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Estimation of Combining Ability for Yield and Component Traits in Maize (*Zea mays* L.) Cultivars Using North Carolina Mating Design II

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Abstract

The study was conducted to estimate general combining ability (GCA) and specific combining ability (SCA) of 13 maize cultivars on grain yield and component traits using North Carolina mating design II (NCII). Genotype x environment interaction for the agronomic traits was also estimated. Crossing was carried out among thirteen elite maize cultivars which were planted in November 2014 under irrigation. The progenies were evaluated in April, 2015 during the early season and in August 2015, for the late season. Data were subjected to analysis of variance (ANOVA) and thereafter, GCA and SCA were estimated. The results showed that there was little variation among parental genotypes in the early season while in late season, the parents exhibited wider variations in yield component traits evaluated. GCA/SCA ratio showed preponderance of specific combining ability (SCA) effects for all the yield component traits studied in the early and late cropping seasons except for number of grain rows/ear and number of grains/row. This implies that SCA was more important in these maize cultivars as parents to hybrid or synthetic variety populations. Highly significant differences were observed for genotypes x season interaction in almost all the characters, indicating that selection should be carried out on seasonal basis. Five top performing hybrid genotypes were identified and selected based on grain yield from each of the seasons: (11A11990)*(11A11917); (11A11990)*(07A04207); (11A11990)*(11A11991); (11A11936)*(11011896) and (09A2567)*(11A11895) for the early season and (11A11990)*(11A11991); (11A11936)*(11A11991); (12C24114)*(11011896); (11A11990)*(11011896) and (11A11936)*(12C24117) for the late season. These genotypes are therefore recommended for use in population improvement programme.

Keywords: General combining ability, specific combining ability, genotypes, North Carolina Design II.

1. Introduction

Maize (*Zea mays* L.) is considered the most important cereal crop after wheat and rice the world over. Maize is consumed as food in various forms such as roasted or boiled snacks, "pap" (porridge made from maize flour) and most of all as a staple food in most parts of Nigeria, particularly in Northern Nigeria. It is also utilized in formulating poultry and other livestock feed [14]. Moreover, it is used for industrial purposes for the manufacture of glue, soap, paint, insecticides, toothpaste, shaving cream, rubber tires, rayon, molded plastics, fuels and others [23].The importance of maize is enormous and so, increasing maize productivity increases food security and thereby addressing the current global economic recession particularly in Nigeria and other sub-sahara African countries. Combining ability has a prime importance in plant breeding since it provides insights regarding nature and types of gene action. Estimation of combining ability, which aids the determination of genetic variability present in genotypes or populations, is a first step in some breeding programmes. [12] stated that GCA is the mean performance of a line, when expressed as a deviation from the mean of all crosses, while SCA is a deviation from expected values of GCA of the two lines in combination of crosses [22, 5]. The differences in GCA are due to the additive and additive x additive gene interactions in the base population while the differences in SCA are attributable to non-additive genetic variance [7]. According to [2] GCA allows a breeder to choose a more appropriate breeding method by providing information on additive and dominance variances. This study was conducted in order to identify possible parental materials that can be used by breeders to develop improved cultivars, hybrids, inbred lines and synthetic cultivars that are well adapted to the rain forest zone of Nigeria with a

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particular reference to Edo State and perhaps, other similar environments.

2. Materials and Methods

Thirteen maize (*Zea mays* L.) cultivars were used in this study comprising medium maturing and white endosperm elite cultivars. The cultivars were obtained from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. Seven of thecultivars were randomly designated as males: 07A04207 (A), 12C24117 (B), 09AA2562 (C), 11A11895 (D), 11011896 (E), 11A11917 (F) and 11A11991 (G), while the remaining six were designated as female parents: 12C24123 (H), 12C24122 (I), 09A2567 (J), 12C24114 (K), 11A11990 (L) and 11A11936 (M). North Carolina mating design II was used in this study. Crosses were carried out in the field during the late season of 2014. Forty-two F_1 progenies were generated from the crosses between the parents. The evaluation trials of the F_1 progeny were carried out in two seasons. The first progeny trial was carried out during the early season April to July 2015, while the second evaluation was carried out during the late season, August to October 2015 at the Research Farm of the Department of Crop Science, Faculty of Agriculture, University of Benin, Benin City, Nigeria. (Latitude 6°14' and 7°34' N, Longitude 5°43' and 6°43' E). The experiments were laid out as a randomized complete block design with three replications. Planting was done on the flat. Each progeny was planted on a single 5.0 m long row plot spaced 0.75 m between rows and 0.25 m within row. Two seeds were planted per hole and later thinned to one plant per stand after seedling establishment. Agronomic practices such as thinning, weeding and fertilizer application were adequately carried out as when appropriate and when due. Data were collected on yield component traits: ear length, ear circumference, number of rows/ear, number of grains/row and grain yield.

Data were subjected to analysis of variance (ANOVA) using [9]. General and specific combining ability (GCA and SCA) were estimated according to [21].

3. Results

The general combining ability of the parents varied from one character to the other. Estimates of general combining ability (GCA) effects for the male parents in the early and late seasons for grain yield and yield components traits are shown in Table 1. While, Table 2 shows the GCA of the female parents in both seasons for yield and yield components, only 12C24117 i.e. parent B had significant positive GCA value in the early season for ear length, and none of the parents had a significant and positive GCA value in the late season. There were no significant GCA effects in males and females for ear circumference and grain yield. Parent F and G (11A11917 and 11A11991) had positive significant GCA effect $p < 0.05$ in the early season estimate for number of rows/ear. 12C24117 and 11A11895 i.e. Parent B and D had positive significant GCA value in the early season for number of grains/row. Only parent H (12C24123) had positive significant GCA effect for number of grains/row in the late season.

The estimates of specific combining ability (SCA) for the traits evaluated in the early and late seasons are shown in Table 3. There was significant positive SCA effects $p < 0.05$ in the crosses K*B, and L*F in the early, K*E, L*G and M*G in the late season for grain yield. Only the crosses J*D in the early season and M*B late season had a positive significant SCA effect ($p < 0.05$) for ear length. There was significant positive SCA effects for ear circumference in the crosses L*A, M*E early and L*G in the late season. None of the crosses had positive significant SCA effects for number of grains/row and number of rows/ear, in the early season. However, the crosses H*F, L*G, M*G and L*E were positively significant ($p < 0.05$) for number of grains/row and number of grain rows/ear respectively in the late season. Percentage contribution of male genotypes, female genotypes, and their interaction (cross) effects to total variance is shown in Table 4. In the early season, interaction effect had the highest percentage for all the traits except number of rows/ear, and number of grains per row which were 93.9% and 70.6% respectively for male GCA effects. This implies GCA/SCA ratio was unity for number of grain rows/ear and tends to unity for number of grains/row, while the rest were farther away from unity in the early season. Late season showed low GCA/SCA ratio for all the traits.

Combined mean square for grain yield and yield components is shown in Table 5. Mean square was highly significant ($p < 0.01$) in all the traits for seasons and genotypes x seasons. Genotypes were not significant for grain yield and number of grains/row as shown in Table 6.

Table 1: General combining ability (GCA) of male parents

Parent	Ear length		Ear circumference		Number of rows/ear		Number of grains/row		Grain yield	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
07A04207 (A)	-0.02	-0.41	0.13	-0.09	-1.27	-0.02	0.12	-1.83	0.08	0.15
12C24117 (B)	0.42	3.79	0.04	-0.74	-1.55	0.03	2.62*	-2.49	-0.10	-0.34
09AA2562 (C)	-0.21	1.64	-0.21	1.20	-1.99*	1.79	1.51	4.03	-0.03	0.42
11A11895 (D)	-0.13	-1.71	0.08	-0.94	-1.49	-1.90	1.78*	-1.25	0.03	0.11
11011896 (E)	-0.22	-1.64	-0.11	0.42	-1.66	0.73	0.56	1.48	-0.23	-0.03
11A11917 (F)	0.14	-0.28	0.24	0.64	3.95**	-0.19	-3.38**	0.34	0.11	-0.08
11A11991 (G)	0.03	-1.39	-0.17	-0.51	4.01**	-0.44	-3.21**	-0.27	0.13	-0.22
$SE.g_i$	0.25	2.38	0.16	1.20	1.04	1.14	1.06	2.51	0.16	0.42
$SE.g_i-g_i$	0.35	3.36	0.23	1.70	1.47	1.62	1.50	3.55	0.23	0.60

* significant at 5%, ** significant at 1%, respectively. S_1 = early season S_2 = late season

Table 2: General combining ability (GCA) of female parents

Parent	Ear length		Ear circumference		Number of rows/ear		Number of grains/row		Grain yield	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
12C24123 (H)	0.18	2.80	-0.10	1.90	-0.28	1.80	0.49	4.71*	-0.11	0.66
12C24122 (I)	-0.16	-1.45	0.03	0.79	0.06	0.87	-0.66	1.91	0.03	0.26
09A2567 (J)	0.02	-2.49	-0.14	-2.03	-0.09	-0.93	0.39	-6.59*	-0.06	-0.59
12C24114 (K)	-0.07	-1.47	0.11	0.35	0.39	-0.35	0.86	0.67	0.18	0.09
11A11990 (L)	0.12	-2.46	0.09	-1.70	-0.37	-2.44*	-0.32	-1.94	0.02	-0.46
11A11936 (M)	-0.09	5.07*	0.01	0.69	0.29	1.05	-0.75	1.24	-0.07	0.04
$SE.g_j$	0.23	2.20	0.15	1.11	0.96	1.06	0.98	2.32	0.15	0.39
$SE.g_j-g_i$	0.32	3.11	0.22	1.58	1.36	1.50	1.39	3.29	0.21	0.56

* significant at 5%, ** significant at 1%, respectively. S_1 = early season S_2 = late season

Table 3: Specific combining ability (SCA)

Crosses	Ear length		Ear circumference		Number of rows/ear		Number of grains/row		Grain yield	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
H*A	-0.17	0.64	-0.39	2.63	-0.11	2.01	1.07	6.46	-0.50	-0.02
I*A	0.09	4.13	-0.47	3.10	0.22	2.27	-1.45	6.81	-0.07	1.11
J*A	-0.94	3.87	0.25	4.67	-0.30	2.35	-0.83	1.53	0.04	0.06
K*A	0.30	-2.89	-0.44	-4.43	-0.11	-4.52*	1.35	-3.39	-0.23	-1.01
L*A	0.39	2.19	0.86**	-0.65	0.31	1.36	-0.79	-0.67	0.51	1.05
M*A	0.33	-7.94	0.18	-5.32*	0.01	-3.46	0.64	-10.74*	0.25	-1.18
H*B	-0.45	-3.08	0.10	3.03	0.50	0.96	-0.77	7.45	0.00	0.13
I*B	0.86	-2.43	-0.22	2.15	0.50	2.33	0.38	-1.86	0.20	0.60
J*B	0.49	-1.20	0.32	2.05	-0.02	3.47	0.33	4.97	0.17	1.16
K*B	0.57	-6.09	0.13	-0.55	-0.17	-1.89	1.20	-0.96	0.73*	-0.28
L*B	-0.49	-12.16*	-0.17	-6.33*	-0.41	-6.69**	-0.29	-10.91*	-1.14**	-1.86*
M*B	-0.99	24.96**	-0.16	-0.35	-0.40	1.82	-0.86	1.31	0.03	0.25
H*C	-0.26	1.46	0.27	-3.18	0.61	-0.91	0.68	-8.07	0.16	0.64
I*C	-0.36	2.48	-0.36	1.91	-0.39	-0.32	0.16	3.29	-0.21	0.53
J*C	-0.32	3.65	0.26	0.54	0.42	2.82	-1.22	4.56	0.02	1.31
K*C	0.37	-4.08	0.02	-2.83	-0.39	-3.65	-1.04	-9.21	0.18	-2.5**
C*L	-0.27	-0.54	-0.08	0.01	0.38	-0.45	6.01	3.25	-0.43	-0.62
M*C	0.84	-2.97	-0.10	3.55	-0.63	2.50	8.49	6.18	0.27	0.61
H*D	0.61	1.65	-0.08	-0.48	-0.56	-0.77	0.07	-3.79	0.18	0.24
I*D	-0.50	3.34	0.50	0.55	0.45	0.05	0.88	5.23	0.14	0.10
J*D	1.15*	-6.62	-0.65*	-5.81*	-0.75	-6.26*	0.16	-7.49	0.01	-2.17*
$SE.g_{ij}$	0.60	5.82	0.40	2.95	2.54	1.82	2.61	3.47	0.40	0.55
$SE.g_{ij}-g_{ij}$	0.85	8.23	0.57	4.17	3.60	2.57	3.68	4.90	0.56	0.78

Male parents: 07A04207 =A; 12C24117 = B; 09AA2562 = C; 11A11895 = D; 11011896 = E; 11A11917 = F) and 11A11991= G

Female parents: 12C24123= H; 12C24122 = I; 09A2567 = J; 12C24114 = K; 11A11990 = L and 11A11936 = M.

* significant at 5%, ** significant at 1%, respectively. S_1 = early season S_2 = late season

Table 3: Continued: Specific combining ability (SCA**)**

Crosses	Ear length		Ear circumference		Number of rows/ear		Number of grains/row		Grain yield	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
K*D	0.56	2.57	0.25	1.17	0.11	1.82	0.69	5.35	0.40	1.57
L*D	-1.10*	1.86	-0.06	1.51	0.54	2.41	-0.78	-0.65	-0.21	0.35
M*D	-0.71	-2.80	0.04	3.06	0.21	2.75	-1.02	1.35	-0.52	-0.08
H*E	0.26	0.90	0.12	1.63	0.28	-0.52	0.63	-0.74	0.27	-0.20
I*E	-0.23	-4.54	0.01	-5.02*	-0.39	-2.03	-1.57	-2.40	-0.38	0.10
J*E	0.38	1.33	-0.07	0.79	0.42	-0.68	3.06	3.00	0.21	-0.29
K*E	-0.93	4.57	-0.48	2.43	-1.06	3.45	-1.09	4.07	-0.69*	1.82*
L*E	-0.28	5.85	-0.41	3.14	0.37	4.72*	-0.90	5.95	0.10	0.23
M*E	0.80	-8.11	0.84*	-2.97	0.38	-4.94*	-0.13	-9.88*	0.50	-1.65
H*F	0.30	4.35	0.39	2.78	-0.33	2.18	-1.10	12.95*	-0.01	0.65
I*F	-0.21	-0.49	0.18	-1.09	-1.34	-1.11	0.05	-3.92	-0.02	-0.77
J*F	-0.46	2.75	-0.31	3.99	0.81	2.35	-2.33	-0.42	-0.62	1.08
K*F	-0.65	0.45	0.23	0.28	1.67	0.88	-0.81	-1.85	-0.27	-0.16
L*F	0.99	-3.09	-0.19	-4.08	-1.24	-2.91	3.71	-7.07	0.76*	-1.07
M*F	0.03	-3.96	-0.30	-1.88	0.43	-1.40	0.47	0.31	0.15	0.27
H*G	-0.30	-5.91	-0.42	-6.39*	-0.39	-2.95	-0.59	-14.27*	-0.11	-1.43
I*G	0.35	-2.49	0.37	-1.61	0.95	-1.19	1.55	-7.14	0.33	-1.65
J*G	-0.30	-3.77	0.19	-6.24*	-0.58	-4.05	0.83	-6.14	0.17	-1.15
K*G	-0.21	5.46	0.30	3.94	-0.06	3.91	-0.31	5.98	-0.12	0.54
L*G	0.75	5.89	0.06	6.40*	0.04	1.56	0.55	10.09*	0.41	1.92*
M*G	-0.30	0.83	-0.50	3.90	0.04	2.73	-2.02	11.48*	-0.68*	1.78*
$SE.g_{ij}$	0.60	5.82	0.40	2.95	2.54	1.82	2.61	3.47	0.40	0.55
$SE.g_{ij}-g_{ij}$	0.85	8.23	0.57	4.17	3.60	2.57	3.68	4.90	0.56	0.78

Male parents: 07A04207 =A; 12C24117 = B; 09AA2562 = C; 11A11895 = D; 11011896 = E; 11A11917 = F) and 11A11991= G
Female parents: 12C24123= H; 12C24122 = I; 09A2567 = J; 12C24114 = K; 11A11990 = L and 11A11936 = M.
* significant at 5%, ** significant at 1%, respectively. S_1 = early season S_2 = late season

Table 4: Percentage contribution to total variation

Traits	Combining ability effects							
	% GCA_{male}		% GCA_{female}		% SCA		GCA/SCA	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
Ear length	11.4	8.0	3.6	19.7	85.0	72.2	0.2	0.3
Ear circumference	15.8	4.3	5.7	15.7	78.5	80.1	0.2	0.2
Number of rows/ear	93.9	9.7	1.1	17.8	5.0	72.5	1.0	0.3
Number of grains/row	70.6	7.3	5.4	21.4	24.0	71.3	0.8	0.3
Grain yield	8.2	3.9	5.3	12.5	86.5	83.6	0.1	0.2

Table 5: Combined mean squares for grain yield and yield component traits

Source of variation	Degree of freedom	Mean square				
		Ear length	Ear circumference	Number or rows/ear	Number of grains/ row	Grain yield
Seasons	1	1345.62**	2437.27**	2812.92**	9802.35**	166.639**
Reps (season)	4	77.65	82.98**	210.4**	674.18**	21.784**
Genotypes	40	67.42**	22.97**	28.62**	93.36	2.318
Males	6	42.34	4.91	67.47**	82.41	1.214
Females	5	104.49	23.8	29.77	131.9	1.815
Males x females	30	63.85	23.58**	19.67	87.09	2.862*
Genotype x season	40	73.34**	23.37**	28.64**	104.70**	2.54*
Seasons x males	6	31.93	5.89	87.07**	81.87	0.712
Seasons x females	5	103.99	23.85	23.61	140.35	2.094
Seasons x males x females	30	73.98	23.72**	16.16	98.03	3.01**
Error	124	53.1	13.25	21.91	66.11	1.732

* significant at 5%, ** significant at 1%, significant at 0.01%,***

Table 6: Mean values of the parents

Parents	Early cropping season					Late cropping season				
	Ear length (cm)	Ear circumference (cm)	No. of grain rows/ear	No. of grains/row	Yield (t/ha)	Ear length (cm)	Ear circumference (cm)	No. of grain rows/ear	No. of grains/row	Yield (t/ha)
07A04207 (A)	15.4	15.2	14.4	28.1	4.3	10.7	8.5	9.1	13.5	2.8
12C24117 (B)	15.9	15.1	14.1	30.6	4.1	14.6	8.2	9.1	12.8	2.3
09AA2562 (C)	15.3	14.8	13.7	29.5	4.2	12.5	10.0	10.9	19.4	3.1
11A11895 (D)	15.3	15.1	14.2	29.8	4.3	9.1	7.8	7.2	14.1	2.8
11011896 (E)	15.2	14.9	14.0	28.6	4.0	9.1	9.7	9.8	16.8	2.6
11A11917 (F)	15.6	15.3	19.6	24.6	4.3	10.6	9.4	8.9	15.7	2.6
11A11991 (G)	15.5	14.9	19.7	24.8	4.3	9.4	8.3	8.7	15.1	2.4
12C24123 (H)	15.6	14.9	15.4	28.5	4.1	13.6	10.7	10.9	20.0	3.3
12C24122 (I)	15.3	15.1	15.7	27.3	4.3	9.3	10.1	10.0	17.3	2.9
09A2567 (J)	15.5	14.9	15.6	28.4	4.2	8.1	6.9	8.2	8.8	2.1
12C24114 (K)	15.4	15.1	16.1	28.9	4.4	9.4	9.1	8.8	16.0	2.7
11A11990 (L)	15.6	15.1	15.3	27.7	4.2	8.6	6.9	6.7	13.4	2.2
11A11936 (M)	15.4	15.0	16.0	27.2	4.2	16.1	9.4	10.2	16.6	2.7
MEAN	15.5	15.0	15.7	28.0	4.2	10.9	8.8	9.1	15.3	2.7
$Lsd_{0.05}$	2.6	1.8	8.5	8.7	1.7	6.6	3.3	3.2	7.0	1.2

4. Discussion

There was very low significant GCA and SCA effect indicating low genetic variability among the parental lines used in this study. This may be due to high degree of relatedness among the parental genotypes. However, the existence of high variability for different characters among maize varieties had been reported by [6]; [4]; [8], and [3]. Presence of highly significant GCA and SCA variances for some of the characters also indicated the importance of additive and non – additive genes in the expression of the traits [10].

The result obtained indicated that none of the parents within the early or late season's estimate had a significant GCA effect for yield and as a result may not be good combiners for yield. However parents can be selected for yield through yield component traits as suggested by [13]. Although none of the parents was a good general combiner for grain yield, hybrid L*F and K*B were good specific combiners for grain yield. A situation as this was reported by [4] where GCA effect for grain yield across environments was not significant, whereas SCA effects were highly significant.

The relative contribution of GCA and SCA effects to genetic variance may help determine the optimum mating scheme for the improvement of a given trait in a population [1]. GCA/SCA ratio was very low and farther from unity in all the traits. These indicate preponderance of non-additive genetic variance (SCA). Conversely, GCA effects were primarily of paternal origin for number of rows/ear and number of grains/row in the early season. Thus, selection for these traits would be more efficient when carried out in the prospective male parents. Grain yield which showed more of SCA effect in this study is in consonance with the work of [20], [11], [4] and [2]. In contrast, [18] and [19] reported higher GCA effect than SCA for maize grain yield. Similarly [17] asserted that additive genetic action was more important than non-additive gene action for grain yield in maize. SCA was important in this study probably as the parental genotypes used were open pollinated and thus, highly heterozygous.

This study also showed highly significant genotypes x seasons (environment) interaction, this agreed with [16] who observed highly significant ($p < 0.01$) effects for environment in inbred maize grown in three environments in Brazil. Generally, there were high significant interactions between the genotypes and environment. This stems from the fact that environmental factors such as temperature, rainfall, humidity and soil moisture were at varying degrees during the two seasons, this is in agreement with [15] who emphasized that apart from the great variation as determined by latitude, day length and temperature, there is an expressive variation among locations, even when they are not far from one another. The high significant genotype x seasons interaction observed in this study implied that selection should be carried out for the different seasons, since genotype performance varied for the two seasons under consideration.

5. Conclusions

This study showed the relative importance of general and specific combining ability (GCA and SCA) effects for maize yield component traits which may vary depending on populations used or environment (season) where the study was conducted. Result from this study however, showed high importance of SCA in the genetic attributes of the genotypes used indicating they were highly heterozygous being open pollinated cultivars. Genotype x season (environment) interaction was also very pronounced in the genetic expression of the parental cultivars and the derived hybrid progenies from the crosses among the parents. Five hybrid crosses with highest grain yield among the 42 crosses were identified from the early and late season evaluation viz; L*F, K*B, L*A, L*G, M*E and K*E, M*G, L*G, L*E, M*B respectively. These could be very promising materials for further development of hybrid and synthetic varieties and also for population improvement in maize. The hybrid from the cross L*G had a good performance at both seasons, it could therefore be recommended as a cultivar or further advanced for population improvement due to its relative stability than all others. Since grain yield and yield component traits were primarily governed by non-additive genetic variance, use of biparental crosses followed by modified recurrent selection is recommended for future breeding for yield improvement with these genotypes.

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