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Seed Production, Growth and Grain Yield of Self, Half-sib and Bulk-sib Progenies Developed from an Early-maturing Maize (*Zea mays* L.) Population

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NFO and AO managed the study, performed the statistical analysis, managed the literature searches and wrote the first draft of the manuscript. Author MABF designed the study and contributed to the first draft of the manuscript, Author ROA assisted with generation of the progenies. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objectives of this study are to assess the effect of pollination methods on the seed quality and yield of progenies from an early-maturing maize population and to determine the relationship between seed quality and grain yield of the different progenies.
Study Design: Experimental field design was split plot design with three replicates using the stratum for developing the progenies as the main plot and the pollination methods as the sub-plots.
Place and Duration of Study: Seed Science Laboratory and Teaching and Research Farm, Obafemi Awolowo University Ile-Ife, Osun State, Nigeria between 2013 and 2015.
Methodology: Self, half-sib and bulk-sib pollination methods were used to produce progenies during the late cropping seasons of 2013 and 2014. Evaluation of the progenies developed by the three methods was carried out in the laboratory in 2014 for progenies developed in 2013 and 2015 for 2014 developed progenies. The field experiment was conducted in the early and late cropping seasons of 2014.

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Results: Pollination method had no significant effect on germination traits of progenies generated in both years, but significantly affected most of the seedling vigour traits. In 2014, there was no significant effect of pollination method on seed weight before ageing, but germination percentage of progenies from self (86%) and half-sib (90.41%) pollinations were significantly higher than that of bulk-sib (46.40%) pollination after ageing. The speed of germination from self (4.04) and half-sib (4.02) pollinations were significantly faster than that of bulk-sib (5.23) pollination after ageing. Half-sibs and bulk-sibs progenies performed better than the self-pollinated progenies for anthesis-silking interval (2.39, 2.28 and 3.50 respectively) ear length (11.96 cm,12.23 cm and 10.06 cm respectively), ear diameter (3.92cm, 4.00cm and 3.56 cm respectively), kernel row number (12.04, 11.92 and 11.77 respectively) and grain yield (1.63, 1.72 and 0.72 tons/ha respectively).

Conclusion: Self-pollination method produced the highest number of seeds while bulk-sibs pollination method produced seedlings that are more vigorous. Bulk-sib and half-sib progenies produced higher grain yield than the selfed progenies. Only root number of the half-sibs progenies had a positive relationship with yield in the early cropping season

Keywords: Half-sibs; bulk-sibs; S_1 Lines; stratum.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the main cereal crops of West and Central African countries, and the most abundant food crop in Nigeria [1]. It is one of the main crops grown by smallholder farmers in Nigeria and has been a major food and source of livelihood for most Nigerians [2]. Maize is naturally a cross-pollinating crop but over the years, plant breeders have learnt ways of modifying this natural process through controlled pollination. The two major methods of controlled pollination in maize are self and cross-pollination, however, with modification they are handled in different ways, such as half-sib, bulk-sib, full-sib, and self-pollination methods [3]. These pollination methods are being used in the development of new improved varieties and seed multiplication.

Seed is the most vital and crucial input in crop production. In seed production, the quantity and quality of the seed produced are very important. Seed quality is a multi-component property that includes germination capacity, vigour, genetic characteristics, moisture content, analytical purity, and seed health. Among these properties, the most important is germination capacity and vigor [4]. In commercial seed production and certification; analytical purity, germination capacity, and moisture content are the mandatory aspects of seed quality to be tested in Nigeria [5].

Production of good quality seeds from a high yielding maize variety enables seed companies to maximise profit. Akbari et al. [4] stated that seed quality is very important for optimum growth and yield in farm and its viability and vigour are the most important factors influencing it. Seed viability is measured using seed testing methods such as Standard Germination and Biochemical test, while recommended vigour tests are Conductivity and Accelerated Ageing test [6]. Viability is the potential of a seed to germinate. Standard Germination Test is used to determine the percentage of seed capable of producing normal seedlings under optimal conditions. Germination tests are conducted for a prescribed time period under laboratory conditions that assure optimum moisture, temperature and light. Unfortunately, these conditions are seldom encountered in the field and as a result, field emergence is often overestimated by standard germination tests. On the other hand, vigour test such as the accelerated ageing test indicates the seed’s ability to germinate and establish healthy seedlings under stressful conditions. According to the definition of AOSA [7], seed vigour is the seed property that determines its ability to have fast and uniform emergence, and development of healthy seedlings under a wide range of field conditions. Seed vigour has a high influence on the establishment of an initial population of plants as well as on their adequate development, which affects crop yield [8]. In other words, high vigour seeds should always be used to ensure good stand establishment under varying field conditions [9].

Despite the importance of pollination in the development of new improved varieties and seed multiplication, little or no information is available on the effects of the pollination methods on seed quality and quantity in maize. Therefore, the objectives of this study are to determine the effect of pollination methods on seed quality, growth and yield of progenies from an early-maturing maize population and to determine the relationship between seed quality and grain yield of the different progenies.

2. MATERIALS AND METHODS

2.1 Generation of Progenies

A yellow endosperm early maturing maize population was used to generate progenies. The progenies were generated at the Teaching and Research Farm, Obafemi Awolowo University (OAU), Ile-Ife, Osun State, Nigeria during the 2013 and 2014 late cropping seasons. The experimental field was divided into twenty equal strata, measured at 6.75 m × 5 m with 10 rows in a stratum and 22 stands in each row. The rows were spaced 0.75 m apart and 0.5 m within rows. Two seeds were planted per stand with a total of 220 plants per stratum and an approximate density of 53,333 plants/ha. The progenies were generated on each stratum using three controlled manual pollination methods, namely; self, half-sib and bulk-sib pollination on each stratum.

i. Fifteen plants were randomly selected and self–pollinated in each stratum.
ii. For half-sib pollination, pollens were collected from three different plants in a stratum and each was used to pollinate five plants in the same stratum to produce a total of fifteen half-sib progenies. The procedure was carried out in other strata.
iii. For bulk-sib pollination, bulked pollens from five males in a stratum were used to pollinate five different females in the same stratum, and this was repeated for two other sets of plants to produce a total of fifteen bulk-sibs per stratum. Care was taken to ensure that self- pollination does not occur in half-sib and bulk-sib pollinations.

In the late season of 2014, progenies were generated using the bulk-sibs produced from the original population in 2013 (F_1 bulk-sibs). The seeds were bulked and used as parents to generate S_1, half-sibs, and bulk-sibs progenies.

At harvest, ears from each pollination method were harvested per stratum, dried to 11% moisture content at 45°C, hand-shelled and sorted to remove broken and diseased seeds. Seeds obtained from each ear were packaged in a brown envelope and properly labelled according to the pollination method used to generate them and the stratum. Afterwards, they were kept in sealed polythene bags and stored in a deep freezer until evaluation. Owing to yield loss in both years, some strata did not have sufficient progeny seeds for one or two of the three pollination methods. In 2013, only six strata had sufficient progeny seeds for all the three pollination methods and as a result of this, laboratory evaluation was restricted to those six. For 2014, none of the strata had sufficient progeny seeds for all three pollination methods so stratum was not used as a factor.

Evaluations were carried out in the laboratory and on the field.

2.2 Laboratory Evaluation

The laboratory investigations were carried out in the O.A.U Seed Science Laboratory in 2014 for progenies generated in 2013 late cropping season, and 2015 for progenies generated in 2014 late cropping season, according to the standard laboratory tests and seedling evaluations of International Seed Testing Association [10]. Viability and vigour tests were conducted using germination and accelerated ageing tests respectively.

Germination test was carried out on 2013 progenies. From the progenies of each pollination methods 150 seeds were counted in each of the selected stratum. Fifty seeds were planted on sterilised riverbed sand in plastic containers in three replicates.

The accelerated ageing test was carried out by counting 150 seeds from progenies of each pollination methods in each selected stratum. Accelerated ageing boxes were used in conducting this test. Forty (40) millilitre of distilled water was poured inside each ageing boxes and a wire mesh was suspended in it. Fifty (50) seeds were placed on the wire mesh after initial weight had been taken and the boxes were covered. These ageing boxes were properly labelled and kept inside a hot air oven at 43°C for 72 hours. At the end of the ageing period, the accelerated ageing boxes were removed and cooled at room temperature. The seeds were then subjected to germination test.

For progenies developed in 2014, one hundred seeds were counted from the progenies of each pollination methods in an unequal number of strata. Same procedures were taken in evaluating progenies generated using the three pollination methods but in two replicates.

2.2.1 Data collection

Germination counts were taken at 4^{th}, 5^{th}, 6^{th} and 7^{th} days after planting (DAP), from which germination percentage, germination index and germination rate index were computed. Seedling vigour data were collected on the following seedling traits using 10 seedlings per container: number of abnormal seedlings, number of primary roots, length of shoot and of the longest root, fresh weights of shoots and roots, and dry weights of shoots and roots. Roots of the 10 seedlings were removed, bulked and oven-dried at 80°C for 24 hours to obtain root dry weight. Shoot dry weights were similarly obtained.

Germination percentage (G%), germination index (GI), and germination rate index (GRI) were calculated by substituting germination counts at 5^{th} and 7^{th} dayaccording to the following equations [11]:

G% = {(Number of seedlings emerged 7 DAP)/ (Total number of seeds planted) x100}

GI = ∑(Nx) (DAP)/Seedlings emerged 7 DAP

Nx = number of seedlings that emerge on day x

GRI= {(Germination index)/(Germination percent) x100}

2.3 Field Evaluation

Field trials were conducted during the early (May 21^{st}) and late (Aug 4^{th}) cropping seasons of 2014 at the Teaching and Research Farm of O.A.U. A total of sixty-six seeds from each progeny type were counted out from each selected stratum and bulked for evaluation. The experimental site was ploughed and harrowed and the field was laid out in a Split-Plot design with three replicates using the stratum as the main plot and the pollination methods as the sub-plots. Each subplot was a single row, 5 m in length. Seeds were treated with Apron plus before planting. Two seeds were planted per hole at the spacing of 0.75 m x 0.5 m to give a total of 53,333 plants/ha.

Primextra, a pre-emergence herbicide was applied one day after planting at the rate of 5 litres/ha. Primextra contains atrazine (2-chloro-4-(ethyl amino)-6-isoprpylamino-s-triazine) and alachlor (N-(1-methyl-2-methoxy-ethyl)-2-ethyl-8-methyl-chloroacetaniilde) as active ingredients. Fertiliser NPK was applied three weeks after planting at the total rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare. Weeds were controlled by hand weeding and contact herbicides as necessary after the crop had established.

2.3.1 Data collection

The following data were collected from each plot: emergence count at 5^{th}, 7^{th}, and 9^{th} day after plantation (DAP), to 50% tasselling, anthesis, silking and anthesis-silking interval (ASI), plant aspect, plant height, ear height, root lodging, shoot lodging and ear aspect. Field weight of harvested ears per plot, kernel row number, ear diameter, ear length, moisture content and grain weight data were also collected after harvesting. Data collected from emergence count at 5^{th}, 7^{th}, and 9^{th} DAP were used to calculate emergence percent (E%), emergence index (EI), and emergence rate index (ERI) using the formula proposed by Fakorede and Agbana [11]. Difference between days to 50% silking and anthesis was used to calculate ASI. Plant aspect was based on a scale of 1 to 5, where 1= excellent and 5 = poor and ear aspect was scored on the scale of 1 to 5 where, 1 = clean, uniform, and well-filled ears and 5 = ears with undesirable features. Plant height was measured from the base of the plant to the height of the first tassel branch and ear height was measured from the base of the plant to the node bearing the top ear. Root lodging was measured as a percentage of plants leaning more than 30 degrees from the vertical and stalk lodging was measured as a percentage of plants broken at or below the top ear node. Grain yield converted to t/ha was obtained using the formula:

Grain yield (t/ha) =
[{field weight (kg/plot)/ Plot area (5 m x 0.75 m) x (100-grain moisture)/85}×shelling% x 10000 m^2/1000 kg]

2.4 Statistical Analyses

Progeny seed number, weight, and 100-seed weights were subjected to simple descriptive statistics, while laboratory and field evaluations were subjected to Analysis of Variance (ANOVA) using General Linear Model (GLM) procedures. Mean separation was carried out using Fisher's Least Significant Difference (F-LSD) at 0.05 level of probability, and the correlation was done using the correlation analysis program of SAS, version 9.2 [12].

3. RESULTS

A number of seeds and seed weight obtained from the progenies of self, half-sib and bulk-sib pollination methods varied considerably. Self and bulk-sib pollination methods produced significantly higher seed number and weight than half-sib pollination methods for progenies developed in 2013 (Table 1).

The half-sib progenies also had the highest variance (11228.30, 675.90) and widest range (40.00 g -606.00 g, 4.10 -146.30 g) in both seed number and weight respectively, producing ears with the smallest and highest seed number, while bulk-sib pollination method produced progenies with the lowest variance (4270.53, 477.96) and narrowest range (200.00 g–485.00 g, 26.64 g - 139.53 g) for both seed number and weight respectively. For progenies generated in 2014, self-pollination method produced the highest seed number (180 seeds) and weight (25.66 g), while bulk-sib pollination method produced the lowest number of seeds (95 seeds) and seed weight (14.95 g). Self-pollination method gave the highest variance (11584.94) for seed number, while bulk-sib pollination method gave the lowest (6275.22). Half-sib pollination method produced progenies with the widest range in seed number (2.00 – 521.00), but the narrowest range for seed weight (0.30 g – 66 g). Pollination method had no significant effect on one hundred seed weight of the progenies produced in 2013 and 2014 late cropping seasons (Table 2).

Table 1. Descriptive statistics for seed number and seed weight per ear (g) of progenies developed using self, half-sib and bulk-sib pollination methods from an early-maturing yellow maize population during 2013 and 2014 late cropping seasons at the TRF, O.A.U, Ile-Ife

Pollination methods	[1]Self (ENO =204; 2013, 177; 2014)		Half-sib(ENO =208; 2013, 190; 2014)		Bulk-sib(ENO =77; 2013, 123; 2014)	
	Seed No	Seed Wt (g)	Seed No	Seed Wt (g)	Seed No	Seed Wt (g)
2013						
Mean	331.81	78.16	277.21	65.06	327.00	79.21
S. Error	5.70	1.70	7.35	1.80	7.45	2.49
Variance	6631.38	587.30	11228.30	676.90	4270.53	477.96
Min	69.00	22.30	40.00	4.10	200.00	26.64
Max	534.00	159.62	606.00	146.30	485.00	139.53
2014						
Mean	179.73	25.66	147.35	21.02	94.81	14.95
S. Error	8.09	1.12	7.10	0.95	7.14	1.36
Variance	11584.94	222.77	9577.08	171.07	6275.22	228.71
Min	6.00	1.00	2.00	0.30	2.00	0.30
Max	459.00	73.00	521.00	66.10	347.00	142.00

[1] ENO = Number of ears

Table 2. Descriptive statistics for hundred seed weight (g) of progenies developed using self, half-sib and bulk-sib pollination methods during 2013 and 2014 late cropping seasons at the TRF, O.A.U, Ile-Ife

Pollination methods	Self	Half-sib	Bulk-sib
2013			
Mean	23.77	24.28	24.20
S. Error	0.36	0.42	0.54
Variance	25.87	37.00	22.23
Min	11.78	10.33	11.10
Max	40.24	56.31	35.12
2014			
Mean	15.51	16.37	18.17
S. Error	0.38	0.44	1.20
Variance	25.81	36.35	176.10
Min	5.43	5.33	4.00
Max	32.50	32.65	151.00

For seedling vigour traits analysis conducted for 2013 progenies, there was no significant difference in root number (RN) of half-sib (1.74) and bulk-sib seedlings (1.73) (Table 3), but both were significantly higher than the selfed progeny (S_1) (1.68).

Also, SL of bulk-sib seedlings (9.84 cm) was significantly higher than those of S_1 (9.32), but not significantly different from half-sibs (9.55). While bulk-sib seedlings produced significantly higher primary and longest root length (20.56, 20.92 respectively) than S_1 (18.91, 19.19) and half-sib seedlings (17.53, 18.05), RFW and RDW obtained from bulk-sib seedlings (8.67, 1.43 respectively) were significantly lower than those of S_1 (10.41, 1.52) and half-sibs (10.29, 1.70). For seedling vigour test of progenies produced in 2014, bulk-sib seedlings had the highest RFW (7.99 g) and half-sib seedlings gave the lowest (3.95 g). RDW of bulk-sibs and S_1 seedlings were similar (2.57g 2.45 g), but significantly different from that of half-sib seedlings (1.53 g) (Table 3). Shoot dry weights obtained from S_1 (0.38 g) and half-sib seedlings (0.42 g) were significantly lower than those of bulk-sibs (0.51 g). Half-sib progenies had significantly higher 50SWB (12.97 g) than self-pollinated progenies (12.40 g) and bulk-sibs (12.11 g) (Table 4).

For accelerated ageing test of seeds produced in 2014, there was no significant effect of pollination method on 50SWB (Table 4), but progenies from self and half-sib pollination had significantly higher germination percent and germination index which measures the speed of germination (85.67%, 4.04; 90.41%, 4.02) than bulk-sib progenies (46.40%, 5.23) (Table 4).

Table 3. Means of seedling vigour traits from self, half-sib, and bulk-sib pollination methods, developed during 2013 and 2014 late cropping seasons, and evaluated at O.A.U Seed Science Laboratory

	2013 cropping season					
Pollination methods	**PRL[1]**	**RN**	**SL**	**LRL**	**RFW**	**RDW**
Self	18.908	1.676	9.322	19.191	10.409	1.515
Half-sib	17.525	1.741	9.551	18.053	10.286	1.701
Bulk-sib	20.564	1.728	9.836	20.923	8.665	1.432
$LSD_{0.05}$	1.492	0.034	0.344	1.333	0.732	0.135
	2014 cropping season					
Pollination methods	**RFW[2]**	**RDW**	**SDW**			
Self	5.544	2.448	0.381			
Half-sib	3.946	1.533	0.415			
Bulk-sib	7.992	2.565	0.509			
$LSD_{0.05}$	0.678	0.549	0.048			

[1,] PRL = Primary root length, RN = Root number, SL = Shoot length, LRL = Longest root length, [2]RFW = Root fresh weight, RDW = Root dry weight, SDW = Shoot dry weight

Table 4. Means of accelerated ageing traits from self, half-sib, and bulk-sib pollination methods, developed during 2013 and 2014 late cropping seasons, and evaluated at O.A.U Seed Science Laboratory

	2013 cropping season	
Pollination methods	**50SWB[1] (g)**	
Self	12.403	
Half-sib	12.968	
Bulk-sib	12.108	
$LSD_{0.05}$	0.290	
	2014 cropping season	
Pollination methods	**G%[2]**	**GI**
Self	85.667	4.039
Half-sib	90.412	4.024
Bulk-sib	46.400	5.225
$LSD_{0.05}$	20.091	0.226

[1, 2]50SWB = 50 seed weight before ageing, G% = Germination percent, GI = Germination Index

Late cropping season had significantly higher E% (90.74%) than early cropping season (81.57%) (Table 5), while emergence index (EI) which measures the speed of emergence and ERI as a measure of emergence rate was significantly lower in the late cropping season (5.74, 6.41 respectively). Furthermore, progenies evaluated during the late cropping season took significantly shorter days to reach 50% flowering (55-59 days) compared to the early cropping season (57 –62 days) (Table 5). In the early cropping season, EHT (71.67 cm), SL (19.88 cm), RL (14.34 cm), and MC (21.63%) were significantly higher than in the late cropping season (64.10%, 4.53 cm, 3.27 cm and 17.85% respectively) (Table 5). However, EL (11.42 cm) and GNYD (1.34 tons/ha) were significantly lower in the early cropping season (Table 5).

Progenies obtained from self-pollination method took significantly longer days to 50% tasseling, anthesis and silking in the early (57, 60 and 64 days respectively) and late (56, 58 and 61 days respectively) cropping seasons of 2014 (Table 6). Anthesis-silking-interval (ASI) was also significantly longer in self-pollination method (4 days) than in half-sib (2 days) and bulk-sib (2 days) pollination methods in the early season whereas in the late season both the self and half-sib pollination methods had longer ASI (3 and 2 days respectively) than the bulk-sib pollination method (1 day) (Table 6).

Progenies obtained from half-sib and bulk-sib pollination methods had significantly lower Plant Aspect (PASP) than progenies from self-pollination method in the early (2.75 and 2.58 respectively) and late (2.86) cropping seasons (Table 6), while self-pollinated progenies had significantly lower EHT (64.08 cm) and PHT (134.63 cm) than the half and bulk-sibs pollinated progenies in the early (75.46 cm; 153.42 cm and 75.48 cm; 154.22 cm respectively) and late (69.38 cm; 152.20 cm and 66.44 cm; 151.13 cm respectively) seasons (Table 6). Progenies from self-pollination method had significantly higher ear aspect (EASP) (3.92) than those of half-sibs (2.97) and bulk-sibs (2.94) in the early and late (4.28, 3.08 and 3.14 respectively) cropping seasons (Table 6). Furthermore, in the early season of this study, progenies from half-sib and bulk-sib pollination methods produced significantly higher grain yield (1.63 and 1.72 tons/ha respectively) and higher yield components such as, Ear length (12.39 cm and 13.32 cm respectively), Ear-Diameter (4 cm and 3.56 cm respectively) and Kernel row number (12) than self-pollinated progenies (0.67 tons/ha, 10.06 cm, 3.56 cm and 11.77 respectively) and also during the late season, the self-pollinated progenies produced the lowest yield, ear length, ear diameter and kernel row number (0.71 tons/ha, 10.59 cm, 3.40 cm and 11.59 respectively) in comparison to the half and bulk-sibs pollinated progenies (2.30 and 2.28 tons/ha; 12.39 and 13.32 cm; 3.90 and 3.91 cm; 12.56 and 12.54 respectively) (Table 6). Only the root numbers obtained from the half-sib progenies had a significant positive correlation with grain yield (0.52) in the early season of 2014 the progenies were evaluated. None of the other seedling vigour traits showed significant correlation with grain yield in the early and late cropping seasons of this study (Table 7).

Table 5. Means of emergence, flowering, vegetative, pre-harvest, grain yield and yield components traits for early and late cropping seasons of self, half-sib, and bulk-sib progenies from, developed in 2013 late cropping season, and evaluated at TRF, O.A.U, in 2014

Traits	Early season	Late season	$LSD_{0.05}$
E%	81.57	90.74	3.16
EI	7.58	5.74	0.19
ERI	9.43	6.41	0.40
DTS	56.74	54.96	0.44
DAT	59.76	57.35	0.37
DSK	62.48	59.32	0.61
ASI	2.72	1.96	0.52
EHT	71.67	64.10	2.53
SL	19.88	4.53	3.24
RL	14.34	3.27	4.97
EL	11.42	12.43	0.34
MC	21.63	17.85	0.43
GYLD	1.34	1.76	0.17

E% = Emergence percent, EI = Emergence Index, ERI = Emergence Rate Index, DTS = Days to 50% Tasseling, DAT = Days to 50% Anthesis, DSK = Days to 50% Silking, ASI = Anthesis-Silking Interval, EHT = Ear height, SL = Stalk lodging, RL = Root lodging, EL = Ear length, MC = Moisture content, GNYD = Grain yield

Table 6. Means of flowering traits of progenies from self, half-sib, and bulk-sib pollination methods, developed from an early-maturing yellow maize population in 2013 late cropping season, and evaluated during the early and late cropping seasons of 2014 at the TRF, O.A.U, Ile-Ife, Nigeria

Early season	Pollination methods	DTS	DAT	DSK	ASI	PASP	EHT	PHT	EASP	KRN	EL	ED	YLD
	Self	57.22	60.39	63.89	3.50	3.75	64.08	134.63	3.92	11.77	10.06	3.56	0.67
	Half-sibs	56.22	59.22	61.61	2.39	2.75	75.46	153.42	2.97	12.04	11.96	3.92	1.63
	Bulk-sibs	56.78	59.67	61.94	2.28	2.58	75.48	154.22	2.94	11.92	12.23	4.00	1.72
	$LSD_{0.05}$	0.90	0.70	1.05	0.67	0.29	3.64	4.50	0.44	0.67	0.71	0.17	0.31
Late season													
	Self	55.67	58.33	61.22	2.89	3.92	56.47	131.22	4.28	11.59	10.59	3.40	0.71
	Half-sibs	54.56	56.78	58.50	1.72	2.86	69.38	152.20	3.08	12.56	12.39	3.90	2.30
	Bulk-sibs	54.67	56.94	58.22	1.28	2.86	66.44	151.13	3.14	12.54	13.32	3.91	2.28
	$LSD_{0.05}$	0.91	0.70	1.39	1.15	0.35	4.78	5.03	0.33	0.61	0.69	0.15	0.30

Table 7. Spearman's correlation among the seed quality traits and yield of the Self-, Half- and Bulk-sib progenies developed during the late cropping season of 2013 and evaluated in the Seed Science Laboratory and Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Nigeria during the early and late cropping seasons of 2014

Traits	Progeny	Early season	Late season
PRL	Self	0.20	-0.02
	Half-sibs	0.26	-0.38
	Bulk-sibs	-0.11	-0.02
RN	Self	-0.11	-0.08
	Half-sibs	0.52*	-0.18
	Bulk-sibs	-0.13	-0.07
SL	Self	0.28	-0.15
	Half-sibs	0.27	-0.02
	Bulk-sibs	-0.30	0.13
LRL	Self	0.15	-0.10
	Half-sibs	0.27	-0.38
	Bulk-sibs	-0.30	-0.05
RFW	Self	0.21	0.14
	Half-sibs	0.01	0.27
	Bulk-sibs	-0.47	-0.03
RDW	Self	-0.05	0.30
	Half-sibs	0.01	0.42
	Bulk-sibs	-0.28	-0.08

4. DISCUSSION

The significantly lower number of seeds and seed weight obtained from the progenies of half-sib pollination method when compared to self and bulk-sib pollination methods in 2013 might have resulted from insufficient pollens during fertilisation, a situation where pollens were collected from one plant and used to pollinate five plants (half-sib pollination) compared to where pollens were collected from a plant and used to pollinate the same plant (self-pollination), or where bulked pollens collected from five plants were used to pollinate five different plants (bulk-sib pollination). Collins et al. [13] observed similar results for *Scorzonera humilis* (Asteraceae) and reported that pollen limitation can reduce both the number and quality of offspring. Also, Richardson and Stephenson [14] found in *Campanuala americana* L. (Campanulaceae) that progenies from fruits receiving high pollen loads outperformed the progenies from fruits receiving low pollen loads for several traits. The higher variance and wider range obtained from the seed number of half-sib pollinated progenies suggested that some plants would have enjoyed higher pollen loads than others and this affected the number of seeds produced from each ear. The trend in the 2014 progeny generation was, however, different from what was obtained in 2013. While pollen limitation might still be the reason the half-sib pollination method produced significantly lower seed number and weight than the self-pollination method, the reason the bulk-sib pollination method produced the lowest mean seed number and weight might be as a result of the terminal drought that occurred at the Teaching and Research Farm where the progenies were generated during the late cropping season of 2014. The terminal drought could be said to have affected the number of seeds produced from the bulk-sib pollination method more than self and half-sib pollination methods. However, even though bulk-sib produced the lowest seed number and weight, half-sibs still had the widest seed number range, producing the lowest and highest number of seeds from the ears. This might confirm that insufficient pollen had an effect on the number of seeds produced. A good look at the total quantity of seeds produced in 2013 and 2014 late cropping seasons showed that the three pollination methods produced higher seed quantity in 2013 than in 2014. The terminal drought that occurred during the flowering stages in 2014 late cropping season is most likely the reason for this lower production. Hundred seed weight is one of the important scales used in determining seed quality. Maize is generally known to be sensitive to inbreeding depression after continuous selfing, and seeds obtained from selfed maize plants are often smaller in size and weigh lesser than seeds generated from other pollination methods. However, the non significant effect of the pollination methods on the hundred-seed weight of progenies from self, half-sib, and bulk-sib pollination methods in both years indicated that there was no visible sign of inbreeding depression in terms of seed weight of the selfed pollinated progenies at this stage. Akbari et al. [4] and Moshatati and Gharineh [15] considered seed weight as one of the factors that determine seed vigour and that seed vigour is one of the most important factors influencing seed quality, explaining that the higher the seed weight, the more vigorous the seed. The fact that there was no significant difference in the hundred-seed weight of progenies produced using the three pollination methods suggested that the methods should have no effect on the vigour of the seeds. Results from the germination test conducted under optimum conditions for progenies produced in 2013 and 2014 late cropping seasons agreed with this. The non significant effect of pollination method on the germination traits of progenies from the 2013 and 2014 late cropping seasons implies that the pollination methods does not affect the viability of the seeds. The germination capacity of seeds might be more of a function of the genetic quality of the seeds of the progenies and their storage and not the pollination method used to generate progeny. The fact that the micro-environment (stratum) where the progenies were generated had no significant effect on any of the germination traits of the progenies implies that the germination capacity of the progenies was not influenced by the microenvironment in which they were produced. Bulk-sib pollinated progenies generated in 2013 late cropping season showed relative consistency in producing more vigorous seedlings for most of the seedling vigour traits than seedlings from self and half-sib pollination method. The significantly lower root fresh weight in bulk-sibs than those of self-pollinated progenies and half-sibs implies that bulk-sibs were able to utilise most of their stored nutrients than the others, and this was evident in how significantly vigorous their seedlings were for most of the seedling vigour traits compared to those of self and half-sib progenies. As mentioned by AOSA [7] the environmental and physiological factors during growth in the mother plant are one of the factors responsible for differences in vigour. This might explain the significant difference observed in the strata for some of the seedling vigour traits, suggesting that there was variability in the microenvironment where the progenies were produced. However, for progenies generated during 2014 late cropping season, the non significant difference observed in primary root length, root number, shoot length, and longest root length means that the pollination methods had no effect on these seedling vigour traits. Moreover, unlike progenies generated in 2013, root fresh weight and root dry weight of seedlings from bulk-sib pollination method were significantly higher than those of self and half-sib pollination methods. The inconsistency in the results for seedling vigour traits of progenies generated in 2013 and 2014 cropping seasons might suggest that the effect of pollination method on seedling vigour depends on the parent genetic material. Khan [16] confirmed that there is a significant positive correlation between seed weight and seed germination percent. For 2013 progeny evaluation, a significant difference was observed in fifty seed weight of the progenies with the half-sib pollination method producing seeds with the highest fifty seed weight before ageing. However, there was no significant difference in the germination percent after ageing. Meanwhile, in 2014 there was no significant difference in fifty seed weight of the progenies, but there was a significant difference in germination percent after ageing. Neither of the two years agreed with Khan [16] although this might be because the seeds had gone through stress before germination test was done. Bulk-sib pollination method produced seeds that had significantly lower germination percent and emergence speed for progenies generated during 2014 late cropping season. This means that the bulk-sib progenies in storage would lose their vigour faster than progenies from the self and half-sib pollination methods, suggesting that the lifespan of these bulk-sib progenies would be significantly shorter than those of the self and half-sib progenies. This might also imply that under adverse field conditions, the progenies from bulk-sib pollination method, produced from the F_1 bulk-sibs of the original population, might not fare as well as S_1 and half-sibs in terms of seedling establishment. Bielinski [9] stated that good quality seed results in good germination, viability, rapid emergence, and vigorous growth. The percentage of the 2014 late cropping season selfed and half-sib progenies that germinated even after ageing indicates that self and half-sib pollination method produce higher quality seeds than bulk-sib pollination method. Field emergence is a function of the environment and not the pollination method used to generate the progenies as indicated by the highly significant seasonal effect on the emergence of traits. However, pollination methods did have an effect on how long it took for progenies to flower as the self-pollination method took significantly longer days to complete 50% anthesis and silking, resulting in delayed flowering. Progenies from self-pollination method showed signs of inbreeding depression with at least 17.7% and 14.9% reduction in ear and plant height, respectively when compared with half-sib and bulk-sib progenies. The architectural beauty of the plants and ears (plant and ear aspect) showed depreciation in self-pollinated progenies and this might indicate that the progenies have started showing signs of inbreeding depression. Inbreeding depression could also be suggested as the likely reason for the significantly lower grain yield observed in the progenies from self-pollination method when compared to half-sib and bulk-sib progenies. Half-sib families could be used as a source of improved maize germplasm for developing maize genotypes with superior attributes [17,18,19]. The performance of the half-sibs from flowering to grain yield showed their superiority to self-pollinated progenies and this coincides with their suggestion. Bulk-sibs also performed as well as half-sibs indicating superiority to progenies generated from self-pollination method. For most of the traits evaluated, half-sib and bulk-sib pollinated progenies outperformed self-pollinated progenies except in percent moisture content at harvest. This agreed with Cornelius and Dudley [20] when they carried out inbreeding on an ear-to-row basis through seven generations of sib-mating and four generations of selfing, and found out that traits such as grain yield, plant height, ear height, percent oil and kernel weight, showed significant inbreeding depression except for percent moisture content at harvest. The significantly higher emergence percent, the speed of emergence (germination index), and the lower anthesis-silking interval during the late cropping season compared to the early cropping season showed that late-season planting is more favourable for maize seed production as a result of more stable rainfall, unlike during the early season. The significantly lower moisture content at harvest during the late cropping season indicated that there was sufficient period of sunshine that enabled seeds to dry faster before harvest, unlike during the early season where rainfall was still heavy at harvest.

There was no significant correlation between grain yield and most of the seedling vigour traits of the progenies for the three pollination methods in the early and late seasons except for the positive correlation between the root number and yield of half-sib progenies in the early season of this study. This showed that only the most vigorous seedlings generated by half-sib pollination method will result in higher yield as shown in this study and other studies [21,4]. These studies indicated that seed quality is very important for optimum growth and yield production.

5. CONCLUSION

Pollination method has no significant effect on the viability of the progenies at optimum condition. However, bulk-sib pollination method produced seedlings that were more vigorous than seedlings from self and half-sib pollination methods in 2013, but in 2014, germination percent and vigour of progenies generated from bulk-sib pollination of F_1bulk-sibs fared worst after ageing. Therefore, bulk-sib pollination method has an effect on seed vigour, but that bulk-sibs are more or less vigorous than seeds generated from self or half-sib pollination methods, depend on the genetic parent material.

Self-pollinated progenies outperformed by half-sibs and bulk-sibs for growth and grain yield resulting in 184.4% and 190.3% reduction in their grain yield when compared to half-sib and bulk-sib progenies, respectively. Only the root number of the half-sibs progenies showed a positive relationship with yield in the early cropping season of this study.

6. DISCLAIMER OF THE PRESENTATION

The research' findings were presented at the 2016 Annual Meeting of ASA, CSSA, SSSA in Phoenix Arizona, USA with the title "Effect of Pollination Methods on Seed Production, Growth and Grain Yield of Progenies of an Early-Maturing Maize (Zea mays L.) Population". The full paper was not published as proceedings or research article but as a book of abstract.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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