

Sesame Seed Yield and Growth Traits Response to Different Row Spacing in Semi-Arid Regions

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Abstract Plant density is one of the most important factors influencing the physiological, morphological characteristics, and yield of sesame. Sesame is an important oilseed and cash crop production in Sudan. The effects of different rows spacing on the growth attributes, yield and yield compound on three sesame seeds varieties were investigated at rainfall conditions in semi-arid regions. Two field experiments were conducted in 2014-2015 and 2015-2016. Three varieties were planted at four rows spacing [5(control), 10, 20 and 30cm]. The experiment was laid out in RCBD in split plots with three replications. There were significant differences between row spacing, varieties and interaction between row spacing and varieties for all parameters except the 1000 seeds weight. Moreover, Abo Nama has recorded the highest plants, number of branches and number of capsules per plant, while the abo Radom recorded the highest number of seeds per capsule and seed yield, and abo sofa had the highest weight of 1000 seeds. Planted varieties at the 5 cm between rows can increase the seed yield (210.18 kg/h). The interaction between Abo Radom and control recorded the high seed yield by 265.30 kg per h⁻¹. This study suggests that the appropriate rows spacing can actively increase the yield of the sesame plant.

Keywords Sesame, Plant Density, Row Spacing, Seed Yield, Yield Components

1. Introduction

Sesame (*Sesamum indicum* L.) is one of the ancient seed oil crops and is mainly grown cultivated under rainfall conditions in tropical and subtropical regions

(Pathak et al., 2014; Oyinloye et al., 2016). Among the oilseed crops, sesame has the highest oil, protein contents and carbohydrates (Raja et al., 2007; Wei et al., 2015). Sesame oil contains essential antioxidants such as sesamin and sesamol, which prevent the rancidity (Rangkadilok et al., 2010; Mei et al., 2017). Several unsaturated fatty acids are present in sesame seeds such as linoleic and oleic acids that are mainly responsible for oil quality (Uzun et al., 2008). Sesame seeds contain all the essential amino acids, important vitamins and minerals, sesame meal contains rich amounts of fiber, ash, and carbohydrates which is extremely nutritious for livestock soap. It is also used in paints, cosmetics, perfumes and insecticides (Babaji et al., 2005).

Different environmental, genotypic, and crop management conditions (maturity group, sowing date, genotype, climate, rainfall, temperature, radiation, and physicochemical properties of the soil and the cultural practices applied in the field continuously) influence the performance of the community of plants from germination to the senescence of the plants (Agudamu et al., 2016; Pereira-Flores and Justino, 2019), and therefore can help to explain variations in yield response to plant density (Norsworthy and Frederick, 2002). For example, adverse environmental conditions limit plant plasticity, requiring an increase in plant density to offset the reduction in the branching ability (Carpenter and Board, 1997). Rainfall is the most common form of water supply, and its intensity and variability are pointed out as determinants of the risk to the success of production in most plant producing regions (Carciochi et al., 2019) Rainfall amount and distribution during the growing season are considered as the most serious environmental problems limiting crop production under rainfed conditions (Sabel et al., 2015).

In recent years, from 1998 to 2009, decreased the agricultural land area dropped by 0.8%, we have managed to produce more yield on less land. We need to increase productivity on agricultural land by focusing on good varieties of high productivity and planting them in small areas (Food, 2011).

The seed yield of any plant is a combination of the quantitative character beneath a range of ecological factors, which perhaps influences its production. Ecological factors (climatic factors such as temperature, rainfall), and agricultural practices (such as plant populations, plant density, and sowing date) are one of the most important factors that affect the productivity of sesame plants (Geleta et al., 2002; Adebisi, 2004; Ozturk and Saman, 2012), the more important of them being the yield per plant and number of plants per area (Alegbejo et al., 2003). Adverse environmental conditions limit sesame plasticity, requiring an increase in plant density to offset the reduction in the branching ability (Carciochi et al., 2019). Plant population density has important impacts on plant growth, increase or decrease the productivity of the seed yield, increase or decrease of the plant density leads to a competition between the plants on plant nutrients in the soil (Ozturk and Saman, 2012; Fromme et al., 2019). The of suitable plant density is one of the factors that lead to the high yield of sesame (Voh, 1998). Several studies evaluated changes in yield components due to variations in plant density. These studies indicated that a decrease in plant density produces greater growth of individual plants (Luca and Hungria, 2014) and consequently more leaf area, branches, pods, and seeds per plant in soybean plants (Cox et al., 2010). However, in low productive environments, variations in per-plant leaf area and yield components at low plant density might not compensate for the lack of plants required to maximize light interception, for improving canopy photosynthesis, growth rate, and yield (Lee et al., 2008; Gaspar and Conley, 2015; Carciochi et al., 2019). Furuhashi et al. (2008) reported that the seed yield increased as the row width narrowed from 80 to 60, 40, and 30 cm, indicating the adaptability of this varieties to higher plant density. It has been reported that narrow-row cultivation not only increased the seed yield but also reduced the weed density due to more rapid canopy closure (Harder et al., 2007; Saitoh et al., 2007; Matsuo et al., 2018). Also, increases in plant density usually increase heads and kernel number per unit area and decrease kernel weight and kernels per head in the wheat plants (Valério et al., 2013; Bastos et al., 2020). Sesame growth parameters, seed yield and yield components response/influence to plant density has been reported by many researches such as Adeyemo et al. (1992) and Ngala et al. (2013), who reported that the increased of the seed productivity increase with plant population per area. Also, cultivated of the sesame plants in the wider spacing between rows lead to increase the number of capsules per plant and number of seeds per

capsule (Olowe and Busari, 2003), seed weight per plant, seed index and oil, as compared with the closer spacing (Roy et al., 2009; Rahnama and Bakhshandeh, 2018). Mandal et al. (1990), who studied the relationship between plant population and the seed productivity of sesame genotype and described that the increase in the plant population lead to increasing the seed yield.

The objective of the present study was to examine the impact of plant density (adjusted by row width) on growth parameters, seed yield, and yield components for three sesame varieties under rainfall conditions. This information will provide growers with new cultivation options which will lead to more stable and higher sesame seeds yields than those obtained using conventional cultivation methods.

2. Materials and Methods

2.1. Experimental Site and Soil Characteristics

This study was performed during summer 2015 and summer 2016 at the demonstration farm, college of agricultural and environmental science, Gadarif university. To study the effect of different plant spacing between rows (5 cm (control), 10 cm, 20 cm and 30 cm) on the growth parameter, yield and yield component of three sesame varieties (variety Abo Radom is the high yielding, the seeds are the red and the large size, the seeds contain a high percentage of oil and protein, it is short plants and have the number of branched, and low number of leaf) variety Abo Nama (red seeds and small size, the plants of this variety change to the yellow and lacked shattering resistance, causing seeds to naturally drop onto the soil surface before harvest, also drop the leaves onto the soil surface when the plant maturity, it is longer plants and have many leaves and branches, the oil ratio is very high) and variety Abo Sofa is early maturity, and the red seeds, this variety responsive to moisture, the plants are the medium and have low number of branch and many leaf) under rain-fall condition. Gadarif city is located in the eastern of the Sudan Latitude 14°1' 20"N, Longitude 35° 21' 45"E, elevation 592 m above the sea level. The soil of the site is described by Blokhuis (1993), the soil is dark heavy cracking clay (75%), with low organic matter and low nitrogen contents, pH (7.5-8), and high exchangeable sodium percentage. The climate is semi-arid, and with low relative humidity, rainfall per year is 300 to 500 mm in the North city and 600 to 900 mm in the South city. Mean temperature is 20°C in winter and 40°C in summer (Ismaeil et al., 2012).

2.2. Experimental Design and Land Preparation

The experiment was arranged in a randomized complete block design (RCBD) with three replications. The main

plots were assigned for varieties, while the spacing between row constituted the sub-plots. Each variety was planted in plots (3.5m×2m), each plot including for 6 rows (at wider spacing of 30 cm) to 18 rows (at closer spacing of 5 cm), each row long 3 meters and 5, 10, 20 and 30 cm between rows. Sowing date was carried out on the first August at 2015 and August 5th at 2016. Weeding was done twice using hand without fertilizer and insecticide.

2.3. Seeds Varieties

Sesame seeds of three varieties, Abo Sofa, Abu Radom and Abo Nama were used in this study. Seeds within a variety were selected for uniform size, shape, and color. All seeds were less than 9-mo old and were previously stored in paper bags under laboratory conditions (RH 40-60% at 15-20 °C) to maintain good germination ability. Seeds were obtained from the Agricultural Research in Gadarif. Five seeds were planted in the hole and thing to three plants after two-week form sowing date.

2.4. Phenotypic Characteristics

After 90 days of sowing date, five plants from the middle of each plot were randomly selected and marked. Growth parameters were measured including plant high (cm) and number of branches per plant.

2.5. Yield Attributes

At four months after planting, the five plants of each plot were harvested. Yield compound parameters were measured including number of capsules per plant and number of seeds per capsule.

2.6. 1000 Seeds Weight (g)

A sample of 1000-seeds was taken randomly from the yield of each plot, then weighed to determine the 1000 seed weight for each treatment.

2.7. Seeds Yield (kg/ha)

Plants on the one-meter length from middle of each plot of each treatment were harvested, sun-dried, weighed to obtain the biological yield. The pods of the harvested plants were threshed, and seeds were collected. The seed yield per unit area was converted into kg ha⁻¹.

2.8. Statistical Analysis

The data of each variable were statistically analyzed of variance for RCBD as a factorial design with the statistical package of MSTATC (Freed et al., 1991). When F values were significant, means were separated by the least significant difference (LSD) test ($P \leq 0.05$ probability) as described by Snedecor and Cochran (1980).

3. Results and Discussion

The results of the analysis of variance for growth phenotypic, seed yield and yield attributes are presented in Table (1). Highly significant differences among the rows spacing for all parameters. Varieties also significantly affected on most of the measures except the 1000-seeds weight. A significant affected on the interaction between varieties and rows spacing on all parameters (Table 1 and 2).

3.1. Plant Height (cm)

Plant height was increased by rows spacing increase as compared with the control. At the highest row spacing of 30 cm was significantly increased plant height by 14.23% as compare with 5 cm (Fig 1a). Abo Nama had the taller plant height (Table 3). In the interaction between rows spacing and varieties, Abo Nama at 30 cm was increased the plant height by 21.55% as compare with Abo Radom at 5cm (Fig 1b). Maybe, the long time between the rain (increase drought period) on the later growth period lead to the competition between the plant in soil moisture and nutrients with increasing the number of the plant in the area to perform photosynthesis. Many studies indicated that the increase plant height linked to decreased the spacing between rows. The biggest spacing between the rows lead to the lesser competition between plants for available nutrients and other growth resources (Olowe and Busari, 1994; Ngala et al., 2013). These results are in agreement with the Caliskan et al. (2004), Ijoyah et al. (2015), Ngala et al. (2013) in sesame and Dugje and Odo (2006) in the millet.

3.2. Number of Branches Per Plant

Sesame at the wider space within row receipting maximum sunlight for the process of photosynthesis, increased photosynthesis lead to increasing the plant growth, biomass and the number of branches per plant (Idoko et al., 2018). In our study, at the control (5 cm), all varieties produced the lower number of branches per plant decreased by 23.99% as compared with 30 cm (Fig 2a). In the interaction between varieties and rows spacing, at the 30 cm, Abo Nama and Abo Radom recorded the big number of branches per plant (Fig 2b). This result agreement with Idoko et al. (2018), who reported that reducing the space within row had negatively influences the growth parameter and productivity of seeds sesame, and also agreement with the resulting of Oad et al. (2002) in sunflower. While this result was in disagreement with the Tiwari et al. (1994), who reported that the better growth parameters of sesame show at the closer spacing within rows. Abo Nama and abo Radom increased the number of branches per plant by 64.9% as compared with abo Sofa (Table 3).

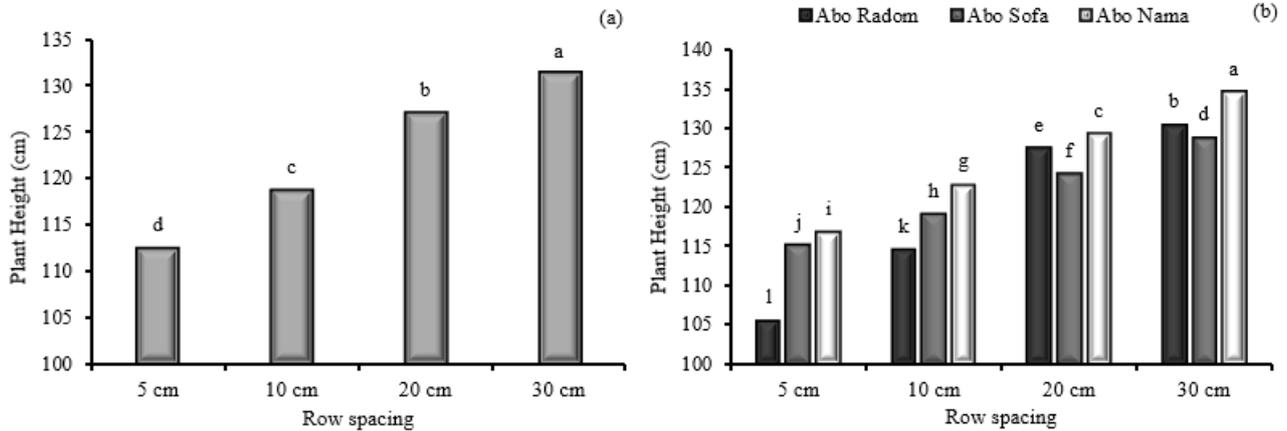


Figure 1. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on plant height of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$

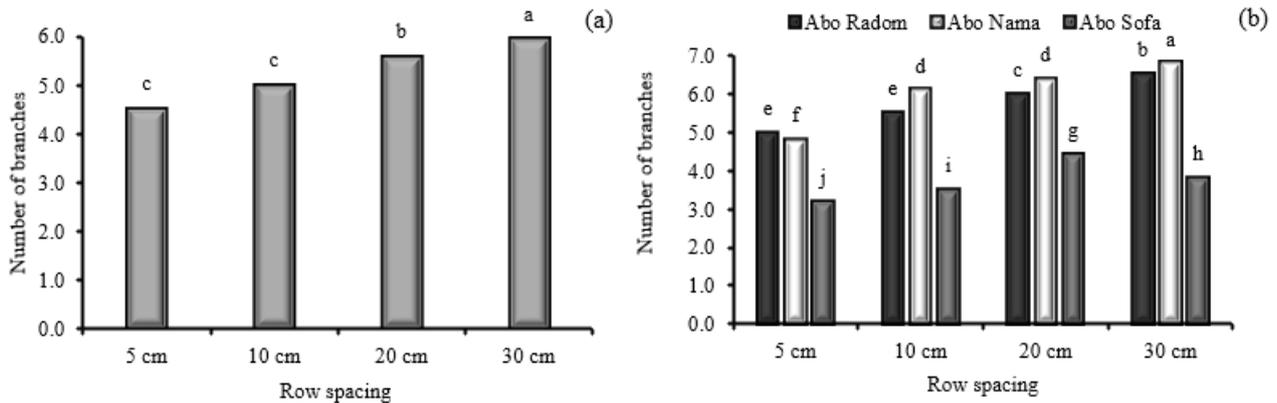


Figure 2. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on number of branches per plant of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$.

Table 1. Summary of analysis of variance for effects of Varieties (V), Row spacing (RS) and their interaction on sesame growth and yield parameters under rainfed condition at 2014 and 2015

Source	F value											
	Plant Height		Number of branches		No. capsule per plant		No. seeds per capsule		Weight of 1000 seeds		Weight of Seed yield	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Replication	66.03	1.63	800.4	7.38	166.5	475.4	65.71	60.99	224.9	0.24	13.08	12.68
Varieties (V)	56.63**	26.09**	105.3***	9.82*	147.1***	187.4***	30.39**	24.15**	0.26 ^{ns}	1.60 ^{ns}	333***	5.43*
Row spacing (R)	145.8***	418.8***	92.04***	9.41***	121.9***	249.4***	69.86***	161.1***	44.63***	17.13***	523.8***	4.39*
V × R	10.71***	3.38*	17.22***	0.39 ^{ns}	29.28***	6.87***	3.66*	42.84***	9.44***	3.79*	277.67***	8.84***

Note: NS, no significance; *, low significance at $P \leq 0.05$; **, medium significance at $P \leq 0.01$; ***, high significance at $P \leq 0.001$.

Table 2. Summary of analysis of variance showing the average of two seasons for effects of Varieties (V), Row spacing (RS) and their interaction on sesame growth and yield parameters under rainfed condition

Source	Mean square					
	Plant Height	No. branches per plant	No. capsule per plant	No seeds per capsule	1000 seeds Weight	Weight of Seed yield
Replication	294.54	49.11	290.18	328.34	109.56	30055.2
Row spacing (R)	632.48***	3.71***	197.57**	144.57**	0.54*	8919.3**
Varieties (V)	122.16*	23.65***	5.36***	79.69**	0.56 ^{ns}	10310.2**
V×R	27.34***	0.503***	23.58*	18*	0.80**	2145.4*
CV%	0.06	2.49	1.09	1.28	2.20	1.24

Note: *, low significance at $P \leq 0.05$; **, medium significance at $P \leq 0.01$; ***, high significance at $P \leq 0.001$.

Table 3. The average of two seasons (2014 and 2015) plant height (cm), number of branches per plant, number of capsules per plant, number of seeds per capsule, weight of 1000 seeds (g) and weight of seeds yield (kg/ha) of three varieties of sesame as influenced by different row spacing under rainfed condition.

Variety	Plant Height (cm)	Number of branches	No. capsule per plant	No. seeds per capsule	Weight of Seed yield
Abo Radom	119.5c	6.1b	30.96b	68.5a	197.8a
Abo Sofa	121.8b	3.7b	32.04a	64.2c	156.6b
Abo Nama	125.8a	6.1a	32.21a	63.9b	146.3c
Mean	122.3	5.3	31.74	65.5	166.9
LSD	2.64**	0.39***	2.26***	2.53**	1.03***

Note: **, medium significance at $P \leq 0.001$; ***, high significance at $P \leq 0.0001$. Within the same column, means followed by the same letters are not statistically different at $P \leq 0.05$.

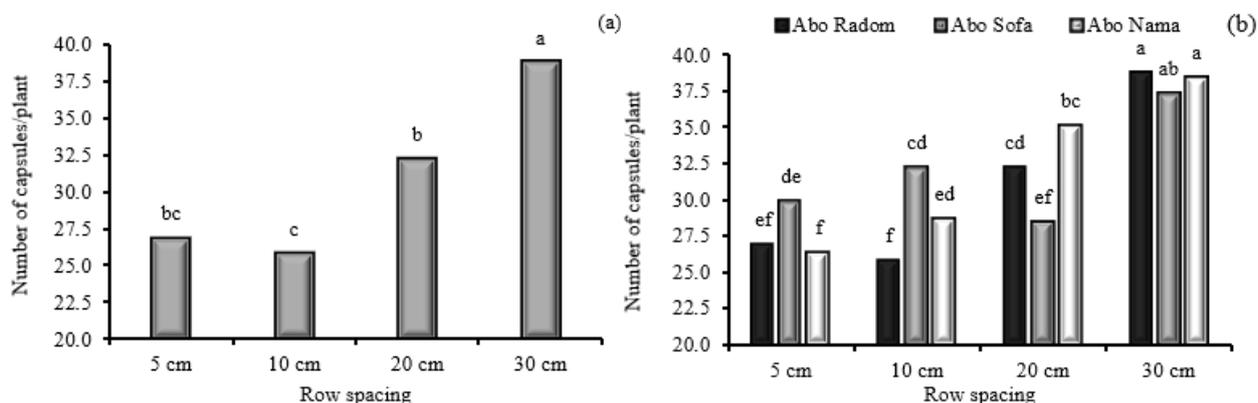


Figure 3. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on number of capsules per plant of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$

3.3 Number of Capsules Per Plant

Number of capsules per plant was increased by rows spacing increase as compared with the control. At the highest row spacing of 30 cm was significant increasing the number of capsules per plant by 16.83%, 33.30% and 30.54% as compare with 20 cm, 10 cm and 5 cm, respectively (Fig 3a). Abo Nama and Abo Sofa produced the highest number of capsules per plant, while the Abo Radom had the lowest number of capsules per plant (Table 3). In term of interaction between varieties and rows spacing, at 30 cm Abo Nama and Abo Radom was recorded the highest number of capsules, while the same varieties at 5 cm had the lowest capsules per plant (Fig 3b). The reduction of the number of capsules per plant might be due to the extreme limitation of spacing and leaves for the formation and development of capsules. Many researches stated that the decreased within plant spacing at row reduced the number of capsules per plant, might be attributed to narrow spacing between plants and increase interplant competition in nutrition (Roy et al., 2009). These results are in agreement with Subrahmaniyan and Arulmozhi (1999), Tiwari et al. (2000) and Roy et al. (2009) who reported that the number of capsules per plant was increased by increasing the plant spacing.

3.4. Number of Seeds Per Capsule

At the 30 cm was increased the number of seeds per capsules by 12.04% as compare with 5 cm (Fig. 4a). Abo Radom produced the biggest number of seeds per capsules (Table 3). In term of interaction between varieties and rows spacing, Abo Radom and Abo Sofa at 30 cm had the highest number of seeds per capsule, while the Abo Sofa and Abo Nama at 5cm recorded the lowest number of seeds per plant (Fig 4b). This work confirms the earlier work reported by Jakusko et al. (2013), who stated that the number of seeds per capsule significantly increased with increasing the rows spacing. These findings also are in line with Kathiresan (2002), who stated that reduction in row spacings increased intra-specific competition which finally caused a decrease in the number of seeds per capsules compared with wider spacing. Our results in disagreement with Ahmed et al., (2010) who mentioned that the number of capsules per plant reduction at the closer rows spacing (increasing plant densities). These results may be attributed to the reduced competition between plants and between the different parts of the individual plant under the wide rows spacing.

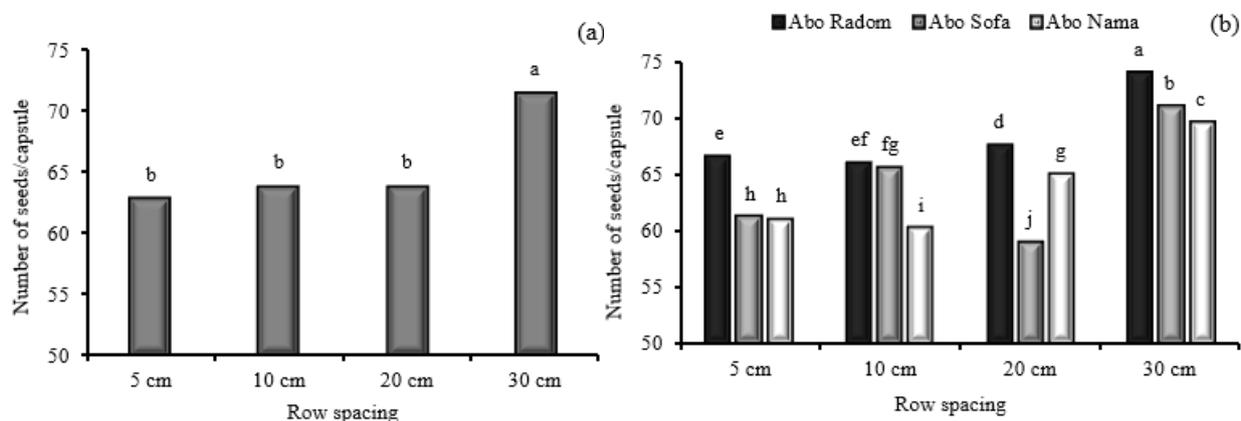


Figure 4. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on number of seeds per plant of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$.

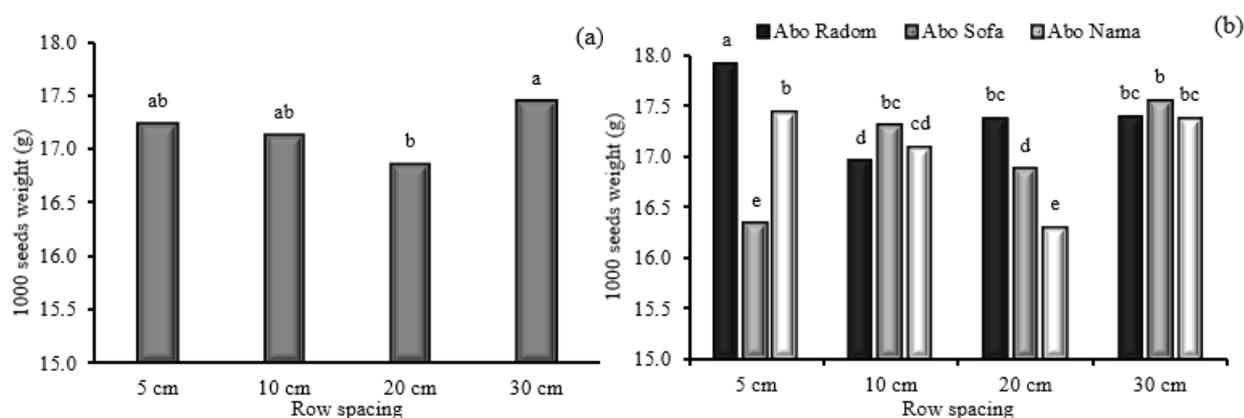


Figure 5. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on 1000 seeds weight (g) of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$.

3.5. 1000 Seeds Weight (g)

Compared to the control, the 1000 seeds weight increased with the increase of rows spacing. The big weight of 1000 seeds recorded at 30 cm (17.44g) (Fig 5a). At control, Abo Radom recorded the higher weight of 1000 seeds by 17.92g, and Abo Nama registered the lowest weight of 1000 seeds at the same spacing (Fig 5b). Olowe and Busari (2003), who stated that 1000 seeds weight was increasing 1000 seeds weight at the wide rows spacing compare with the narrower spacing, this may be due to increase the plant population lead to reduces the seed size, this result disagreement between our result.

3.6. Seed Yield (kg/ha)

Compared to the control, the seeds yield decreased with the increase of rows spacing. The seeds yield was decreased by 34.20% in 30 cm as compared with control (Fig 6a). Abo Radom produced the highest seeds yield by 197.83 kg per ha⁻¹, whereas the Abo Nama was recorded the lowest seeds yield by 146.31 kg per ha⁻¹ (Table 3). Abo Radom at 5cm had the biggest weight of seeds yield, while Abo Nama at 30 cm was recorded the lowest seeds yield (Fig 6b). Ozturk and Saman (2012), who reported that the

highest plant population density lead to increase yield productivity, may be due to the highest number of plants per area in closer rows spacing or hills on row, could compensate that decreasing in the yield component of the plant such as the weight of 1000 seeds, seeds weight and number of capsules per plant. In this study, it was found that wider row spacings reduced the seeds yield, but increasing the plant population on the closer spacing increase the seed productivity. Similar result was mentioned by Channabasavanna and Setty (1992), stated that the increase plant density per ha⁻¹ lead the increasing yield productivity. Also, Adeyemo et al. (1992), Chimanshette and Dhoble (1992), Tiwari et al. (1994), Basavaraj et al. (2000), Imayavaramban et al. (2002), Caliskan et al. (2004), and Ojikpong et al. (2007), wherein they noted to get to the higher seeds productivity when the grown plant on the high plant density. These results are in disagreement with those studies by Ahmad et al. (2002), Rahnama and Bakhshandeh (2018) and Carciochi et al. (2019), who observed that the planting sesame and soybean on the wider planting distance produced the highest seeds productivity. Also, this result dissimilarly with Ahmed et al., (2010) pointed that seed yield substantially decreased with increasing plant population (at the wide row spacing).

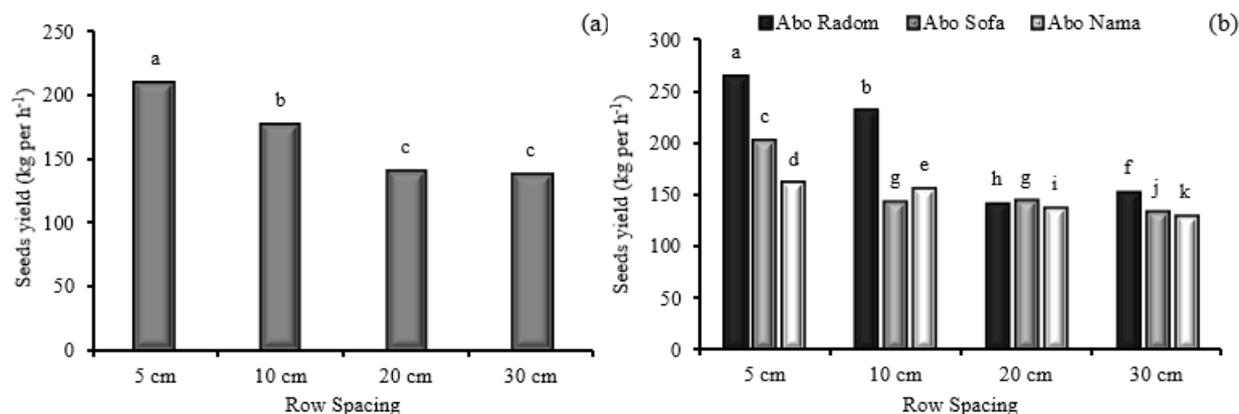


Figure 6. Effects of: (a) rows spacing and (b) interaction between varieties and rows spacing on weight of seed yield (kg/ha) of sesame seeds varieties under rainfed condition. Bars with different letters are statistically different at $P = 0.01$

4. Conclusions

The most probable agronomic optimal plant density depended on the yield environment. With the plant density increased (5 cm between rows) the seeds yield increased, while decreased by 15.5%, 32.7% and 37.0 in 10 cm, 20 cm and 30 cm between rows relative to 5 cm. The results concluded that growth parameter, yield and yield component were the highly significant difference affected by the row spacing and row spacing and interaction between them. Reducing the row spacing decreased the growth parameter and yield component. All varieties at 5 cm recorded the high seed yield. The interaction between abo Radom and 5 cm in 2014 and Abo sofa with 5cm in 2015 recorded the high seed yield. Abo Radom is the best variety grown at 5 cm. As evidenced by the result of the field experiment to include row spacing and different genotype. Based on this, a farmer may select different plant density with varying levels of spacing between plants, and good genotypes depending on the yield environments, could be used to decrease weather-related production risk.

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