworm attacks as often as they were noticed. A compound fertilizer, NPK was applied by side placement method at 2 weeks after planting at the rate of 60 kgN/ha and at 4 weeks after planting, urea was applied to topdress by side placement 30 kgN/ha. For weed control, glyphosate was sprayed at planting at the rate of 5 L/ha and hand weeding was done subsequently to keep the field weed free.

2.3. Data collection

Data were collected on number of days to 50% silking as the number of days it took 50% of maize plants in a plot to extrude silk, the female reproductive flower, anthesis-silking interval was computed as the dif-

Table 1. Sum of squares from ANOVA for days to 50% silking for the 9 experimental designs used for the evaluation of 108 maize genotypes across two environments at the Teaching and Research Farm, OAU, Ile-Ife in 2018.

Source	RCBD	3 × 36 alpha lattice	4 × 27 alpha lattice	6 × 18 alpha lattice	9 × 12 alpha lattice	12 × 9 alpha lattice	18 × 6 alpha lattice	27 × 4 alpha lattice	36 × 3 alpha lattice
Block/Rep*E	—	411.67**	519.53**	589.08**	750.22**	792.09**	1190.44**	1437.66**	1669.88**
Rep/E	141.15**	177.48**	177.48**	177.48**	177.48**	177.48**	177.48**	177.48**	177.48**
Environment (E)	879.44**	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56
Genotype (G)	636.11	750.63**	793.09**	677.00**	649.89**	609.76*	600.89**	485.97*	486.45**
G*E	5.56	577.39	571.93	496.62	508.84	455.43	396.10	355.79	355.27
Error	2336.85	1888.85	1780.99	1711.44	1550.30	1508.42	1110.08	862.86	630.64
R ² (%)	41.60	52.80	55.50	57.20	61.20	62.30	72.20	78.40	84.20
CV (%)	3.71	3.39	3.32	3.30	3.22	3.25	2.94	2.84	2.71
[†] PBRE	0	17.89	22.58	25.61	32.61	34.43	51.75	62.49	72.59

** Significant at 0.01 and * significant at 0.05, CV is coefficient of variation and R-square is coefficient of determination.

[†]PBRE = Proportion of total variation explained by Block/Rep*E factor.

ference between days to 50% silk and days to 50% anthesis anthesis is when the pollen grains start shedding from the male reproductive organ called anther, plant height and grain yield. The plant height was recorded with the aid of meter rule as the height of plant from the soil level to the first tassel branch for the average of 6 plants per plot. Yield was computed using the formula in Eq. (1): [8]

$$Y = \epsilon + \frac{(100 - n)}{85} \times \frac{10000}{\phi} \times 0.80 \tag{1}$$

where Y = grain yield (kg/ha), ϵ = ear weight (kg/m²), n = moisture content, ϕ = plot area (m²), (100-n)/85 was the term used to adjust varying moisture content of the kernel to 15%, 10000 was the term to convert plot to an hectare, which is 10000m², while 0.80 was the term to adjust to 80% shelling percentage [8].

2.4. Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) assuming randomized complete block design such that the replication was taken as block, 3 × 36, 4 × 27, 6 × 18, 9 × 12, 12 × 9, 18 × 6, 27 × 4, and 36 × 3 alpha lattice designs; where the first number for each alpha lattice design is the number of blocks while the second number is the number of plots or genotypes in a block. Coefficient of variation (CV) in

percentage and R-square value in percentage were used in comparing the effectiveness of the models in the analysis. Correlation analysis was carried out on the arithmetic mean of RCBD and least square means generated from each of the alpha-lattice designs to establish relationship between RCBD and each of the alpha lattice designs. Similarly, stepwise multiple regression analysis was performed to further analyse the relationship where RCBD was made the dependent variable and alpha lattice designs as the independent variables. All analyses were carried out using Statistical Analysis Software (SAS) version 9.4 [9].

3. Results and discussion

Results of the analysis of variance for days to silking showed that replication and block within replication effects were highly significant for randomized complete block design and all alpha lattice designs (Table 1). This implies that blocking is effective in the field study for analyzing the phenological data in maize. This is in line with the report by [1] who mentioned that completely randomized design that does not consider the effect of blocking is not appropriate for field study. Environment effect was significant for only randomized complete block design meaning RCBD was sensitive enough to detect environment effect for phenological traits, In contrast, only RCBD showed no significant difference among maize genotypes tested. By implication, the alpha lattice designs were more appropriate in determining genotypic effect for

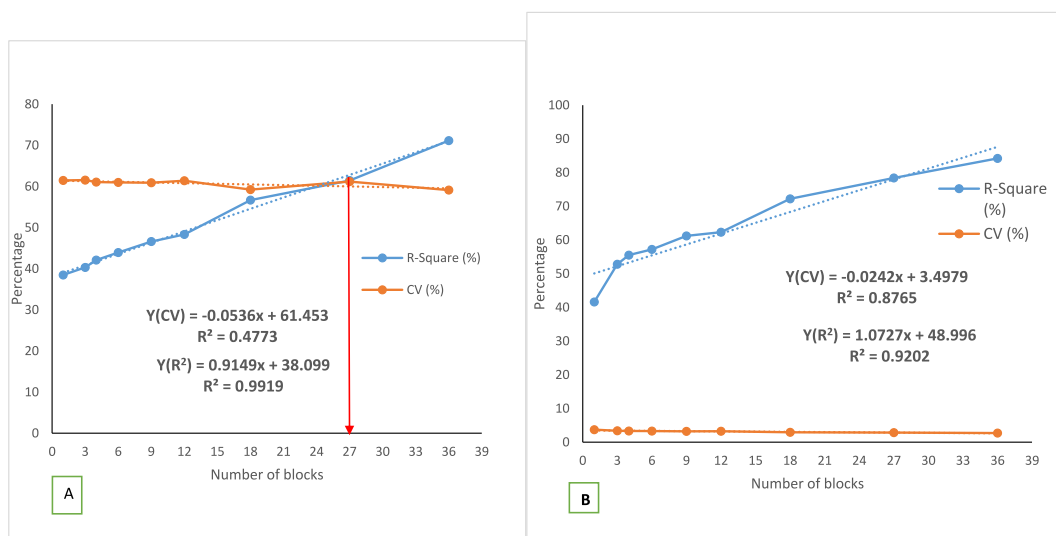


Figure 1. Linear graph of coefficient of determination (R) and coefficient of variation (CV) for flowering data (A) days to 50% silking and (B) anthesis-silking interval when regressed on the number of blocks in each experimental design.

Table 2. Sum of squares from ANOVA for anthesis-silking interval for the 9 experimental designs used for the evaluation of 108 maize genotypes across two environments at the Teaching and Research Farm, OAU, Ile-Ife in 2018.

Source	RCBD	3 × 36 alpha lattice	4 × 27 alpha lattice	6 × 18 alpha lattice	9 × 12 alpha lattice	12 × 9 alpha lattice	18 × 6 alpha lattice	27 × 4 alpha lattice	36 × 3 alpha lattice
Block/Rep*E	—	28.87	56.96	85.66	127.70	154.66	285.67*	360.45	512.62
Rep/E	15.57*	15.68	15.68	15.68	15.68	15.68	15.68	15.68	15.68
Environment (E)	275.20	84.50**	84.50**	84.50**	84.50**	84.50**	84.50**	84.50*	84.50*
Genotype (G)	228.50	261.72	256.17	259.19	251.54	247.29	238.19	222.23	210.65
G*E	84.50**	217.69	219.22	211.35	194.72	195.46	172.18	166.17	160.79
Error	965.77	936.78	908.69	880.00	837.95	810.99	679.99	605.20	453.04
R ² (%)	38.47	40.31	42.10	43.93	46.61	48.33	56.68	61.44	71.14
CV (%)	61.46	61.44	61.06	60.98	60.90	61.39	59.23	61.18	59.12
[‡] PBRE	0	2.99	5.90	8.87	13.22	16.02	29.58	37.33	53.09

** Significant at 0.01 and * significant at 0.05, CV is coefficient of variation and R-square is coefficient of determination.

[‡]PBRE = Proportion of total variation explained by Block/Rep*E factor.

days to silking among 108 maize genotypes than RCBD. There was no significant difference for genotype by environment interaction effect regardless of experimental designs.

The R² values for the statistical model was least for RCBD (41.60%) and values gradually increased as the number of blocks within replication increased with the highest value for 36 × 3 alpha lattice (84.20%) (Table 1). In contrast, the values for CV was highest for RCBD (3.71%) and the values decreased with the lowest value for 36 × 3 alpha lattice (2.71%). Both R² and CV are good measures of the reliability of any statistical model of ANOVA. This results is corroborated by the findings of [4] who reported higher CV values for RCBD compared to alpha lattice design in rice evaluation. The higher the value of the R², the more the total variability that is captured by the statistical model and by implication, the more reliable the statistical analysis. On the other hand, decrease in the values of coefficient of variation signifies increase in the reliability of the statistical model. The proportion of total sum of squares accounted for by block within replicate effect for the alpha-lattice designs also increased with increase in the number of blocks (Table 1). Based on this, the result of the present study revealed that the alpha lattice designs were more appropriate in the analysis of 108 maize genotypes for days to silking than RCBD and the higher the number of blocks within replication, the more the reliability of the statistical model in analyzing data on flowering.

In addition, when values for CV and R² were regressed on the number of blocks within replicates, the result showed that R² values increased at a rate of 1.07 while CV decreased at rate of -0.02 (Figure 1B).

For anthesis-silking interval (ASI), the trends of results is not similar with that of days to silking. Replication and block within replication effects were generally not significant for all designs except replicate

effects for RCBD, and block within replicate effect for 18 × 6 alpha lattice (p < 0.05). Environment effect was significant for all alpha lattice designs but not for RCBD. There was no significant difference among genotypes for ASI regardless of the designs. However, G × E was significant only for RCBD (Table 2).

Anthesis-silking interval is an important adaptive trait in maize especially under abiotic stresses such as drought and low soil N [10]. Adequate field evaluation of this trait using appropriate experimental design is important to enhance efficiency of breeding maize for tolerance to such stresses. Values of R² and CV followed similar trends with those for days to silking. The RCBD had the lowest R² value (38.47%) and the highest CV (61.46%) signifying that RCBD was the least appropriate for evaluating the maize genotypes for ASI while 36 × 3 alpha lattice had the highest R² value (71.14%) and lowest CV (59.12%) implying that 36 × 3 alpha lattice was the most appropriate design for the evaluation. Similarly, the proportion of total sum of squares due to block within replication effects was just 2.99% for 3 × 36 alpha lattice design and increased to 53.09% for 36 × 3 alpha lattice design (Table 2). Figure 1A presented the result of the analysis of the trends of increase of the R² and CV values. The b-value of R² for ASI, which signifies the rate of increase as number of blocks increases was 0.91 while that of CV was -0.05. From the graph, the point at which the two curves intercept can be taken as the appropriate number of blocks best for the evaluation of ASI and this is 27 blocks. In other words, the most appropriate experimental design for ASI is 27 × 4 alpha-lattice design.

For plant height, the two blocking factors in the sources of variation were significant for all experimental designs. This implies that blocking is very important for field measurement of plant height in maize. The significance of block within replication effect indicates that just replication effect is not

Table 3. Sum of squares from ANOVA for plant height for the 9 experimental designs used for the evaluation of 108 maize genotypes across two environments at the Teaching and Research Farm, OAU, Ile-Ife in 2018.

Source	RCBD	3 × 36 alpha lattice	4 × 27 alpha lattice	6 × 18 alpha lattice	9 × 12 alpha lattice	12 × 9 alpha lattice	18 × 6 alpha lattice	27 × 4 alpha lattice	36 × 3 alpha lattice
Block/Rep*E	—	8607.67**	16231.46**	23233.79**	25539.71**	32616.95**	50439.19**	56401.08**	66401.21**
Rep/E	10828.28**	10838.43**	10838.43**	10838.43**	10838.43**	10838.43**	10838.43**	10838.43**	10838.43**
Environment (E)	28591.72*	28603.45**	28603.45**	28603.45**	28603.45**	28603.45**	28603.45**	28603.45**	28603.45**
Genotype (G)	20172.03	27110.51*	27704.26**	25619.94**	23566.66*	23323.49*	17909.68*	12398.79*	15540.21*
G*E	28603.45**	18372.95	16568.24	15003.26	14509.09	13436.25	12998.69	11575.39	11361.55
Error	89658.78	81040.97	73417.18	66414.85	64108.93	57031.69	39209.45	33247.56	23247.43
R ² (%)	49.59	54.43	58.72	62.66	63.95	67.93	77.95	81.31	86.93
CV (%)	9.38	9.07	8.69	8.39	8.44	8.16	7.13	7.18	6.71
[‡] PBRE	0.00	9.60	18.11	25.92	28.49	36.38	56.26	62.91	74.07

** Significant at 0.01 and * significant at 0.05, CV is coefficient of variation and R-square is coefficient of determination.

[‡]PBRE = Proportion of total variation explained by Block/Rep*E factor.

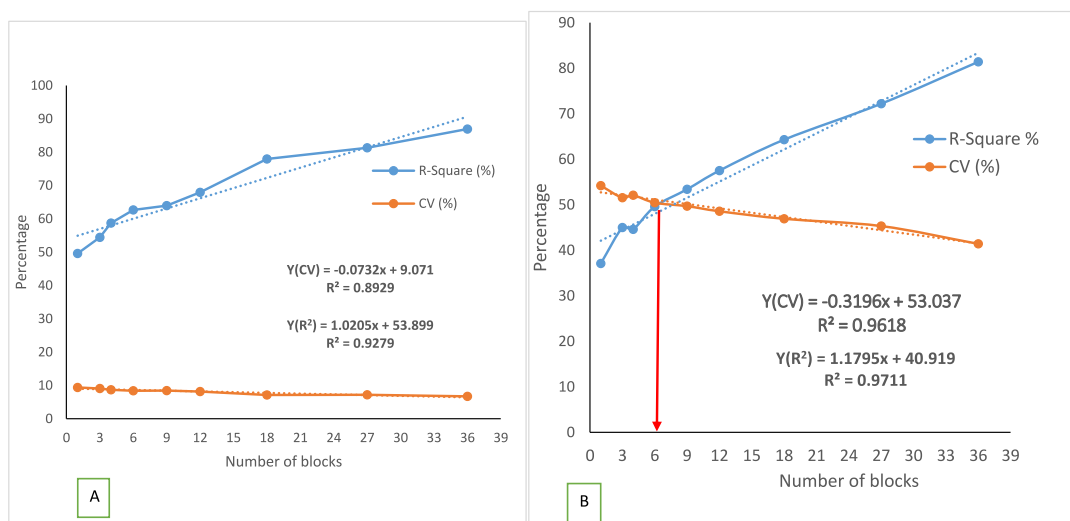


Figure 2. Line graph of coefficient of determination (R) and coefficient of variation (CV) for (A) Plant height and (B) grain yield when regressed on the number of blocks in the experimental designs.

Table 4. Sum of squares from ANOVA for grain yield for the 9 experimental designs used for the evaluation of 108 maize genotypes across two environments at the Teaching and Research Farm, OAU, Ile-Ife in 2018.

Source	RCBD	3 × 36 alpha lattice	4 × 27 alpha lattice	6 × 18 alpha lattice	9 × 12 alpha lattice	12 × 9 alpha lattice	18 × 6 alpha lattice	27 × 4 alpha lattice	36 × 3 alpha lattice
Block/Rep*E	.	58680407.8**	54872023**	104832018**	142974810.4**	184527390.6**	252955451.3**	332542392**	425220550**
Rep/E	11028278.2*	31473594.0**	31473594**	31473594**	31473594**	31473594**	31473594**	31473594**	31473594**
Environment (E)	190015161.2	1689589.4	1689589.4	1689589.4	1689589.4	1689589.4	1689589.4	1689589.4	1689589.4
Genotype (G)	171226211	179184335.0*	180675234.4**	170778041	175094660.2*	150637899.3	149027984.6	112764413	100912317
G*E	1689589.4	171682512	163682447.5	160112646	151273540.2	141171085.8	125055949.2	108147375	93779984.3
Error	633092295	503966571	457774956	507814961	469672168	428119588	359691528	280104587	187426428
R ² (%)	37.1	45.0	44.6	49.6	53.4	57.5	64.3	72.2	81.4
CV (%)	54.2	51.55	52.1	50.5	49.7	48.58	46.9	45.3	41.4
[†] PBRE	0	9.58	8.9	17.1	23.3	30.1	41.2	54.2	69.4

** Significant at 0.01 and * significant at 0.05, CV is coefficient of variation and R-square is coefficient of determination.

[†]PBRE = Proportion of total variation explained by Block/Rep*E factor.

enough to capture variation in the soil for evaluating 108 maize genotypes. Environment effect was significant for all experimental design and genotypic effect was significant for all design except RCBD. This indicate that RCBD is not sensitive enough to detect differences in plant height among 108 maize genotypes unlike the alpha-lattice designs. However, only RCBD detected significant difference in the G × E interaction effects.

Trends of values of R² and CV for this trait were similar to those of phenological traits. The RCBD had the lowest R² value (49.59%) and the highest CV (9.38%) signifying that RCBD was the least appropriate design for evaluating the maize genotypes for plant height. Again, the results is corroborated by the findings of [4] on rice. In contrast, 36 × 3 alpha lattice had the highest R² value (86.93%) and lowest CV (6.71%) implying that 36 × 3 alpha lattice was the most appropriate design for the evaluation. The proportion of the total sum of squares due to block within replication effects ranged between 9.60 % for 3 × 36 alpha lattice design and 74.07% for 36 × 3 alpha lattice design (Table 3). Analysis of trends of increase in R² and decrease in CV values showed that the b-value of R² for ASI which signifies the rate of increase as number of blocks increases was 1.02 while that of CV was -0.07 (Figure 2A). In the graph, the two curves did not intercept implying that increase in the number of blocks increase the appropriateness of the experimental design for the evaluation of plant height.

Grain yield is a complex quantitative trait and controlled by many genes. The expression of the trait is also greatly influenced by

environmental factor [11]. Grain yield is the ultimate target of most breeding objective because it is the major economic trait valued by farmers. Determining appropriate experimental design is very crucial to breeders in order to make a good progress from selection for improved grain yield. Results from ANOVA revealed that replicate and block within replicate effects were significant for all experimental designs (Table 4). There was no significant difference in the environments and G × E interaction for any design but genotypic effect was significant for three designs; namely 3 × 36 alpha lattice, 4 × 27 alpha lattice, and 9 × 12 alpha lattice. This implies that three designs with relatively less number of blocks were sensitive enough to detect significant differences among the maize compared to the designs with higher number of blocks. R² and CV values took similar pattern with the other three traits showing increase in the R² values from 37.1 % for RCBD to 61.4% for 36 × 3 alpha lattice. The CV values decreased from 24.2% for RCBD to 11.4% for 36 × 3 alpha lattice. This result also indicates that the more the number of block within replicates used in the evaluation of maize, the more reliable the statistical model.

Regression analysis of the trends of R² and CV values showed that the b-value for R² was 1.18 while that of CV was -0.32 (Figure 2B). In addition, the two curves intercepted on block 6, indicating that appropriate experimental designs for yield trial start with 6 × 18 (Figure 2B). Any experimental design with number of blocks less than 6 is not

Table 5. Correlation coefficient of randomized complete block design with different alpha lattice designs for grain yield and other agronomic traits.

Design	Days to 50% silking	Anthesis-silking interval	Plant height (cm)	Grain yield (kg/ha)
3 × 36 alpha lattice	0.95**	0.99**	0.97**	0.96**
4 × 27 alpha lattice	0.92**	0.97**	0.93**	0.96**
6 × 18 alpha lattice	0.92**	0.96**	0.91**	0.93**
9 × 12 alpha lattice	0.89**	0.93**	0.90**	0.91**
12 × 9 alpha lattice	0.89**	0.91**	0.87**	0.86**
18 × 6 alpha lattice	0.81**	0.83**	0.77**	0.78**
27 × 4 alpha lattice	0.80**	0.74**	0.70**	0.77**
36 × 3 alpha lattice	0.76**	0.68**	0.64**	0.61**

** Significant at 0.01.

Table 6. Stepwise multiple regression of the different alpha lattice designs to randomized complete block design for grain yield and selected agronomic traits.

Step	Variable entered	Label	Partial R ²	Model R ²	C(p)	F Value	Pr > F
Days to silk							
1	3 × 36 alpha lattice	3 × 36 alpha lattice	0.9098	0.9098	7.9355	1069.42	<.0001
2	27 × 4 alpha lattice	27 × 4 alpha lattice	0.0037	0.9135	5.384	4.45	0.0373
Anthesis-silking interval							
1	3 × 36 alpha lattice	1	0.9703	0.9703	13.8751	3468.09	<.0001
Plant height							
1	3 × 36 alpha lattice	3 × 36 alpha lattice	0.9307	0.9307	49.0436	1422.76	<.0001
2	4 × 27 alpha lattice	4 × 27 alpha lattice	0.0158	0.9464	16.2309	30.92	<.0001
3	6 × 18 alpha lattice	6 × 18 alpha lattice	0.0052	0.9516	6.837	11.09	0.0012
Grain yield							
1	3 × 36 alpha lattice	3 × 36 alpha lattice	0.9307	0.9307	49.0436	1422.76	<.0001
2	4 × 27 alpha lattice	4 × 27 alpha lattice	0.0158	0.9464	16.2309	30.92	<.0001
3	6 × 18 alpha lattice	6 × 18 alpha lattice	0.0052	0.9516	6.837	11.09	0.0012

appropriate. Considering the design that detected significance among genotypes which also had high R² and low CV, 9 × 12 alpha lattice will be adjudged the best in the evaluation of the maize genotypes.

Based on the proportion of total variation captured by block within replicate effects, blocking was more effective for days to silking, followed by yield, plant height and the least was anthesis-silking interval.

To further study the relationship between RCBD and the various alpha lattice designs, simple linear correlation was employed. Result revealed highly significant association between randomized complete block design and all the alpha lattice design for all traits but the magnitude of association (correlation coefficient) decreased as the number of blocks increased (Table 5). A further analysis of the relationship among the designs using stepwise multiple regression analysis (Table 6) showed that designs 3 × 36 and 27 × 4 alpha lattice were not significantly different from RCBD in evaluating days to silking. Only 3 × 36 alpha lattice assessed ASI the same way with RCBD. However, alpha lattice designs 3 × 36, 4 × 27, and 6 × 18 were not different from RCBD in their evaluation of plant height and grain yield. In general, this result is in line with [12], who reported that as the number of varieties increases as large as sixteen, RCBD becomes inappropriate.

4. Conclusions

Generally, as the number of blocks increased, the relative efficiency proportion of total variation due to blocking increased and of the alpha lattice designs increased for all traits measured, which implies increase in precision of experimental designs.

On the basis of coefficient of variation and determination, the best experimental design is trait-specific. While alpha lattice designs with 6 blocks and above were most suitable for grain yield, randomized block design was appropriate for days to 50% silking and plant height. Based on

stepwise multiple regression analysis of the relationship between RCBD and other alpha lattice designs, aside 3 × 36 alpha lattice design and 27 × 4 alpha lattice for the days to 50% silking, any of the alpha lattice designs were suitable in evaluation of the maize genotypes.

In addition to designs 3 × 6 alpha lattice, 4 × 27 alpha lattice, design 6 × 18 alpha lattice was not suitable for the evaluation of the maize genotypes for plant height. For grain yield, any alpha lattice design with minimum of 9 blocks was most adequate. Although relative efficiency of alpha-lattice over RCBD increased for all traits measured as number of block increased, it was observed that phenological traits such as days to silking was less responsive compared to plant height and grain yield.

Overall, the 9 × 12 alpha lattice design was identified as the best as it was the only one that identified significant differences among the 108 maize genotypes for grain yield.

Declarations

Author contribution statement

Richard Olutayo Akinwale; Love Kayode Odunlami; Chinedu Emmanuel Eze: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Atanda Samuel Oladejo: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

- [1] K.A. Gomez, A.A. Gomez, *Statistical Procedures for Agricultural Research*, 1984, USA, 1984.
- [2] H.D. Patterson, E.R. Williams, A new class of resolvable incomplete block designs, *Biometrika* 63 (1976) 83–92.
- [3] P. Singh, D. Bhatia, Incomplete block designs for plant breeding experiments, *Agric. Res. J.* 54 (2017) 607–611.
- [4] M. Kashif, M.I. Khan, M. Arif, M. Anwer, M. Ijaz, Efficiency of alpha lattice design in rice field trials in Pakistan, *J. Sci. Res.* 3 (2011) 91–95.
- [5] L. Nishu, K. Mujahid, K. Kiran, T. Nitin, Study on optimum block size and shape in uniformity trial of sunflower (*Helianthus annuus*), *Adv. Res.* 9 (2017) 1–8.
- [6] M.A. Masood, Y. Mujahid, M. Khan, S. Abid, Improving precision of agriculture field experiments, *J. Sustain. Dev.* 3 (2006) 11–13.
- [7] K. Mujahid, R.C. Hasija, B.K. Hooda, T. Nitin, K. Banti, Relative efficiency of experimental designs in relation to various size and shape of plots and blocks in Indian mustard (*Brassica juncea* L.) crop, *Int. J. Agric. Stat. Sci.* 13 (2017) 253–258.
- [8] B. Badu-Apraku, M.A.B. Fakorede, A. Menkir, D. Sanogo, *Conduct and Management of maize Field Trials*, IITA, Ibadan, Nigeria, 2012, p. 59.
- [9] SAS Institute, *The SAS System for Windows*, Release 9.4, SAS institute Cary, North Carolina, USA, 2012.
- [10] S.H. Molla, S. Nakasathien, E. Sarobol, V. Vichukit, Anthesis and silking dynamics of maize under contrasting nitrogen and water levels, *Kasetsart J. Nat. Sci.* 48 (2014) 837–850.
- [11] M.S. Kang, *Handbook of Formulas and Software for Plant Geneticists and Breeders* Publisher Haworth Press/CRC Press, USA, 2003.
- [12] R. Yang, Z.Y. Terrance, S.B. Stanford, B. Manjula, Efficiency of spatial analyses of field pea variety trials, *Crop Sci.* 44 (2004) 49–55.