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Effect of seeding rate on the vegetative growth, yield and grain quality of two sesame varieties planted early season in the southern guinea savannah of Nigeria

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Abstract
Background*: Sesame is one of the most ancient oilseed crops, adapted and grown in almost all tropical and sub-tropical regions of Africa. The presence of some antioxidants (sesamum, sesamolin and sesamol) makes the oil one of the most stable vegetable oils in the world. However, due to poor quality it can only be used for industrial purposes resulting in a far lower price than food grade sesame. The poor-quality sesame, exacerbated by poor production practices, is characterized by high incidences of aflatoxin produced by Aspergillus species. Therefore, there is the need to investigate the effect of seeding rate on the vegetative growth, yield and grain quality of two sesame varieties planted early season*
Materials and Methods: *A field trial to determine the effect of seeding rate, variety and location on vegetative growth, yield and seed quality of sesame planted in the early season of 2017 was conducted across 3 locations in Nigeria's southern guinea savannah zone. The experiment was a 2 x 3 x 3 factorial arranged in Randomized Complete Block Design (RCBD) and replicated four times. Treatments comprised 2 varieties of sesame (E-8 and Ex-Sudan), 3 seeding rates (3 kg ha^{-1}, 5 kg ha^{-1} and 7 kg ha^{-1}) and 3 locations (Makurdi, Tor-Musa and Akwanga).*
Results: *Results indicated significant interaction between seeding rate and location on some plant attributes. Clearly, grain yield was enhanced as plant density increased. Interaction between variety and seeding rate showed significant effect on some vegetative characters and grain yield. Performance of genotypes varied across seeding rates with respect to some evaluated traits like Leaf Area Index (LAI), plant biomass and number of branches. Grain yield of the variety E-8 increased as seeding rate increased from 3 – 7 kg ha^{-1} while that of Ex-Sudan increased to a peak at 5 kg ha^{-1} seeding rate and thereafter declined. Taller plants resulted from higher seeding rates of 5 and 7 kg ha^{-1}compared to the least seeding rate (3 kgha^{-1}). Tor Musa and Akwanga locations produced significantly higher grain yield in contrast to the Makurdi location. Oil content of E-8 was not consistent across seeding rates but that of Ex-Sudandecreased as plant density increased. On the other hand, protein content of the cultivars did not vary significantly across seeding rates. Across varieties and seeding rates, crude protein values were lower for Makurdi than the other two locations.*
Conclusion: *The study therefore established a positive response of seed yield to higher seeding rates. Although oil content responded significantly to interaction of the factors, the two varieties maintained statistically similar values across seeding rates.*
Keywords: **Sesame, Seeding rate, Growth, Yield, Quality**

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I. Introduction

Sesame is one of the most ancient oilseed crops. It is well adapted and grown in almost all tropical and sub-tropical regions of Africa, Asia, Latin America and southern Europe for its seeds and oil from the seeds[1]. Over 6 million hectares (ha) of land are subjected to sesame cultivation globally, 66% of which is planted in Asia with China, India and Burma being the largest producers[2]; 26% is planted in Africa and 8% percent in the Americas (Venezuela, Mexico, Guatemala and Colombia)[2]. According to[3] FAOSTAT figures shows that India and China are the largest sesame producers, each producing up to 750,000 tons (t), with four African countries (including Nigeria) featuring in the top ten biggest producers. According to[4], about 65% of the annual sesame crop produced is processed into oil for domestic and industrial uses while 35% is consumed as whole seed.

Sesame is also used for pharmaceutical purposes. The presence of some antioxidants (sesamum, sesamolin and sesamol) results in the oil being one of the most stable vegetable oils in the world. It is also rich in carbohydrates, calcium, phosphorus and protein. The seed cake is rich in protein and is used in compounding protein-rich feeds for livestock[5].

The growing environment, cultural practices and cultivars play an important role in the yield of sesame[6]. Various research and recommendations on spacing (both inter row and intra row spacing) have been proffered[7,8;], but farmers would rather sow sesame by broadcasting, which may result in uneven stands rendering farming operations difficult, subsequently resulting in lower yields. In the year 2000, it was estimated that up to 570 000 ha of land was under sesame cultivation, producing an estimated 24 945 metric tons. The contemporary global wave of knowledge and understanding of the health and nutritional attributes of sesame and other emerging crops[10] has resulted in an increase in world market demand thereby motivating farmers to expand their land areas of sesame cultivation[1]. By the year 2001, Nigeria became the main exporter to the world's largest importer of sesame seeds – Japan[3]. However, when compared to the productivity of other competing countries, Nigeria's sesame productivity is sub-optimal. Part of the reason for this may be that there is no optimum plant population on the field. Sesame is the second biggest export crop product in Nigeria, but due to poor quality it can only be used for industrial purposes (sesame oil) resulting in a far lower price than food grade sesame. The poor-quality sesame, exacerbated by poor production practices, is characterized by high incidences of aflatoxin produced by *Aspergillus* species. Most field research on aflatoxin has been on maize and groundnut. There is limited literature on aflatoxin in sesame field research. Therefore, there is the need to investigate if optimal seeding rate can increase quality and yield of sesame seeds.Better sesame prices can be obtained by production of high-quality sesame seeds and even more so if sesame can be produced optimally. Harvesting and threshing regime might also play a role to reduce aflatoxin incidence. Thus, the effect of varying seeding rates and threshing regimes on sesame yield and seed quality will be investigated. The objectives of this work therefore are to determine the effects of seeding rate on the vegetative growth and development of late season planted sesame varieties in the southern guinea savanna of Nigeria.

II. Methodology

Sesame seeds

Two varieties of sesame were used for the experiments: E8 and Ex-Sudan sourced from National Cereal Research Institute (NCRI), Badeggi, Niger State, Nigeria. Both varieties are high yielding and early maturing at 90 days after planting[11]. However, E8 is preferred by researchers for its relatively high oil content while Ex-Sudan is preferred by farmers for its white colour.

Prior to sowing, a pre-field seed germination test was conductedin the Seed Science laboratory of the University of Agriculture Makurdi. The aim was to ascertain the quality of the seed lot in order to determine the actual quantity of seeds needed to balance up the recommended quantity for sowing for a desired plant population on the field. The following formulae were used to calculate the germination index and seedling vigour:

Locations of the trials

Makurdi Location

In Makurdi, the experiments were located at the Teaching and Research Farm of the University of Agriculture, Makurdi, Benue State, Nigeria at latitude 07^{0}45'N, longitude 08^{0}45'E, 98 m above sea level. The land was previously cultivated with cassava (*Manihot esculenta*) and maize (Z*ea mays* L.). At a depth of 0-15 cm, the soil texture was loamy sand, with a content of 87.4% sand, 4.8% silt and 7.8% clay. The active soil pH (H_20 pH) was 6.34. The organic content carbon was 1.62% while the organic matter content was 2.79%. The nitrogen (N) content was 0.35%, phosphorous (P) was 4.25 ppm, while potassium (K) was 0.32 cmol kg^{-1}. Calcium (Ca), magnesium (Mg) and sodium (Na) contents were 3.67, 1.46 and 0.21 cmol kg^{-1} respectively. The exchangeable acidity (EA), cation exchange capacity (CEC) and base saturation (BS) were 0.50 cmol kg^{-1}, 5.66 cmol kg^{-1} and 91.2% respectively.

Tor Musa Location

In Tor Musa, the experiment was located at Km 6 Tarkum Road, Taraba State at 09^{0}23'N and 12^{0}37'E at an altitude of 368 m above sea level. The land was previously cultivated with sorghum and yam. The soil texture at a depth of 0-15 cm was characteristic of loamy sand soil with 85.4% sand, 4.8% silt and 9.8% clay. The soil active pH (H_2O pH) was 6.34. Its organic carbon content was 1.60% while the organic matter was 2.75%. The percentage N, available P and K were 0.14%, 3.01 ppm and 0.26 cmol kg^{-1} respectively. Ca, Mg and Na were 3.11, 1.53 and 0.11 cmol kg^{-1} respectively. The EA of the soil was 0.83 cmol kg^{-1}; the CEC was 5.01 cmol kg^{-1} and the BS was 83.4 %.

Akwanga Location

In Akwanga, the experiment was located at Km 6/60 Akwanga/Keffi road at $08^0$59'N and $07^0$18'E at an altitude of 188 m above sea level. The land was previously cropped with soybeans as sole crop. The soil at a depth of 0-15 cm was characteristic of sandy loam soil with 83.4% sand, 4.8% silt and 11.8% clay. The soil active pH (H_20) was 6.18, 1.62% organic carbon and 2.79% organic matter content. The percentage N, available P and K were 0.28%, 3.86 ppm and 0.35 cmolkg^{-1} respectively; while the micronutrient content Ca, Mg and Na were 3.66, 1.81 and 0.30 cmolkg^{-1} respectively. The EA was 0.50 cmolkg^{-1}, CEC was 6.06 cmolkg^{-1} while the BS was 92.0%.

Experimental design and treatment

A 2 x 3 factorial experiment laid out in a Randomized Complete Block Design with four replications was used for the study. The experiment consists of 2 varieties of sesame (E8 an Ex- Sudan), 3 seeding rates (3 kg ha^{-1}, 5 kg ha^{-1} and 7 kg ha^{-1}) established at 3 Locations (Makurdi, Tor Musa and Akwanga), which gave six treatments in each location. The experiment was conducted as early and late season plantings.

Agronomic Practices

Land preparation and layout

The land was ploughed and harrowed to obtain a fine seedbed after which it was marked out into blocks and plots for ease of assigning treatments. The 18 treatments were assigned to plots of 9 m^2 (3 m x 3 m) flat seedbeds. The 18 plots were further divided into two blocks of nine plots each, with 0.75 m wide alley ways within blocks and 1 m wide alley ways between blocks. A distance of 1.5 m was maintained between replicates. Thus the total area of land utilized at each location was 654 m^2 (33 m x 24 m).

Planting and cultural practices

Seeds were sown by means of the broadcasting method. In order to facilitate even distribution of seeds on the seedbeds, the seeds were mixed with dry sharp sand at broadcasting and then raked into the soil lightly with the use of garden forks. Pre-emergence herbicide (pendimethaline) was sprayed immediately after sowing at the rate of 2 l ha^{-1} using a 20 l knapsack sprayer. A formulation of NPK fertilizer was applied by broadcasting method at the rate of 40:15:15 ai ha^{-1}, at three weeks after sowing (3WAS). Weeding was done manually at 3WAS and repeated at 6WAS to maintain a weed free field.

Insect management

An organic insecticide (Bio-neem) was used to control insect attacks on all plots using recommended rates of 100 ml in a 20 l knapsack.

Data collection

Vegetative parameters

Plant heights of five randomly selected plants from each treatment were taken at 4, 6 and 8 WAS, which represent the ends of the juvenile stage, pre-reproductive stage and mid-bloom stage and on-set of the lower leaf senescence in sesame development respectively as presented by[12]; plant heights were obtained by placing a meter tape at the base of the plant and measuring the distance to the tip. Using the same plants, the leaf area indices were measured manually and non-destructively using the formula ($LAI= LA_M. N/A$) as described by[13]; where N is the number of leaves per plant, A is the area (cm^2) occupied by one plant in the cropped area and LA_M is the mean leaf area of the plant (cm^2 leaf^{-1}) given by the sum of the leaf areas of all the leaves per plant divided by the total number of leaves of the plant. The leaf area was determined by measuring the length and width of the lamina. The leaf length (L) was determined by placing a transparent simple ruler on the surface of the lamina and measuring the distance from the tip to the base of the midrib (which is also the intersection of the lamina and petiole); while the width (W) was measured from tip to tip between the widest lamina lobes. Thus the LA=LW cm^2. At 10 WAS, having determined the plant heights and LAI, the plants were cut at the base and oven dried at 80 ^{0}C to a constant weight for five days to determine the above-ground dry matter accumulation (DM)[14]. The number of branches was determined by taking the average number of all developed branches per plant of ten plants per treatment unit.

Yield parameters

Yield parameters for the treatments were determined as follows: Number of capsules per plant was determined by taking the average of total number of capsules of ten plants per treatment unit. An average weight of capsules from the ten plants was taken to determine weight of capsules per plant (WC/P g) in grams using a sensitive electronic weighing machine Mettler Balance (Golden – Mettler U.S.A). Total seed yield was determined by taking the weight of seeds from plants within a 1 m^{2}quadrant which was then converted to seed yield in kilograms per hectare[15]. Weight of 1000 seeds per treatment was determined by direct counting and weighing 1000 seeds per treatment unit.

The agronomic efficiency was determined using the formula as follows:
Agronomic Efficiency (AE) = (Grain yield$_f$ - Grain yield$_C$ / Fertilizer applied) kg kg^{-1}. Where the indices f and c denote ‘fertilized crop’ and ‘unfertilized control’ respectively[16].
The Nitrogen Use Efficiency (NUE) as described by[17] was calculated using the formula:

$$\mathrm{NUE}\ (\mathrm{kg.kg^{-1}}) = \frac{\text{yield per unit area}}{\text{Applied N per unit area}}$$

Post-harvesting handling of plant samples
The experiments were terminated at 14 weeks after sowing (WAS). Plants were harvested by cutting the stem at the ground level using sickles. The stems were tied up at the middle and made to stand in cone shapes. Threshing was done at 2 weeks after harvest and the seeds packaged in paper envelopes and stored in the refrigerator after which seeds were used for seed quality analyses.

Seed quality analyses

Percentage crude protein and fat and oil
The crude protein content of the samples was determined using the Microkjeldahl method of Association of Official Analytical Chemists[18], which involved protein digestion, distillation and titration.

Sample preparation
Each sample of sesame seed to be used was first ground to powder and passed through a 1 mm sieve to obtain a working sample for analysis.

Digestion
Two grams of sample to be analysed was added to 8 g of a copper sulphate - anhydrous sodium sulphate mixture in an appropriately labelled digestion flaskand then digested by heating it in 30 ml of sulphuric acid in a fume chamber. Heating was started gently until initial frothing ceased. Thereafter strong heat was applied until solution cleared to light blue-green colour. Total digestion time was 2 hrs.

Semi-micro distillation
After the digestion was completed, the digestion flask was connected to a receiving flaskcontaining an excess of boric acid,by means of a tube. The solution in the digestion flask was then made alkaline by addition of sodium hydroxide, which converts the ammonium sulphate into ammonia gas. The ammonia gas that was formed was liberated from the solution and moved out of the digestion flask and into the receiving flask. Ammonium borate distillate was formed in the receiving flask.Nitrogen content was then estimated by titration of the formed ammonium borate with hydrochloric acid. At the end-point of the reaction, the green colour of the distillate turned to purple.
The following equation was be used to determine the nitrogen concentration of a sample that weighs *m* grams using *x*M HCl acid solution for the titration[18]:

$$\% N = \frac{x\ \text{moles}}{1000\ \text{cm}^3} \times \frac{(v_s - v_b)\ \text{cm}^3}{m\ \text{g}} \times \frac{14\ \text{g}}{\text{moles}} \times 100$$

The percentage crude protein was calculated from the % N as: % crude protein = % N x F Where F (conversion factor), is equivalent to 6.25. Total fat/oil was determined using complete extraction using the Soxhlet extractor (Konte, USA). The extraction was done for 6 hrs starting with methanol and ethanol, respectively[19]. Seventy grams of each powdered seed sample was put into a porous thimble and placed in a Soxhlet extractor, connected to a weighed flask containing 100 ml petroleum spirit (with boiling point of 40-60 ^{o}C) as extracting solvent for 6 hours. The oil was obtained after the solvent was removed under reduced temperature and pressure and refluxing at 70 ^{o}C to remove the excess solvent from the extracted oil.

Fat yield determination
The oil obtained after the extraction was transferred into a measuring cylinder which was placed over a water bath for 30 min at 70 ^{o}C to ensure complete evaporation of solvent and volume of the oil was recorded and expressed as fat content (%).

The % fat was computed using the formula below[18] (AOAC, 1995):

$$\%\ \text{Fat} = \frac{\text{weight of fat extracted}}{\text{weight of sample}} x100$$

Determination and analysis of aflatoxin from sesame grain samples
The Enzyme Linked Immunosorbent Assay (ELISA) method for Aflatoxin analysis was used as described by[20].

Sample Preparation
One hundred grams of sesame seeds were collected from eachtreatment and blended separately in a Waring commercial blender. After each blending operation, the blender was washed and rinsed thoroughly with sodium hypochlorite (NaOCI) to prevent cross contamination between samples. Twenty grams (20 g) each of the blended sample was further ground into fine powder and titrated with 100 ml of 70% methanol (v/v 70 ml absolute methanol in 30 ml distilled water) containing 5 g potassium chloride to enhance homogeneity. The extract was transferred into a labelled 250 ml flat bottom flask and shaken on a Benchmark orbital shaker (Model ORBI-Shaker) for 30 minutes. Filtration was done using Whatman filter paper number 41 after which the filtrate was diluted in 1:10 phosphate buffer saline in tween-20 (1 ml of extract and 9 ml of buffer) and left standing for 10 hours after which analysis of each sample commenced.

Sample analysis
AFB_1- BSA antigen was coated unto an ELISA plate. Specific antibodies available in the sample or standard competed with the bound AFB_1-BSA antigen with help of immune-globulins. Para nitro phenyl phosphate substrate was added to facilitate colour development. With the use of a spectrophotometer (Jenway 6305), which produced optical density values at 405 nm wavelength, AFB_1 levels were ascertained. A standard curve was extrapolated with a known correlation coefficient thereby giving AFB_1 concentrations in parts per billion.

Statistical Analysis
All the collected data were organized for analysis using Microsoft Excel package and subjected to Analysis of Variance (ANOVA) using GenStat (V.17) statistical package. Significant means were separated using Tukey test ($p \leq 0.05$).

III. Results

The result of analysis of variance presented (Table 1) shows that variety x seeding rate x location (VxSRxL) interaction in early-planted sesame did not influence any of the vegetative parameters measured. Similar result was observed for VxL interaction as well as the main effect of variety as no significant effect was observed on all parameters. Seeding rate x location interaction showed significant effect on Leaf Area Index (LAI) at 6WAS, LAI at 8WAS and plant biomass. However, number of branches, plant height and grain yield showed no significant SRxL interaction effect. Also, VxSR interaction showed significant difference in the number of branches, LAI at 6WAS, LAI at 8WAS, and plant biomass. Plant height and branching showed no significant difference with respect to varied locations. The effect of SR significantly influenced plant height of early planted sesame in the study.

Table 1: Probability values for some vegetative parameters of early planted sesame

SOV	Df	No. of Branches	Leaf Area Index 6 WAS	Leaf Area Index 8 WAS	Plant height	Plant Biomass
Variety (V)	1	0.222ns	0.149ns	0.147ns	0.101ns	0.707ns
Seeding Rate (SR)	2	0.062ns	0.003*	0.053*	0.028*	0.001**
Location (L)	2	0.604ns	0.000**	0.002**	0.349ns	0.000**
V x SR	2	0.036*	0.018*	0.012*	0.078ns	0.006**
V x L	2	0.096ns	0.300ns	0.130ns	0.325ns	0.984ns
SR x L	4	0.080ns	0.037*	0.051*	0.103ns	0.029*
V x SR x L	4	0.368ns	0.948ns	0.823ns	0.954ns	0.449ns
Standard Error		0.086	0.003	0.003	1.62	258
CV		17.30	9.60	10.80	7.50	23.40

Key: *= significant at 5%. **= highly significant at 1%. Ns= not significant.

Effect of seeding rate x location on vegetative parameters of early-planted sesame
The effect of SRxL on vegetative growth of early-planted sesame was found to significantly influence plant biomass and LAI at both six and eight weeks sampling periods (Table 1). The result of SRxL interaction on plant biomass shows that planting sesame in both Akwanga and Tor Musa locations at 5 kg ha^{-1} seeding rate produced higher plant biomass of 9711.30 kg ha^{-1} and 9649.93 kg ha^{-1} respectively, in both cases significantly

higher than at 7 kg ha^{-1} (Table 6.2). However, planting sesame at 3 kg ha^{-1} seeding rate in Makurdi produced the least biomass (5285.19 kg ha^{-1}), although there were no significant ($p > 0.05$) differences between any of the seeding rates.

The effect of SRxL on LAI at 6WAS showed that lower LAI (0.145) was recorded for Makurdi at 5 kg ha^{-1} seeding rate, but was however not significantly different from the LAI at 6WAS in sesame seeds planted at 3 kg and 7 kg rates in the same environment (Table 2). Higher LAI of 0.180 and 0.178 was however observed in Akwanga and Tor Musa respectively at a seeding rate of 7 kg ha^{-1}. In Akwanga 7 kg seeding rate had significantly ($p < 0.05$) higher LAI than 3 kg seeding rate but at Tor Musa the differences were not significant. The study reveals that in Akwanga and Tor Musa, the LAI at 6WAS increases with increase in seeding rate.

Similar results were obtained for LAI at 8WAS (Table 2). The significant SRxL interaction on early-planted sesame showed that LAI at 8WAS was significantly higher at Akwanga and Tor Musa at 5 kg ha^{-1} and 7 kg ha^{-1} seeding rates, compared to the 5 kg ha^{-1} seeding rate in Makurdi. At each location however there was not significant ($p > 0.05$) differences between the three seeding rates but at Akwanga and Tor Musa there was an increasing trend of LAI at the two higher seeding rates. This however was not evident at Makurdi.

Table 2: Interaction effect of seeding rate x location on vegetative parameters of early-planted sesame

Seeding Rate	Location	Plant Biomass	Leaf Area Index 6 WAS	Leaf area Index 8WAS
3 kg	AKW	7237.210 ab	0.151 bc	0.168 ab
5 kg	AKW	9711.300 a	0.176 ab	0.191 a
7 kg	AKW	6832.170 b	0.180 a	0.191 a
3 kg	MKD	5285.190 b	0.152 bc	0.171 ab
5 kg	MKD	5296.790 b	0.145c	0.159 b
7 kg	MKD	5432.690 b	0.151 bc	0.165 ab
3 kg	TM	7224.600 ab	0.159 abc	0.168 ab
5 kg	TM	9649.930 a	0.175 ab	0.190 a
7 kg	TM	6785.660 b	0.178 a	0.191 a
S.E.D		823.28	0.01	0.01

Means within the same column with similar alphabet are not significantly different at 95% level of probability

Effect of variety x seeding rate on vegetative parameters of early-planted sesame

The effect of VxSR showed differential response in LAI at 6WAS, LAI at 8WAS, plant biomass and number of branches (Table 3). The effect of VxSR rate on LAI at both 6WAS and 8WAS shows the differential response of the two varieties to varying seeding rates as Ex-Sudan variety planted at 5 kg ha^{-1} seeding rate and E-8 variety planted at 7 kg ha^{-1} produced higher LAI, although the differences between treatments were not always significant. These both resulted in an increase in grain yield, where E-8 variety, planted at 7 kg ha^{-1} seeding rate produced grain yield of 733.13 kg ha^{-1}. Similarly, a reduced LAI (0.157) was as observed in Ex-Sudan variety planted at 3 kg ha^{-1} seeding rate.

Table 3: Interaction effect of variety x seeding rate on vegetative parameters of early-planted sesame

Variety	Seeding Rate	Leaf Area Index 6 WAS	Leaf Area Index 8WAS	Plant Biomass	No. of Branches
E-8	3kg	0.162 ab	0.181 a	6070.67 bc	3.94 a
E-8	5kg	0.160 ab	0.175 ab	8478.03 a	3.61 ab
E-8	7kg	0.175 a	0.185 a	7149.93 abc	3.75 ab
Ex-Sudan	3kg	0.146b	0.157 b	7602.33 abc	3.47 ab
Ex-Sudan	5kg	0.170a	0.185 a	7960.65 ab	3.92 a
Ex-Sudan	7kg	0.165ab	0.179 ab	5717.08 c	3.09 b
S.E.D		0.01	0.01	672.20	0.25

Means within the same column with similar alphabet are not significantly different at 95% level of probability

Significant plant biomass difference as influenced by VxSR showed that the two varieties under study vary significantly in their response to different seeding rates (Table 3). The E-8 variety planted at the rate of 5 kg ha^{-1} produced higher biomass (8478.03 kg ha^{-1}), significantly better than biomass obtained at rates of 3 kg. Plant biomass was found to be lowest in Ex-Sudan variety planted at a seeding rate of 7 kg ha^{-1}. Plant biomass increased in both varieties when seeding rates were increased from 3 kg to 5kg, but declined thereafter at 7 kg seeding rate. This is clearly evidenced as higher plant density of 7 kg ha^{-1} in Ex-Sudan produced a significantly reduced number of branches.

The effect of VxSR interaction on number of branches showed that variety E-8 at a seeding rate of 3 kg ha^{-1} produced more branching (3.94) in early-planted sesame (Table 3). A decrease in the number of branches was observed however where seeding rate exceeded 3 kg ha^{-1} but the differences were not significant. On the contrary, branching in Ex-Sudan variety was highest at 5 kg seeding rate, decreasing significantly at 7 kg seeding rate.

Main effects of seeding rate and location on vegetative traits of early-planted sesame

Main effects of seeding rate on plant height are presented in Table 4. Higher plant height was obtained at seeding rates at and above 5 kg ha^{-1}. Plant height as influenced by seeding rate was significantly ($p<0.05$) higher at 5 kg ha^{-1} (172.31cm) than at 3 kg ha^{-1} (162.70cm).

Table 4: Main effect of seeding rate on plant height of early planted sesame

Seeding Rate	Plant height (cm)
3 kg	162.701b
5 kg	172.312a
7 kg	170.257ab
S.E.D	3.65

Means within the same column with similar alphabet are not significantly different at 95% level of probability

Effect of variety, seeding rate and location on yield and seed quality of early-planted sesame

The result of analysis of variance showing the effect of VxSRxL for early-planted sesame is presented in Table 5 below. The result shows that the three-way interaction only significantly influenced crude protein content. Number of capsules per plant, weight of capsules per plant, 1000 seed weight, oil content and grain yield showed no significant response to VxSRxL interaction. Seeding rate x location interaction was significant for number of capsules and percentage fat and oil. However, weight of capsules, 1000-seed weight and grain yield all showed no significant SRxL interactions. Variety x location interactions were significant for weight of capsules per plant, but not for number of capsules per plant, 1000-seed weight, percentage fat and oil and grain yield. Variety x Seeding rate interaction was found to also influence weight of capsules, percentage fat and oil content and grain yield. Similarly, both number of capsules per plant and 1000-seed weight were not significantly influenced by VxSR interaction.

Table 5: Probability values for variety, seeding rate and location on yield and seed quality parameters of early-planted sesame

SOV	Capsules per plant	Mass of capsule per plant (g)	1000 Seed Weight (g)	%Crude Protein	%Fat & Oil	Yield $Kgha^{-1}$
Variety (V)	0.395	0.003**	0.098ns	0.273ns	0.305ns	0.394ns
Seeding Rate (SR)	0.000**	0.000**	0.490ns	0.433ns	0.000**	0.000**
Location (L)	0.000**	0.000**	0.053ns	0.000**	0.076ns	0.004**
V x SR	0.069ns	0.000**	0.894ns	0.002**	0.000**	0.028*
V x L	0.683ns	0.024*	0.057ns	0.632ns	0.204ns	0.854ns
SR x L	0.002**	0.455ns	0.964ns	0.006**	0.000**	0.435ns
V x SR x L	0.239ns	0.164ns	0.604ns	0.001**	0.996ns	0.424ns
CV	15.30	18.80	12.90	4.80	3.30	17.1

Key: *= significant at 5%. **= highly significant at 1%. Ns= not significant.

Effect of variety, seeding rate and location on percentage crude protein of early-planted sesame

Variations in crude protein content in early-planted sesame as influenced by VxSRxL interaction shows that higher protein contents (23.77 % and 23.99 %) was recorded for variety E-8 planted at 3 $kg.ha^{-1}$ seeding rate in Akwanga and Tor Musa, respectively (Table 6). These were significantly different from protein content obtained in Makurdi when variety E-8 was planted at 3 $kg.ha^{-1}$. Also, the result of variety E-8 planted at 5 $kg.ha^{-1}$ is similar to that of the 3 $kg.ha^{-1}$seeding rate. However, at the higher seeding rate of 7 kg in variety E-8 there was no significant differences between the protein contents at the three locations. The result further reveals that while 5 kg seeding rate favours the increased production of crude protein content in both Akwanga and Tor Musa, 7 kg seeding rate is suitable for higher crude protein content in Makurdi. The varied response of Ex-Sudan variety in terms of amount of crude protein shows that at 3 kg seeding rate, trends were very similar to those of E-8 (Table 6). At 5 kg and 7 kg seeding rates, responses were similar than at the 3 kg seeding rate. Contrary to the E-8 variety, seeding rates of 7 kg did not increase protein content of variety Ex-Sudan in Makurdi.

Table 6: Interaction effect of variety x seeding rate x location on percentage crude protein of early planted sesame

Variety	Seeding Rate	Location	%Crude Protein/g SD
E-8	**3 kg**	**AKW**	23.77 abcd
E-8	**3 kg**	**MKD**	19.07 g
E-8	**3 kg**	**TM**	23.99 abc
E-8	**5 kg**	**AKW**	25.24 a
E-8	**5 kg**	**MKD**	18.92 g
E-8	**5 kg**	**TM**	24.85 ab
E-8	**7 kg**	**AKW**	22.22 bcde
E-8	**7 kg**	**MKD**	21.02 defg
E-8	**7 kg**	**TM**	22.00 cdef
Ex-Sudan	**3 kg**	**AKW**	24.74 abc
Ex-Sudan	**3 kg**	**MKD**	19.31 fg
Ex-Sudan	**3 kg**	**TM**	25.24 a
Ex-Sudan	**5 kg**	**AKW**	22.91 abcd
Ex-Sudan	**5 kg**	**MKD**	19.79 efg
Ex-Sudan	**5 kg**	**TM**	23.15 abcd
Ex-Sudan	**7 kg**	**AKW**	24.36 abc
Ex-Sudan	**7 kg**	**MKD**	19.89 efg
Ex-Sudan	**7 kg**	**TM**	24.21 abc
S.E.D			0.76

Key: Means within the same column with similar alphabet are not significantly different at 5% level of probability.

Effect of seeding rate and location on capsules per plant and percentage oil content of early-planted sesame

The effect of SR x L interaction was found to significantly influence number of capsules per plant and percentage oil content of early-planted sesame (Table 7). At Akwanga planting at 5 kg ha^{-1} produced 219 capsules per plant,which was significantly different from the number of capsules per plant recorded from seeds planted at 3 kg ha^{-1} and 7 kg ha^{-1} seeding rates, which recorded 170 and 161capsules, respectively. At Tor Musa similar effects than in Akwanga were observed (Table 7).The result shows that number of capsules per plant increased with increased seeding rate from 3 kg to 5 kg, declining thereafter at higher planting density of 7 kg seeding rate at both Akwanga and Tor Musa. At Makurdi planting at 3 kg seeding rate produced significantly more capsules (181 capsules) than at 7 kg seeding rate (116), but not significantly different from that produced at 5 kg seeding rate (163 capsules) (Table 7).

Table 7: Interaction effect of seeding rate x location on capsules per plant and percentage oil content of early planted sesame

Seeding Rate	Location	Capsules per plant	%Fat & Oil
3 kg	**AKW**	170.00 b	42.00 ab
5 kg	**AKW**	219.00 a	41.65 abc
7 kg	**AKW**	161.00 b	39.73 cd
3 kg	**MKD**	181.00 ab	41.87 abc
5 kg	**MKD**	163.00 b	38.70 d
7 kg	**MKD**	116.00 c	40.85 abcd
3 kg	**TM**	170.00 b	42.53 a

5 kg	**TM**	218.00 a	41.65 abc
7 kg	**TM**	161.00 b	39.86 bcd
SE.D		18.71	0.96

Key: Means within the same column with similar alphabet are not significantly different at 5% level of probability,

The interaction of SR x L influencing the percentage fat and oil content in early-planted sesame showed that at Akwanga, higher oil content (42.00 %) were recorded for seeds planted at 3 kg seeding rate and differed significantly from oil content of 39.73 % recorded at 7 kg seeding rate, but not statistically different from oil content of 41.65 % recorded at 5 kg seeding rate (Table 7). Similar results were observed at Tor Musa where the amount of oil content in sesame decreased with increasing seeding density from 3 kg to 7 kg. At Makurdi, significant higher oil content of 41.87 % was recorded at 3 kg compared to the 5 kg seeding rate (Table 7). However, there were not significant differences between 3 kg and 7 kg seeding rates.

Effect of variety x location on weight of capsules per plant of early planted sesame

Variation in the weight of capsule per plant as influenced by VxL interaction is presented in Table 8. Results showed that in variety E-8, there were no significant differences in capsule weight between the three locations. In the Ex-Sudan variety, significantly higher weight of capsules per plant (64.03 g) was observed at the Makurdi compared to both Akwanga and Tor Musa.

Table 8: Interaction effect of variety x location on weight of capsules per plant of early planted sesame

Variety	Location	Weight of capsulesper plant (g)
E-8	AKW	57.61 ab
E-8	MKD	62.00 a
E-8	TM	57.56 ab
Ex-Sudan	AKW	44.85 c
Ex-Sudan	MKD	64.03 a
Ex-Sudan	TM	45.03 bc
S.E.D		4.23

Key: Means within the same column with similar alphabet are not significantly different at 95% level of probability.

Effect of variety x seeding rate interaction on yield and seed quality parameters of early-planted sesame

Table 9 depicts the effect of VxSR interaction on mass of capsules per plant, % fat and oil content and grain yield of early-planted sesame. Variation of capsule weights per plant in variety E-8 showed that the high weights recorded at 7 kg seeding rates (71.52 g) was statistically similar to that recorded at 5 kg seeding rate (60.77 g) and only differed significantly from the weight of capsules recorded at 3 kg seeding rate (44.89 g). Furthermore, the weight of capsules in variety E-8 increased with increasing seed rate.

Table 9: Interaction effect of variety x seeding rate on yield and some seed quality parameters of early planted sesame

Variety	Seeding Rate	Mass of capsulesper plant (g)	%Fat & Oil	Yield ($Kgha^{-1}$)
E8	3kg	44.89 c	41.97 a	602.50 b
E8	5kg	60.77 a	39.88 bc	715.86 ab
E8	7kg	71.52 a	41.60 a	733.13 ab
Ex-Sudan	3kg	50.27 bc	42.30 a	594.62 b
Ex-Sudan	5kg	58.45 b	41.46 ab	775.67 a
Ex-Sudan	7kg	45.19 c	38.69 c	611.52 b
S.E.D		4.24	0.55	46.79

Key: Means within the same column with similar alphabet are not significantly different at 5% level of probability.

However, for the Ex-Sudan variety a higher capsule weight was observed at 5 kg seeding rate (58.45 g) that differed statistically from capsule weight recorded at 7 kg seeding rate (45.19 g), but were similar to 3

$kg.ha^{-1}$ (50.27 g) (Table 9).Weight of capsules in Ex-Sudan variety increased when seeding rate was increased from 3 kg to 5 kg planting density, but declined significantly when planting was done at a higher density of 7 kg, contrary to what was seen in variety E-8. The result of VxSR interaction in terms of the amount of fat and oil shows the oil content of variety E8- were higher when planted at either 3 kg (41.97 %) or 7 kg (41.60 %) seeding rates and differed significantly from the comparatively low oil content recorded at 5 kg seeding rate (Table 9). However in the Ex-Sudan variety, the higher oil content (42.30 %) recorded at 3 kg seeding rate differed significantly from 38.59 % observed at 7 kg seeding rate, but was however not significantly different from the relatively high oil content (41.46 %) at 5 kg seeding rate. The study reveals steady decreases in the percentage fat and oil present in Ex-Sudan variety with increased seeding rate from 3 kg to 7 kg.Table 9 shows that while seeding rate did not significantly influenced grain yield of variety E-8 during the early planting season, Ex-Sudan variety grain yield increased significantly when planting was done at 5 kg seeding density. The high grain yield (775.67 kg ha^{-1}) recorded at 5 kg seeding rate in Ex-Sudan variety differed significantly from yield obtained at 3 kg (594.62kg ha^{-1}) and 7 kg (611.52kg ha^{-1}) seeding rates.

Effect of location on grain yield of early planted sesame

The current study reveals the presence of significant variations in grain yield caused by differences in environmental locations. Grain yield was comparatively low at Makurdi (604.34 kg ha^{-1}), differing significantly from yield obtained in both Akwanga and Tor Musa, recording grain yields of 707.25 kg ha^{-1} and 705.05 kg ha^{-1} respectively (Table 10).

Table 10: Main effect of location on grain yield of early planted sesame

Location	Yield (Kg ha^{-1})
AKW	707.25 a
MKD	604.34 b
TM	705.05 a
S.E.D	33.08

Key: Means within the same column with similar alphabet are not significantly different at 5% level of probability.

Correlation and regression analyses

Correlation coefficients among evaluated traits as presented in Table 11 reveal a considerable number of significant relationships. Crude protein had significant positive correlation with pod weight, number of capsules, 1000-seed weight, grain yield and fat and oil content. Number of capsules showed a non-significant association with grain yield and the rest of the other traits. Regression coefficients of measured traits, including mass of capsule were however not significant.

Table 11: Correlation and regression coefficients among yield and quality attributes of sesame Correlation

	Mass of capsules per plant	No of capsules per plant	1000-seed weight	Crude Protein	Fat/Oil
No.of capsules per $plant^{-1}$	0.019ns				
1000-seed weight	0.110ns	0.080ns			
Crude protein	-0.451**	0.324**	0.236*		
Fat/Oil	0.060ns	0.103ns	0.162ns	0.306**	
Grain yield $kgha^{-1}$	0.136ns	0.144ns	0.175ns	0.320**	-0.293*

IV. Discussion

Significant interaction between seeding rate and location on some evaluated plant attributes was clearly established in this study. Grain yield was enhanced at higher densities owing to compensation by the greater plant population at those densities. This agrees with results of[21,22]. Results however contrast with those of[23]who did not find significant influence of plant density on number of capsules per plant. Since there was no response of 1000-seed weight to the factors as well as their interaction it may not be readily amenable to factors of the environment. Consequently, neither agronomic practices nor site of production might drastically influence it. It may therefore be more genetically influenced. As reported by[24], the high genetic advance recorded in 1000-seed weight of sesame shows that the trait is genetically controlled.

Higher LAI at higher densities was clearly evident at Akwanga.Similarly, higher seeding rates gave remarkably higer plant biomass in all the locations except at Makurdi, where the reverse was the case. At the same location (Makurdi), differences in LAI in relation to seeding rates were not clear cut. Higher LAI at higher seeding rates as obtained at Akwanga could be expected due to significantly higher leaf numbers in such populations. The significantly higher effects on LAI at 6WAS and 8WAS at both Tor Musa and Akwanga corresponds to significantly higher yields. This shows that the higher yield differences in the two locations could therefore be attributed to increased leaf area of plants. Generally, branching in sesame was neither influenced by variety, seeding rate nor location effects. Variety interacted with seeding rate to also significantly affect some vegetative traits and grain yield of early-planted sesame. Thus E-8 when planted at the highest density (7 kg ha^{-1}), recorded the highest LAI at 6WAS, while Ex-Sudan had its highest LAI at 5 kg ha^{-1}. The significance of LAI in studies involving sesame will be better appreciated when this trait is linked with either weed control or final grain yield. Generally, it is understood that a higher LAI is suggestive of a greater photosynthetic area. Significant variety x seeding rate interaction effect was observed by[25]on the number of capsules per plant, reporting that the lowest number of capsule was observed with seeding rate of 2 kg ha^{-1} in two sesame varieties (E-8 and NCRIBEN 01M), which did not differ significantly from 4 kg ha^{-1} and 6 kg ha^{-1} seeding rates.

Genotypes also varied in their performance across seeding rates with respect to certain traits. E-8 showed highest LAI measured at 6WAS when sown at 7 kg ha^{-1}. As such not all sesame varieties would be expected to give higher LAI at elevated seeding rates. E-8 had its peak biomass at 5 kg ha^{-1}. Ex-Sudan also had its peak biomass at 5 kg ha^{-1} seeding rate. In the case of Ex-Sudan however, seeding rates beyond 5 kg ha^{-1} depressed biomass yield to even less than the lowest seeding rate of 3 kg ha^{-1}. It is therefore advisable that for Ex-Sudan, seeding rate should not go beyond 5 kg ha^{-1} as far as plant biomass is concerned. E-8 had more branches when sown at 3 kg ha^{-1} indicating that it needed more space to exhibit its branching potential in contrast to Ex-Sudan.Variety E-8 increased its grain yield as seeding rate increased from 3 – 7 kg ha^{-1}. However, grain yield of Ex-Sudan increased to a peak at 5 kg ha^{-1} seeding rate and thereafter declined. Thus for the former variety, there is possibility of obtaining higher grain yield if seeding rates beyond 7 kg ha^{-1} are investigated especially when early planting of sesame in the study area is contemplated. Another author[26]evaluated 3 cultivars of sesame across planting densities under rain fed conditions in Sudan. While varieties showed differences in some key traits relating to yield, their performance was statistically similar with respect to harvest index and seed yield.

Main effects of the factors showed significant effects only on two traits investigated. As such higher seeding rates of 5 and 7 kg ha^{-1} recorded taller plants than the least seeding rate evaluated (3 kgha^{-1}). This finding contrasts with the work of[26] who reported lack of significant response of sesame varieties to planting density. On the other hand[27] found taller plants in plots having the widest spacing. It however agrees with observations by[8] that closely spaced plants tend to grow taller as a result of more keen competition for growth resources. Why this observation is not universal could be accounted for by interaction between genotype and environment.Sesame grain yield was significantly higher at Tor Musa and Akwanga, but lower at Makurdi. This may be attributed to the observed differences in average rainfall and maximum temperature in the studied location. The average rainfall for Makurdi location was relatively higher than that of Akwanga and Tor-musa during the seedling stage (April and May). Also, maximum temperatures for Makurdi location was relatively higher than that of Akwanga and Tor-musa during the pod development stage (June - August) of early-planted sesame. In a trial in Southern Nigeria[28], they found sesame yield performance to be higher in the derived savannah compared to the rainforest location. Studies on the contrary[29], did not find significant yield variation among sesame cultivars grown in two sites in Ethiopia. It is therefore logical to infer that when sesame is grown in two or more environments that are more or less contrasting, it will perform better in the one that provides the best combination of growth factors as was found at Tor-Musa and Akwanga, which supports the observation of[28].

Significant responses of some evaluated yield and seed parameters to the interaction of seeding rate and location were observed. For instance, highest capsule weight in Akwanga and Tor Musa were obtained at the intermediate seeding rate of 5 kg ha^{-1}. On the other hand, at Makurdi, the 3 kg ha^{-1} seeding rate recorded the highest capsule weight. However, since capsule weight had a non-significant regression coefficient, it might not make a substantial contribution to grain yield. The corresponding decline in the number of capsules with increased seeding rate from 3 to 7kg further reveals that the former favours the production of higher number of capsules per plant. The variable response of oil content to interaction between seeding rate and location is worth noting. At Akwanga and Tor Musa, oil content increased with increase in seeding rate while at Makurdi, the highest oil content was obtained at seeding rate of 3 kg ha^{-1}, representing the lowest seeding rate. This pattern of result may have to do with levels of particular growth factors available in each environment. Soil characteristics showed that both Akwanga and Tor-Musa locations were relatively lower in percentage sand and higher in percentage clay than the Makurdi location. These soil attributes may have influenced both the available and inherent nutrient fertility status of the study areas, thus leading to variations in oil contents of sesame. Similar deductions could be made to explain variation in protein content of sesame seeds across locations. There are literature reports indicating that decreasing fertilizer N levels increased seed oil content[30,31,32]. As such, site of production may form an important consideration in achieving high oil content in sesame.

Similarly, oil content across seeding rates varied with cultivar. In the case of E-8, oil content was variable as both the lowest and highest seeding rates gave significantly high oil content. In contrast, Ex-Sudan showed a clear pattern of decreasing oil content as plant density increased. In a study involving sesame, seed oil content was found to increase with decrease in plant population from 400,000 to 200,000 plants ha^{-1} [32]. The practical implication is that, when higher oil content is desired, seed yield may be sacrificed by adopting low density planting. An alternative could be to opt for varieties that could give high seed yield and oil content at higher populations. In soybean, another important oil seed crop[33], they did not find significant variation in seed oil content as plant population varied. However, in peanut, [34]found oil content to be significantly higher at lower plant populations. In rape seed[35], no variation was found in seed oil content as between-row and within-row spacing varied. Similar results were reported by[36].

In the present study, protein content among cultivars did not vary substantially across seeding rates. Results agrees with those obtained by[35,37]. It however contrasts with reports by[38] who found elevated protein levels as plant densities increased. In soybean, [39]observed a curvilinear relationship between seed protein content and plant density. Thus, protein content initially decreased with increase in plant density of the two varieties evaluated up to 80 or 100 plants m^{-2}. Thereafter it increased as plant density increased. Fortunately, seed yield also increased as plant density increased, implying that population densities targeting high seed yield could also automatically generate higher protein amounts. In this study, such an advantage does not exist as protein content remained indifferent to plant density. In peanut[34] significant higher seed protein content at lower plant densities was reported. Seemingly, further research is needed to precisely explain seed protein response to plant density. What was clear in this study was the significant positive relationship between protein content and other key attributes particularly oil content and grain yield. Thus, it is plausible that production practices aimed at increasing protein content may most likely also increase grain yield and oil content.It was generally observed that across varieties and seeding rates, crude protein values were lower for Makurdi than the other locations. This is despite soil test results showing higher N values at Makurdi than Akwanga and Tor Musa. Indications from a different study[40] showed that temperature has a key role to play in protein synthesis in plants. It is possible that the relatively higher temperatures during crop growth at Makurdi were less favourable to protein accumulation in the seed compared to what was obtained in the other locations.

The two varieties tested in this study showed slight yield differences in response to seeding rate. In Ex-Sudan, seed yield increased up to 5 kg ha^{-1} and then declined. Variety E-8 however showed a consistent increase in seed yield as seeding rate increased up to 7 kg ha^{-1}. Several authors have reported seed yield increases by increasing planting densities. The study of[41] reported increase in seed yield while increasing seed rate in sesame from 6 kg ha^{-1} to 9 kg ha^{-1}. Similarly,[25]also reported increase in yield of sesame when seeding rates were increased from 2 kg ha^{-1} to 8 kg ha^{-1}. Similar to the pattern shown by the variety Ex-Sudan in this study,[42]reported that yield per unit area tends to increase as plant density increases up to a point and then declines. On the contrary,[26,29] found optimum seed yield at lower seeding rates of 1.5 and 2 kg ha^{-1}. As suggested by[43] sesame cultivation under increased plant density could result in intra-specific competition for light and nutrients and may lead to a reduction in grain yield. Findings of[44] indicates that increased grain yield at higher plant population can be obtained by manipulating intra-row spacing. Therefore, farmers can improve sesame yield by optimizing plant population density, but this maybe cultivar dependent.Sesame seed yield were found to vary from 604.3 kg ha^{-1} (Makurdi) to 707.3 kg ha^{-1} (Akwanga). While demonstrating that certain locations are more profitable for sesame production in Nigeria, these yield values represent a substantial improvement over the reported low yield of 367kg ha^{-1} [45]. In the Northern Guinea Savanna of Nigeria, [44]reported varietal yields in the range of 700-800 kg ha^{-1}. Thus, with adoption of improved varieties and agronomic practices, sesame seed yields in the country can be drastically enhanced.

V. Conclusion

The findings of this study show that variety x seeding rate x location (VxSRxL) interaction did not influence any of the vegetative parameters measured. Similar result was observed for variety x location interaction as well as the main effect of variety. Leaf area was found to contribute to the total plant biomass as increase in LAI both at 6WAS and 8WAS resulted in increased plant biomass, while decrease in plant biomass was as a result of decrease in LAI.Finally, it is conclusive from this study that higher seed yields are obtained at higher seeding rates although for variety Ex-Sudan, seed yield peaked at 5 kg ha^{-1} seeding rate, declining thereafter. While oil content responded significantly to interaction of factors, protein content of the two varieties remained statistically similar across seeding rates.

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