

The Adoption of Temperate Selected Sesame Accessions in the Tropics: Selected for Japan and Grown in Ghana

Kwame D. Ansah¹, Henry O. Sintim¹, Samuel Awuah¹, Joseph E. Ali¹ & George Oteng¹

¹ Department of General Agriculture, School of Applied Science & Technology, Sunyani Polytechnic, Sunyani, Ghana

Correspondence: Henry O. Sintim, Department of General Agriculture, School of Applied Science & Technology, Sunyani Polytechnic, P.O. Box 206, Sunyani, Ghana. E-mail: hosintim@gmail.com

Received: January 12, 2015 Accepted: February 27, 2015 Online Published: April 15, 2015

doi:10.5539/jas.v7n5p47

URL: <http://dx.doi.org/10.5539/jas.v7n5p47>

Abstract

Sesame is an oilseed crop which can be grown on marginal lands. Selection of stable sesame cultivars that can adapt to local environmental conditions can be a very important food security strategy. A set of 21 high yielding sesame accessions that have been selected for a temperate region were grown in the transitional zone of Ghana during the major season of 2014. The seeds were sown after the first rain in the year in a completely randomized design, with three replications. The objective was to evaluate the effect of the contrasting environment on sesame phenology and to select cultivars with yield potential that can be accepted into local farming systems in the new environment. Morphological, physiological and agronomic traits, leading to yield were recorded in this study. Number of capsules per plant had the strongest association (72%) with seed yield. Five accessions showed a combination of early maturity < 12 weeks with high overall mean seed yield (> 20 g per plant) and good harvest index (0.29). Based on their mean performance these cultivars have been selected as promising exotic cultivars for the new locality.

Keywords: sesame, climate adaptability, cultivar selection

1. Introduction

Sesame (*Sesamum indicum* L.) is one of the world's oldest spice and oilseed crop grown mainly for its seeds (Morris, 2002; Dorothea, 2003; Francis, 2013). The leading world producers are India, China, Mexico, Myanmar and Sudan in Africa. Sesame seeds are unusually high in oil, around 50% of the seed weight and 25% protein, compared to 20% seed oil for example in soybeans.

Sesame are those tiny seeds which is most familiar as a topping for hamburger bread buns. It is an annual self-pollinating plant with an erect pubescent and sometimes branching stem. It is between 0.6 to 1.3 m tall. One flower is produced at each leaf axil and the lower flowers usually bloom 2 to 3 months after planting and continue to bloom until the terminal flowers are opened. The world production is estimated at 3.66 million tons with Asia and Africa producing 2.55 and 0.95 million tons respectively. The crop requires only 500-650 mm of rainfall per annum but it could be sensitive to drought during its vegetative stage (Boureima et al., 2011).

As an arable crop, sesame can be grown without irrigation or amended soil nutrition. It is considered drought tolerant, but needs good soil moisture to get established (Myers, 2002). It has a natural pest suppression mechanism (Sintim et al., 2014), can thrive on marginal soils and can be planted three times a year on the same land (Sintim: personal communication). This early or late planting window compares to no other oilseed crop. These attributes make sesame an excellent candidate for inclusion into low-input sustainable food systems.

The total annual consumption is about 65% for oil extraction and 35% for food (RMRDC Survey, 2004). It is used in baking, and has edible oil extracted from the seed (Obiajunwa et al., 2005). The oil carries a premium relative to other cooking oils and is considered more stable due to the presence of some antioxidants (Bedigian & Harlan, 1986; Yoshida & Kajimoto, 1994; Moazzami et al., 2007; Adebawale et al., 2011). After the oil is extracted from the seed, the remnant cake is high in protein and suitable for feedstock (Jefferson Agricultural Institute, 2003). Although for now sesame oil is used almost exclusively for human food consumption, it has potential for a variety of industrial uses. Sesame plants have also been used to successfully remove organochlorine pesticides from soils (Abhilash & Singh, 2010).

Despite the improved potential for increasing the production and productivity of sesame, there are a number of challenges. Over seven million hectares were grown worldwide in 2010, which produced about four million tons of seeds (FAO, 2012). The average world yield is still low at 0.52 ton ha⁻¹ (FAO, 2012) which is from low-yielding dehiscent varieties with poor harvest index values, and have significant yield loss during threshing (Ashri, 1998; Uzun & Cagircam, 2006). Among these production constraints, the most crucial include the lack of improved cultivars which are high yielding, non-dehiscent and also reliable seed supply (Pham et al., 2010; Tiwari et al., 2011). The average grain yield per hectare has been reported to be relatively low in most producing countries; between 300-350 kg/ha (Phillip, 1977; Saha & Bhargava, 1980; Schilling & Cattani, 1991). The fruit capsules dehisce along the suture lines and release the seeds to the ground. These wild characters prevent mechanized harvesting and the expansion of sesame cultivation (Uzun et al., 2003). However, non-dehiscent sesame varieties with yield potential of over 1 ton ha⁻¹ and suitable for mechanical harvest have been developed in the last decade (Langham et al., 2008) confirming the status of sesame as a viable cash crop with tremendous export potential (Oplinger et al., 1990).

Sesame is however catching attention because breeding programs for about 80 years has seen a breakthrough (Anwar et al., 2012) where the crop's major drawback, brittle seed capsules has been solved. The main reason for this delayed success in breeding programs was that it is mainly produced in developing countries and usually by smallholders (Ashri, 2007). For now collections of improved sesame species and cultivars are available in the USA, India, Russia, China, Kenya, South Korea and to a lesser extent Japan, and these provide a valuable gene pool. Ashri (2007) has indicated that, introduced sesame varieties can adapt to new environments within 2-3 seasons of replant. Cultivars to be adopted should be selected based on the local climate, resistance to local pests, and intended use (Sheahan, 2014). Although there is ample evidence indicating that sesame yield depends on the interaction of different climatic parameters such as solar radiation, temperature and humidity (Beech, 1985; Nath et al., 2001) we still had the chance to grow temperate selected sesame cultivars in a tropical area to evaluate its adaptability and yield potential.

2. Materials and Methods

2.1 Location and Plant Materials

Twenty-one sesame accessions (Table 1) were collected from the sesame bank of University of Toyama, Japan and the pericarp size was classified as: medium, big or large with the large being the size found on bread buns were grown under field conditions after the first rain in March 2014 at Sunyani. Sunyani lies 7.3333°N, 2.3333°W in a tropical forest-savanna transitional zone with a bi-modal annual rainfall. The field experiment was carried out at the research fields of Sunyani Polytechnic, where the annual temperature fluctuates between 25 °C and 35 °C.

2.2 Experimental Procedures

The cultivars were sown in 6 m long cultivar-alternating plots which were 100 cm apart with an interplant distance of 40 cm. This was replicated in each of the three blocks. After 2 weeks of growth, plants were thinned to 2 plants per stand and data collection was initiated. Ten mid-row plants of each cultivar per block were randomly tagged as target data subjects.

2.3 Data Collection

Plant height from the base to the terminal leaves; stem height from the base to first capsule; fruiting zone length which was the height between the first basal and terminal capsules were each measured using a graduated wooden measure. The number of branches of five randomly selected tagged plants was counted. The number of capsules per plant from each of the five randomly tagged plants was taken. Plants were each cut at the base and the wet biomass yield/plant was determined (leaves, stem, capsules). Fresh capsule weight from ten plants, seed yield per plant, seeds/capsule, and 1000 seed weight were determined using an electronic balance. Harvest Index was taken as the ratio of seed yield to biomass yield per plant.

2.4 Data Analysis

Analysis of variance was carried out on above mentioned traits using 9th edition of Genstat® (Release 9.2, 2007). Means of treatments were separated using Least Significant Difference (LSD) after Analysis of Variance (ANOVA) in common probability levels.

Table 1. Description of 21 sesame accessions used in the study

No.	Accession	Pericarp colour	Pericarp size
1	965	White	big
2	565	White	medium
3	506	Tan	large
4	5951	White	large
5	999004	White	medium
6	987	White	medium
7	5041	Black	large
8	958	Tan	large
9	6197	White	large
10	5183	Black	large
11	Sudan white	White	large
12	Sudan white (sesamin rich)	White	big
13	5261	Black	medium
14	6295	Tan	big
15	9891	White	big
16	605	White	big
17	52621	Beige	medium
18	603	Tan	big
19	5391	White	medium
20	6071	White	medium
21	5762	khaki	large

Note. These accessions were collected from the sesame bank of University of Toyama, Japan.

*Pericarp size was classified as: medium big or large. Large being the normal size found on commercial buns.

3. Results and Discussion

All the tested sesame varieties had seed colours and a ≈ 12 week maturity period which were true to type as described by the seed breeder or collector. The pericarp sizes were classified to be medium, big or large. The large seed (Table 1) is in reference to commercial seeds used in the bakery industry.

Results obtained from the 21 varieties indicate that there exist wide variations among the varieties. The distance from the first capsule down to the base of the plant was between 22-80 cm (Table 2) and was significant ($p < 0.001$). There was a positive correlation (65%) between the first capsule height from the base and plant height. The tallest variety (5762) measuring 149 cm and the shortest variety (603) measuring 112 cm tall had the first capsule being 63 cm and 28 cm above ground respectively. There was a significant difference ($p < 0.02$) among the plant heights of the varieties. Plant height had a 52% correlation with yield.

The highly branched varieties, with greater than 15 branches per plant (Table 2); as compared to the no branching types could attain a higher fruiting zone length if the branches were considered. Fruiting zone in this experiment was restricted to the main stem leading to plant height. Branching is very variable in sesame and for these varieties was significant ($p < 0.001$, Table 2).

Fruiting zone which for sesame is the distance between the first basal capsule and the terminal capsule was significant among the varieties ($p < 0.001$). The mean fruiting zone length was 87 cm. Results from these varieties indicate that fruiting zone length had a negative correlation 36% with yield. This was especially manifested in the variety (987) with a high above average fruiting zone length of 105 cm producing a seed yield of 13 g/plant. This was in contrast with some varieties e.g. (965) with seed yield 29 g/plant from a fruiting zone of 85 cm. Yield per plant as a consequent was highly significantly different ($p < 0.001$, Table 4).

Table 2. Agronomic parameters of sesame cultivars

No.	Accession	Stem height from base to the first capsule [cm]	Plant height [cm]	Fruiting zone length [cm]*	Number of branches
1	965	44.0	129.0	85.0	1.0
2	565	35.1	142.3	107.2	1.7
3	506	36.4	114.4	78.0	1.3
4	5951	32.4	138.7	106.3	1.0
5	999004	79.9	141.5	61.6	17.7
6	987	29.5	133.9	104.4	0.3
7	5041	28.7	133.7	105.0	0.7
8	958	28.9	117.1	88.2	0.3
9	6197	22.0	112.4	90.4	0.6
10	5183	23.9	117.4	93.5	2.3
11	Sudan white	58.9	141.2	82.3	8.3
12	Sudan white (sesamin rich)	54.7	125.1	70.4	9.3
13	5261	72.4	147.0	74.6	14.7
14	6295	30.9	118.6	87.7	1.3
15	9891	31.7	128.8	97.1	0
16	605	32.9	120.9	88.0	0
17	52621	26.7	114.7	88.0	0.3
18	603	27.7	111.8	84.1	0.3
19	5391	71.4	130.6	59.2	14.7
20	6071	37.9	132.3	94.4	0.3
21	5762	62.8	149.3	86.5	1.00
F. pro		<0.001	0.002	<.001	<0.001
CV%		16.7	9.4	13.7	51.7
LSD		11.4	19.9	19.7	3.3
Grand mean		41.4	128.6	87.2	3.8

Note. *Fruiting zone length was the height between the first basal and the terminal capsules.

There was no significant difference ($p = 0.29$) among the varieties in the wet biomass yield (mean = 243 g/plant) although variety (999004) which is highly branched (17/plant) had a wet biomass yield of 454 g/plant. All other forage or fresh vegetable uses of the sesame varieties were significantly different (Table 3). The fresh capsule weight of the variety (9891), 2 g, was above the collection average of 1.4 g.

The 21 varieties had a mean harvest index/plant of 0.48 which was significant ($p < 0.001$). Variety (999004) also combined a low harvest index (0.29: Table 3) and a high wet biomass with good yield of 23 g/plant. Capsule numbers per plant of these varieties was the best index to predict yield (73% correlation: Table 4).

Table 3. Forage-use indices of the tested cultivars

No	Accession	Fresh capsule weight (g)	Fresh capsule weight/plant (g)	Wet Biomass yield/plant (g)	Harvest index/plant
1	965	1.380	155.4	317	0.5067
2	565	1.170	89.3	179	0.4800
3	506	1.403	110.8	182	0.5333
4	5951	1.253	88.1	182	0.4867
5	999004	1.177	126.6	454	0.2900
6	987	1.560	87.8	158	0.5667
7	5041	1.270	95.7	180	0.5167
8	958	1.367	86.4	168	0.5133
9	6197	1.423	73.7	121	0.6767
10	5183	1.077	82.6	173	0.4867
11	Sudan white	1.320	105.8	310	0.3600
12	Sudan white (sesamin rich)	1.347	87.2	264	0.3433
13	5261	1.057	84.0	768	0.3567
14	6295	1.287	53.0	112	0.4733
15	9891	2.007	98.2	166	0.5400
16	605	1.490	72.3	142	0.5233
17	52621	1.287	59.3	115	0.5233
18	603	1.197	88.5	146	0.5167
19	5391	1.503	203.8	475	0.4467
20	6071	1.183	77.0	149	0.5233
21	5762	1.287	123.0	335	0.3700
	F. pro	<0.001	0.004	0.29	<0.001
	CV%	9.90	36.5	102.9	12.80
	LSD	0.2185	58.7	412	0.1008
	Grand mean	1.335	97.5	243	0.4778

*Wet biomass yield was the fresh weight of leaves, stem and capsules on a plant. Harvest Index was taken as the ratio of seed yield to biomass yield.

The yield of any crop is a very complex quantitative character resulting from different factors, the more important of them being the yield per plant and number of plants per unit area (Menon, 1967). Although sesame has numerous varieties and ecotypes adapted to various ecological conditions (Nzikou et al., 2009; Adebawale et al., 2011) in the present study, we investigated the adaptability of temperate selected varieties in a tropical region. The tested sesame varieties had all the commercial seed colours between white and black. Seed colour is a major trait that affects consumer's acceptability. Paltak and Dixit (1992) reported that the consumer's preference for seed colour differs from region to region for which we need to confirm in Ghana. White sesame seeds, have higher oil, protein and moisture ratios as compared to black seeded sesame (Kanu, 2011). The physical appearance is a key marketing indicator and acceptability of sesame type varies greatly with cultural preferences. The Sudanese favour white seeded sesame whilst the Japanese prefer black seeded ones (Hossain et al., 2010). In particular, a larger seed size, coupled with a light-coloured seed coat like white, often command price premiums in a market-dependent manner (Cassells & Caddick, 2000; Graham et al., 2001). In parts of Asia for example, white seeded sesame sells at least 30% higher than dark coloured varieties (Chakraborty et al., 1984).

Table 4. Seed and capsule yield of sesame cultivars

No.	Accession	Number of capsules per plant	Number of seeds per capsule	Seed yield per plant (g)	1000-seed weight (g)
1	965	134.3	67.8	28.85	3.400
2	565	97.7	94.0	22.86	2.833
3	506	96.3	50.3	17.53	3.000
4	5951	111.7	53.3	17.80	3.467
5	999004	161.3	56.0	22.63	4.233
6	987	66.7	55.3	12.58	3.267
7	5041	134.3	83.7	17.69	2.533
8	958	78.0	80.7	13.62	2.800
9	6197	56.7	54.0	13.36	3.200
10	5183	81.0	81.0	19.21	3.167
11	Sudan white	60.0	60.0	19.02	3.833
12	Sudan white (sesamin rich)	60.3	60.3	15.71	3.700
13	5261	52.7	52.7	18.89	3.200
14	6295	62.7	62.7	10.55	2.733
15	9891	64.0	64.0	14.64	3.667
16	605	57.7	57.7	13.10	2.967
17	52621	82.0	43.0	11.76	3.133
18	603	82.0	66.0	12.29	2.767
19	5391	162.7	58.0	29.75	3.167
20	6071	87.7	51.0	15.97	2.833
21	5762	96.0	72.7	22.10	3.400
F. pro		0.007	0.020	<0.001	<0.001
CV%		34.4	23.1	29.40	9.80
LSD		55.0	9.21	8.534	0.5204
Grand mean		97.0	62.70	17.62	3.205

Plant density is a crucial index in sesame and an optimum of 400,000 plants/ha has been recommended (Katung, 2003). In earlier experiments in Ghana, Sintim and Yeboah Badu (2010) at 250,000 plants/ha obtained yields that were above quoted yield values in Africa. Seed yield is a complex trait governed by polygenes and therefore is influenced more by environmental factors (Basu et al., 2009). Another important factor that influences the seed yield of sesame is varietal differences hence the need to select varieties of good quality that can be adjusted to the local climatic conditions (Pham et al., 2010). In other sesame growing areas in the tropics, seed yield of 37 g per plant has been reported in controlled pollinated fields. The tested varieties with greater than 20g seed yield per plant are very promising and will be introduced into the local farming/cropping system. Although characters such as plant height of determinate varieties (Uzun & Cagiran, 2001) and early maturation (Day, 2000; Day et al., 2002) make a great contribution to seed yield these attributes are variety specific. The most crucial index should rather relate to internode length and capsules per node. In the varieties tested, plant height and fruiting zone length were not a critical determinant of yield. Plants with tall stems should combine with short length of basal capsule from the ground, short internode and number of capsules per internode to ensure high yield. Early maturation is very important where sesame is grown as a second crop in areas with short seasons. Currently we have been able to grow sesame in a three season cycle in a year if we utilize the first rain in early March for our 12 week maturity sesame varieties. The selection of varieties should however not sacrifice plant features related to earliness for only seed yield. There have been instances where seed yield was negatively correlated with plant height (Ngala et al., 2013) which is similar to results from this experiment. In our case it was attributed to long

internodes and low capsule number per node for some varieties.

Sesame has shown in other places to be highly sensitive to day length (Narayanan & Reddy, 1982; Suddhiyam et al., 1992) and has significant interactions with temperature (Suddhiyam et al., 1992). Oil content has been found to be influenced negatively by temperature (Kamal-Eldin & Appelqvist, 1994). It flowers in about 45 days under 10-hour day length. The short day length requirement was not considered to be crucial for these varieties, since summer day length is even longer in temperate regions from where the seeds were collected. Sesame is also reported to adapt to different photoperiod requirements (Ashri, 2007) as well as the existence of day-neutral cultivars. These new temperate selected varieties can fit into our cropping pattern as most of the land is normally fallow after harvesting a main crop due to the long term moisture requirements for native crops. Sesame is also known to be a good candidate when planted as a primary crop or a secondary crop after wheat (Langham et al., 2008). The performance of these adaptable varieties such as: those with more than 100 capsules per plant, 90 seeds per capsule, 4.23 g 1000-seed weight are comparable to the high yield value of 3.59 g 1000-seed weight reported elsewhere for high yielding varieties by Anwar et al. (2012) and Hassan (2012).

4. Conclusions

For other attributes not tested in this experiment: sesame can increase yields in subsequent cash crops by successfully improving soil moisture retention and soil texture. It is notable for its ability to grow under droughty conditions and in extreme heat and under conditions where few other crops can survive as it requires very few inputs. These attributes make sesame an excellent candidate for low-input sustainable food systems as required in Ghana.

References

- Abhilash, P. C., & Singh, N. (2010). Effect of growing *Sesamum indicum* L. on enhanced dissipation of lindane (1,2,3,4,5, 6-hexachlorocyclohexane) from soil. *International Journal of Phytoremediation*, 12, 440-453. <http://dx.doi.org/10.1080/1522651090321394>
- Adebowale, A. A., Sanni, S. A., & Falore, O. A. (2011). Varietal differences in the physical properties and proximate composition of elite sesame seeds. *World Journal of Agricultural Sciences*, 7, 42-46.
- Anwar, M., Hasan, E.-U., Mahmood, T., Iqbal, J., & Hussain, M. (2012). TS-5: A new high yielding sesame cultivar. *Journal of Agricultural Research*, 50, 477-484.
- Ashri, A. (1998). Sesame breeding. *Plant Breeding Reviews*, 16, 179-228. <http://dx.doi.org/10.1002/9780470650110>
- Ashri, A. (2007). Sesame (*Sesamum indicum* L.). In R. J. Singh (Eds.), *Genetic Resources, Chromosome Engineering, and Crop Improvement* (Vol. 4, pp. 231-289, Oilseed Crops). Boca Raton, FL, USA: CRC Press.
- Basu, S. K., Acharya, S. N., Bandara, M. S., Friebe, D., & Thomas, J. E. (2009). Effects of genotype and environment on seed and forage yield in fenugreek (*Trigonella foenum-graecum* L.) grown in Western Canada. *Australian Journal of Crop Science*, 3, 305-314. Retrieved from http://www.cropj.com/saikat_3_6_2009_305_314.pdf
- Bedigian, D., & Harlan, J. (1986). Evidence for cultivation of sesame in the ancient world. *Economic Botany*, 40, 137-154.
- Beech, D. (1985). Sesame research possibilities for yield improvement. In A. Ashri (Eds.), *Sesame and safflower: Status and potential* (pp. 121-126). FAO plant production and protection, Rome. Retrieved from <http://safflower.wsu.edu/newsletter1985.pdf>
- Boureima, S., Eyletters, M., Diouf, M., Diop, T. A., & Van Damme, P. (2011). Sensitivity of seed germination and seedling radicle growth to drought stress in sesame (*Sesamum indicum* L.). *Research Journal of Environmental Sciences*, 5, 557-564. <http://dx.doi.org/10.3923/rjes.2011.557.564>
- Cassells, J., & Caddick, L. (2000). Harvest timing critical for chickpea quality. *Farming Ahead*, 107, 41-42.
- Chakraborty, P. K., Maiti, S., & Chatterjee, B. N. (1984). Growth analysis and agronomic appraisal of *Sesamum indicum* L. *Indian Journal of Agricultural Science*, 54, 291-295.
- Day, J. S. (2000). Development and maturation of sesame seeds and capsules. *Field Crops Research*, 67, 1-9. [http://dx.doi.org/10.1016/S0378-4290\(00\)00073-3](http://dx.doi.org/10.1016/S0378-4290(00)00073-3)
- Day, J. S., Langham, D. R., & Wongyai, W. (2002). Potential selection criteria for the development of high-yielding determinate sesame varieties. *Sesame Safflower Newsletter*, 17, 29-35.

- Dorothea, B. (2003). Evolution of sesame revisited: domestication, diversity and prospects. *Genetic Resources and Crop Evolution*, 50, 779-787. <http://dx.doi.org/10.1023/A:1025029903549>
- FAO. (2012). *FAOSTAT Databases*. Retrieved from <http://www.faostat.fao.org>
- Francis, E. (2013). *Sesame: For the Cooperative Extension Service University of Arkansas System Division of Agriculture*.
- Genstat® Release 9.2. (2007). *Lawes Agricultural Trust*. Rothamsted Experimental Station.
- Graham, J., Matassa, V., Panozzo, J., & Starick, N. (2001). *Genotype and environment interaction for whole grain colour in chickpea* (pp. 372-373). 4th European Conference on Grain Legumes.
- Hassan, M. A. M. (2012). Studies on Egyptian sesame seeds (*Sesamum indicum* L.) and its products 1-physicochemical analysis and phenolic acids of roasted Egyptian sesame seeds (*Sesamum indicum* L.). *World Journal of Dairy & Food Sciences*, 7, 195-201.
- Hossain, S., Ford, R., McNeil, D., Pittock, C., & Pannozzo, J. F. (2010). Inheritance of seed size in chickpea (*Cicer arietinum* L.) and identification of QTL based on 100-seed weight and seed size index. *Australian Journal of Crop Science*, 4, 126-135.
- Jefferson Agricultural Institute. (2003). *Strategies for Commercializing New Crops* (Report of a Workshop). St. Louis, Missouri Thomas Jefferson Agricultural Institute. Retrieved from <http://www.jeffersoninstitute.org>
- Kamal-Eldin, A., & Appelqvist, L. A. (1994). Variation in fatty acid composition of the different acyl lipids in seed oils four *Sesamum* species. *Journal of American Oil Chemists' Society*, 71, 135-139. <http://dx.doi.org/10.1007/BF02541547>
- Kanu, P. J. (2011). Biochemical analysis of black and white Sesame seeds from China. *American Journal of Biochemistry and Molecular Biology*, 1, 145-157. <http://dx.doi.org/10.3923/ajbmb.2011.145.157>
- Katung, P. D. (2003). The response of two varieties of sesame (*Sesamum indicum*, L.) to different plant populations and sowing dates at Samaru, Northern Guinea savanna. *Samaru Journal of Agricultural Research*, 19, 17-27.
- Langham, D. R., Riney, J., Smith, G., & Wiemers, T. (2008). *Sesame grower guide*. Sesaco sesame coordinators, Lubbock, TX. Retrieved December 18, 2014, from <http://www.sesaco.net>
- Menon, E. F. (1967). Effects of varying spacing on yield of sesame. *Indian Journal of Agronomy*, 12, 274-276.
- Moazzami, A. A., Haese, S. L., & Kamal-Eldin, A. (2007). Lignan contents in sesame seeds and products. *European Journal of Lipid Science and Technology*, 109, 1022-1027. <http://dx.doi.org/10.1002/ejlt.200700057>
- Morris, J. B. (2002). Food, industrial, nutraceutical, and pharmaceutical uses of sesame genetic resources. In J. Janick & A. Whipkey (Eds.), *Trends in New Crops and New Uses* (pp. 153-156). ASHS Press, Alexandria, VA.
- Myers, L. R. (2002). *Sesame: A high value oilseed*. Alternative crop guide Jefferson Institute, Columbia, MO. Retrieved from <http://www.jeffersoninstitute.org>
- Myers, R. (2002). *Alternative crop guide: Sesame*. Jefferson Institute, Columbia, MO. Retrieved July 15, 2014, from <http://www.jeffersoninstitute.org>
- Narayanan, A., & Reddy, K. B. (1982). Growth, Development and yield of sesame (*Sesamum indicum* L.) cultivars. *Field Crop Research*, 5, 217-224. [http://dx.doi.org/10.1016/0378-4290\(82\)90024-7](http://dx.doi.org/10.1016/0378-4290(82)90024-7)
- Nath, R., Chakraborty, P. K., & Chakraborty, A. (2001). Effect of climatic variation on yield of sesame (*Sesamum indicum* L.) at different dates of sowing. *Journal of Agronomy and Crop Science*, 186, 97-102. <http://dx.doi.org/10.1046/j.1439-037X.2001.00456.x>
- Ngala, A. L., Dugje, I. Y., & Yakubu, H. (2013). Effects of inter-row spacing and plant density on performance of sesame (*Sesamum indicum* L.) in a Nigerian Sudan savanna. *Science International (Lahore)*, 25, 513-519. <http://dx.doi.org/10.13140/2.1.2230.3368>
- Nzikou, J. M., Matos, L., Bouanga-Kalou, G., Ndangui, C. B., Pambou-Tobi, N. P. G., Kimbonguila, A., & Desobry, S. (2009). Chemical composition on the seeds and oil of sesame (*Sesamum indicum* L.) grown in Congo-Brazzaville. *Advance Journal of Food Science and Technology*, 1, 6-11.
- Obiajunwa, E. I., Adebisi, F. M., & Omode, P. E. (2005). Determination of essential minerals and trace elements

- in Nigerian sesame seeds using TXRF technique. *Pakistan Journal of Nutrition*, 4, 393-395. <http://dx.doi.org/10.3923/pjn.2005.393.395>
- Oplinger, E. S., Punta, D. H., Kaminski, A. R., Hanson, C. V., Oelke, E. A., Schutte, E. E. & Doll, J. D. (1990). *Sesame: Alternative field crop manual*. Retrieved from <http://www.hort.purdue.edu/newcrop.afcm/sesame.html>
- Paltak, H. C., & Dixit, S. K. (1992). Genetic variability and inter-relationship studies in black seeded sesame (*Sesamum indicum* L.). *Madras Agricultural Journal*, 79, 4-100.
- Pham, T. D., Nguyen, T. T., Carlsson, A. S., & Bui, T. M. (2010). Morphological evaluation of sesame (*Sesamum indicum* L.) varieties from different origins. *Australian Journal of Crop Science*, 4, 498-504. <http://dx.doi.org/10.1017/S0021859600088158>
- Phillip, T. A. (1977). *Sesame: An agricultural notebook* (pp. 61-63). New edition, Longman Group Ltd., London.
- Raw Materials Research and Development Council-RMRDC. (2004). Survey report of ten selected agro raw materials in Nigeria. *Beniseed* (1st ed., p. 108).
- Saha, S. N., & Bhargava, S. C. (1980). Physiological analysis of growth, development and yield of oilseed sesame. *Journal of Agricultural Science*, 95, 733-736. <http://dx.doi.org/10.1017/S0021859600088158>
- Schilling, R., & Cattani, P. (1991). Sesame cultivation in tropical Africa. *Oleagineux*, 46, 129-131.
- Sheahan, C. M. (2014). *Plant guide for sesame (Sesamum orientale)*. USDA-Natural Resources Conservation Service, Cape May Plant Materials Center, Cape May, NJ.
- Sintim, H. O., & Yeboah Badu, V. I. (2010). Evaluation of Sesame (*Sesamum indicum*) production in Ghana. *Journal of Animal and Plant Sciences*, 6, 653- 662. Retrieved from <http://www.biosciences.elewa.org/JAPS>
- Sintim, H. O., Yeboah Badu, V. I., Akotsen Mensah, C., & Ansah Duodu, K. (2014). A faunistic description of endemic arthropods associated with sesame. *Advances in Natural Science*, 7, 1-7. <http://dx.doi.org/10.3968%2F4788>
- Suddhiyam, P., Steer, B. T., & Turner, D. W. (1992). The flowering of sesame (*Sesamum indicum* L.) in response to temperature and photoperiod. *Australian Journal of Agricultural Research*, 43, 1101-1116. <http://dx.doi.org/10.1071/AR9921101>
- Tiwari, S., Kumar, S., & Gontia, I. (2011). Biotechnological approaches for sesame (*Sesamum indicum* L.) and niger (*Guizotia abyssinica* L. f. Cass.). *Asia-Pacific Journal of Molecular Biology and Biotechnology*, 19, 2-9.
- Uzun, B., & Cagiran, M. I. (2001). Path-coefficient analysis for seed yield and related characters in a population of determinate and indeterminate types of sesame (*Sesamum indicum* L.). *Turkish Journal of Field Crops*, 6, 76-80. Retrieved from <http://www.field-crops.org/assets/pdf/product51b2ec340cef9.pdf>
- Uzun, B., & Cagiran, M. I. (2006). Comparison of determinate and indeterminate lines of sesame for agronomic traits. *Field Crops Research*, 96, 13-18. <http://dx.doi.org/10.1016/j.fcr.2005.04.017>
- Uzun, B., Lee, D., Donini, P., & Cagiran, M. I. (2003). Identification of an AFLP marker linked to the closed capsule mutant trait in sesame. *Plant Breeding*, 122, 95-97. <http://dx.doi.org/10.1046/j.1439-0523.2003.00787.x>
- Yoshida, H., & Kajimoto, M. (1994). Composition and quality characteristics of sesame seed (*Sesamum indicum*) oil roasted at different temperature in an electric oven. *Journal of Food Science*, 65, 331-336. <http://dx.doi.org/10.1002/jsfa.2740650311>

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/3.0/>).