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Genetic diversity, chemical composition and oil characteristics of six sesame genotypes

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Abstract – The nutritional factors and characteristics of sesame (*Sesame indicum L.*) seeds and extracted oil of six genotypes: G2, G3, G4, G5 and G6 cultivated in Upper Egypt were subjected to comparative evaluation with control (G1), for its genetic diversity, physicochemical properties, fatty acid composition, antioxidant activity and oil oxidative stability (Rancimat test). Estimates of genotypic and phenotypic coefficients of variation revealed high value in seed yield. For heritability estimates, the data showed that four traits out of eight recorded the highest heritability values over of 90%. These traits were oil yield (99.56%), seed yield (98.83%), plant height (96.33%) and seed index (90.03%). Sesame seeds have a high oil content (39.56 to 54.64 g/100g dry weight). The fatty acid profile was varied among the genotypes, in particular oleic acid (37.15 to 46.61%) and linoleic acid (37.49 to 44.33%). Results indicated that G4 has significantly higher in most agricultural traits as well as seed yield, while the G5 was the highest in oil yield and has significantly higher oxidative stability (26.57 h) among the genotypes.

Keywords: genetic diversity / sesame seeds / physicochemical properties / oil yield / fatty acid composition

Résumé – Diversité génétique, composition chimique et caractéristiques des huiles de six génotypes de sésame. Les facteurs nutritionnels et caractéristiques de graines de sésame (*Sesame indicum L.*) et de l'huile extraite de génotypes (G2, G3, G4, G5 et G6) cultivés en Haute Égypte ont été soumis à une évaluation comparative avec le témoin G1, pour leur diversité génétique, leurs propriétés physicochimiques, leur composition en acides gras, leur activité antioxydante et l'oxydabilité de l'huile (test Rancimat). Les estimations des coefficients de variation génotypiques et phénotypiques ont révélé une valeur élevée du rendement en graines. Concernant les estimations d'héritabilité, les données soulignent que quatre traits sur huit ont montré les valeurs d'héritabilité les plus élevées, supérieures à 90 % : le rendement en huile (99,56 %), le rendement en graines (98,83 %), la hauteur de la plante (96,33 %) et l'indice de graines (90,03 %). Les graines de sésame affichent une teneur élevée en huile (39,56 à 54,64 g/100g de poids sec) et leur profil en acides gras varie selon les génotypes, en particulier l'acide oléique (37,15 à 46,61 %) et l'acide linoléique (37,49 à 44,33 %). Les résultats indiquent que G4 a un rendement significativement plus élevé pour la plupart des caractéristiques agricoles ainsi que pour les semences, tandis que G5 possède le rendement en huile le plus élevé et une stabilité à l'oxydation significativement plus élevée (26,57 h) que les autres génotypes.

Mots clés : diversité génétique / graines de sésame / propriétés physicochimiques / rendement en huile / composition en acides gras

1 Introduction

Sesame (*Sesame indicum L.*) has been considered as "Queen of the oilseeds crops" due to its antioxidants, high oil yield, mildness and pleasant taste of the oil (Bhattachary *et al.*, 2014). It is a member of *Pedaliaceae* family, the seeds of tropical annual *sesamum indicum*, originated from dry bush savannah of tropical Africa and then spread to India and China. According to archaeological records, it has been known in India for over 5000 years. This crop is generally cultivated in

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Table 1. The information of studied sesame genotypes in the experiment.

Code	Genotypes	Origin	Main description		
			No. of capsules/leaf axil	Branching habit	Seed color
G1 (Control)	Shandaweel 3	Local genotype	Three	Non branched	White
G2	Line Zehre 15 Family 2	Egypt	Three	Branched	White
G3	Line Zehre 11 Family 2	Egypt	Single	Branched	White
G4	Hybrid 88 Family 2	Egypt	Single	Branched	Beige
G5	N.A. 554	FAO*	Single	Branched	White
G6	Line B4-2	Egypt	Three	Branched	Beige

*Food and Agriculture Organization (FAO).

tropical and temperate regions, the moist soil with minimum irrigation and lack of rainfall results in better yield. The minimum temperature required for sesame germination is between 12 and 14 °C. The normal temperature, which shows the extent with growth blossoms and ripening fruits, is between 25 and 32 °C (Wei *et al.*, 2017; Aglave, 2018).

Tamina and Dasgupta (2003) and Dossa *et al.* (2016) noted that the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for plant height, number of branches/plant, number of capsules/plant, capsules length, seed index (weight of 1000 seeds) and seed yield. Moreover, Ahmed *et al.* (2013) reported that high estimates of PCV and GCV were exhibited for a number of branches/plant, number of capsules/plant and seed yields/plant. The high heritability was exhibited for a number of capsules/plant and seed index.

Sesame chemical composition showed that the seed is a principal source of oil (44–58%), protein (18–25%), carbohydrate (13.5%) and ash (5%) (Uzun *et al.*, 2002; Were *et al.*, 2006; Elleuch *et al.*, 2007). Environmental conditions and genetic diversity effect on the oil content, as well as fatty acid profile of sesame (Carlsson *et al.*, 2009). Sesame oil contains almost equal levels of oleic (35 to 54%) and linoleic (39 to 59%), about 10% of palmitic acid and around 5% of stearic acid (Wacal *et al.*, 2019). Linolenic acid was found but in very small amount (0.5%) (Were *et al.*, 2006). In addition, sesame oil rich in many bioactive compounds, such as tocopherols, phytosterols, and lignans (sesamin, sesamolin, sesamol, pinoresinol and lariciresinol), which play a principal role against oil oxidation and contribute to antioxidative activity (Kanu *et al.*, 2010; Senila *et al.*, 2020).

The oxidative stability of sesame oil is eminent compared to other vegetable oils although it contains nearly 85% unsaturated fatty acids. This could be due to endogenous antioxidants such as lignans and tocopherols (Abou-Gharbia *et al.*, 2000; Aglave, 2018). Sesame seed oil shows an extraordinary high oxidative stability compared to soybean, corn and most other popular vegetable oils (Carrasco-Pancorbo *et al.*, 2005; Minioti and Georgiou, 2010).

In Egypt, there is a high shortage in vegetable oils, so that almost 90% of the consumption needs are currently imported (Zaher *et al.*, 2017). Given that the traditional sesame genotypes were no longer give the desired production, which necessitated a study of the appropriateness of some new genotypes for Egyptian environment, which are characterized by the high yield of oil, as well as study the effect of this on chemical properties of sesame oil. This study was aimed to investigate the genetic diversity effects on physicochemical properties of different genotypes from sesame seeds cultivated in Upper Egypt. As well as, oil characteristics and oxidative stability of extracted sesame oil, as our knowledge the studies on the effect of genetic variation on the oxidative stability of sesame oil is so limited.

2 Materials and methods

2.1 Field trial

The materials of the present study consisted of six promising genotypes (5 new sesame lines and one commercial genotype (Shandaweel-3). The details of tested genotypes are described in Table 1. The lines were evaluated in two successive summer seasons (2017 and 2018), at El-Mtaana Research Station, Agricultural Research Center (ARC), at Luxor Governorate (Coordinates: 25°41′N 32°39′E). Planting date was during April and the harvesting was during August in the two growing season (2017 and 2018). The experiment was laid out using a randomized complete block design (RCBD) with three replications. Each genotype was sown in plots of five rows each of 4-m long, 50-cm width and 20-cm hills within a row. Plants were thinned to one plant per hill. All cultural practices were applied as recommended by Langham (2008) for sesame production at each location.

At harvest, a random sample of 10 plants was taken from each plot in the two growing seasons for the following agronomic characters: (a) Morphological characters: (plant height (cm), length of fruiting zone (cm), number of branches/plant and number of capsules/plant). (b) Yield parameters: seed yield/plant (g), seed index (weight of 1000 seed) in g, seed yield/hectare (ton) and oil yield/hectare. Three central rows of each plot at each location were taken to determine seed yield in (kg), which was adjusted to calculate yield in ton per hectare.

The mature seeds (200 g) were milled in a laboratory grinder (Braun™ GmbH ZK 100, Marktheidenfeld, Germany), after which the ground samples were sieved (sieve mesh No.18) to obtain a powdered processed sample with particle size about 1 mm. Then, ground samples were stored in glass containers at a temperature of −18 °C for further analysis.

2.2 Chemical analysis

All solvents and chemicals were in analytical grade and purchased from Merck, Darmstadt (Germany).

2.2.1 Chemical analysis of sesame seeds

The samples of sesame genotype and control were analysed for moisture, protein (%N* 6.25), ash, fat, and fibre according to methods described in AOAC (2000). Total carbohydrates were calculated by difference [100 − (protein + fat + ash)] on the dry weight.

2.2.2 Oil extraction from sesame seeds

Extraction of the oil was carried out using fully automatically extraction system SOXTHERM^{TM} (Gerhardt GmbH & Co. KG, Germany) with four heating places. The extraction solvent was *n*-hexane.

2.2.3 Physiochemical properties of sesame oils

Refractive index (RI) peroxide value (PV), acid value (AV), Iodine value (IV) and unsaponifiable matter for oil samples were determined (in triplicate) according to the official methods AOCS (1997).

2.2.4 Photometric color index (PCI)

Photometric color index (PCI) is a calculated value that equals the Lovibond *R*-value. The PCI was determined using spectrophotometric method measuring absorbency for four lengths of light waves: 460, 550, 620 and 670 nm. Photometric color index (PCI) was calculated as follows:

$$PCI = 1.29\,(A_{460}) + 69.7\,(A_{550}) + 41.2\,(A_{620}) - 56.4\,(A_{670}), \quad (1)$$

Where: A_{460}, A_{550}, A_{620}, A_{670} are values of absorbance measured for four wavelengths of light waves: 460, 550, 620 and 670 nm respectively (AOCS, 1997).

2.2.5 Fatty acid composition

Fatty acid composition of the oil was determined according to the modified method of Zahran and Tawfeuk (2019). The fatty acids methyl esters (FAMEs) were analysed by gas chromatography (GC-FID). The FAMEs were separated with an HP 6890 plus gas chromatography (Hewlett Packard, USA), using a capillary column Supelco^{TM} SP-2380 capillary column (30 m × 0.25 mm × 0.20 μm) (Sigma-Aldrich, USA). The detector (FID) and the injection temperature was 260 °C. The column temperature was 50 °C (3 min) to 225 °C (17.5 min) at 10 °C/min. and hold at 225 °C (10 min). The carrier gas was helium at a flow rate of 1.2 mL min^{-1}. FAMEs were identified by comparing their relative and absolute retention times to those of authentic standards of FAMEs from $C_{4:0}$ to $C_{24:0}$, (Sigma-Aldrich GmbH, Steinheim, Germany.

2.2.6 Total phenolic content (TPC)

Total phenolic content was determined using the Folin-Ciocalteu method according to the method described by Zahran and Najafi (2019). Sesame oil (2.5 g) was dissolved in 5 mL organic solvent (*n*-hexane). Then, TPC extraction was performed using aqueous methanol/water (80:20, v/v). The aqueous phase was separate and collected by centrifugation at 3500 rpm for 5 min. In 5 mL of aqueous methanol, the dried sample was dissolved and mixed with 2.5 mL of Folin reagent, then in 50 mL volumetric flask, 10 mL of sodium carbonate solution was added and the volume was adjusted by deionized water. The absorbance was measured at 765 nm after 30 min. The results were expressed as mg gallic acid equivalent (GAE/100 g of oil samples) using gallic acid calibration curve.

2.2.7 Antioxidant activity by DPPH method

Antioxidant activities of the extracts, as well as a standard sample of ascorbic acid, were evaluated through using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical assay as reported by Naeem *et al.* (2019). Two mL of 0.1 mM DPPH of the methanolic solution was added into 20, 40, 60, 80 and 100 μg of the extracts and then 1 mL methanol was added. The mixture was thoroughly mixed and kept in a dark place for 30 min. The control was prepared by mixing 1.5 mL of DPPH and 1 mL methanol. Ascorbic acid was considered a standard. The absorbance of the mixture was recorded at 517 nm using a spectrophotometer (Shimadzu UV-2550; Shimadzu, Kyoto, Japan) and percentage inhibition was calculated from the following equation:

$$DPPH\ inhibition\ (\%) = \frac{A_{Control} - A_{Sample}}{A_{Control}} \times 100. \quad (2)$$

The antioxidant activity of the extracts expressed as IC_{50} values, which is calculated from the inhibition percent versus concentration plot. The IC_{50} value indicates concentration (in μg mL^{-1}) of the extract, which is required to scavenge 50% of DPPH free radicals.

2.2.8 Radical scavenging activity by ABTS method

The ABTS assay is colorimetric based on the ABTS cation radical formation (Otieno *et al.*, 2016). The radical formation was catalyzed by the reduction of hydrogen peroxide. The ABTS cation radical exhibits a change of color from slightly yellow to an intensely turquoise-colored solution with an absorbance at 734 nm. The radical cation $ABTS^+$ is generated by persulfate oxidation of ABTS. A mixture (1:1, v/v) of ABTS (7.0 mM) and potassium persulfate (2.45 mM) was mixed and allowed to stand 16 h at room temperature in a dark place to form radical cation $ABTS^+$ (Blue-green color). A working solution was diluted with ethanol to the absorbance value of 0.7 at 734 nm. An aliquot of 100 μL of each sample was mixed with the working solution (2.9 mL) and the decrease of absorbance was measured at 734 nm after standing 6 min at room temperature in the dark. Ethanol (3 mL, without $ABTS^+$ solution) was used as the control. Percentage ABTS inhibition was calculated using the formula:

$$ABTS\quad inhibition\ (\%) = \frac{A_{Control} - A_{Sample}}{A_{Control}} \times 100. \quad (3)$$

2.2.9 Oxidative stability of sesame oil samples (Rancimat test)

For determination of oxidative stability of oils, AOCS Official Method Cd 12b-92 (AOCS, 1997) was used. The test

Table 2. Combined analysis of variance and covariance of a randomized complete block design for 2017 and 2018 seasons.

		ANOVA		ANOCOVA	
Source of variation	D.F	MS	Expectation of MS	Mean cross product	Expectation of M.C.P
Environments (years)	$n-1$	Ma	$\sigma^2e + r\,\sigma^2gs + rn\,\sigma^2g$	Mp a	Cov e + r
Reps/years	$n\,(r-1)$	Mas	$\sigma^2e + r\,\sigma^2gs$	Mp as	Covgs + rnCov g
Genotypes	$a-1$	Me	σ^2e	Mp	Cov e + r
Environ. × genotypes	$(n-1)\,(a-1)$				Covgs
Error	$n(r-1)(a-1)$				Cov e

Table 3. Individual and combined analysis of variance in the three years for six sesame genotypes.

S.O.V	df	Plant height	Fruiting zone	No. branches	No. capsules	Seed yield/plant	Seed yield (ton/ha)	Seed index	Oil yield (ton/ha)
2017									
Rep	2	12.5	9.39	1.06	16.72	0.06	0.003	0.01	0.004
Gen.	5	525.07**	163.82*	4.09**	3426.86**	11.32**	0.090**	0.53**	0.23**
Error	10	5.17	21.66	0.26	26.66	0.16	0.002	0.00	0.002
2018									
Rep	2	12.06	18.17	0.17	51.72	1.92	0.01	0.00	0.01
Gen.	5	867.92**	399.97*	3.87**	1619.16**	8.95	0.05	0.52**	0.32**
Error	10	74.52	84.63	0.43	9.59	2.33	0.01	0.00	0.02
Combined									
Years	1	4.69**	7950.69**	0.44	90.25**	75.40**	1.92**	0.00	2.48**
Rep/Y	4	12.28	13.78	0.61	34.22	0.99	0.01	0.01	0.01
Gen.	5	1320.36**	460.63**	6.11**	4560.23**	17.09**	0.13**	1.05**	0.52**
Gen. X Y	5	72.63**	103.16	1.84**	485.78**	3.18**	0.01**	0.054	0.02
Error	20	48.84	53.14	0.34	18.12	1.24	0.01	0.002	0.01

was performed on an automated Metrohm™ Rancimat model 743 (Herisau, Switzerland) at 110 ± 0.1 °C and an airflow of 20 L h^{-1}, to determine the induction period (IP) of the oil samples.

2.3 Statistical analysis

The values of the means were statistically analysed using SPSS computer software (version 17.0, 2009). The calculation comprised by analysis of variance one-way ANOVA and followed by TUKEY honesty test according to Steel *et al.* (1997). According to the homogeneity test, the results of 2017 and 2018 did not differ significantly. The data of the two seasons were combined and analysed as such. The individual and combined analyses of variance over two years were performed for studied traits. The analyses were used to estimate the phenotypic, genotypic, environmental variances, heritability, genotypic (GCV) and (PCV) coefficients of variability. Coefficients of phenotypic correlations between each pair of studied traits were also estimated in Table 2.

Where: n, r and a number of environments, replications and genotypes, respectively. Phenotypic variance σ^2ph was computed according to the following formula:

$$\sigma^2\mathrm{ph} = \sigma^2\mathrm{g} + (\sigma^2\mathrm{gs} / \mathrm{n}) + (\sigma^2\mathrm{e} / \mathrm{rn}), \quad (4)$$

Where, r = number of replicates; n = number of environment (years), σ^2gs = (Mas − Me)/r, and σ^2e = Me (error mean square).

Genotypic and Phenotypic covariance were calculated in the same way. Genotypic and phenotypic coefficients of variance were calculated according to Burton (1951) as follows:

$$\mathrm{G.C.V.} = (\sigma\mathrm{p} / \mathrm{X}) \times 100, \text{ and P.C.V.} = (\sigma\mathrm{g} / \mathrm{X}) \times 100. \quad (5)$$

Broad sense heritability (H) was calculated as described by Hanson (1963) using the following formula:

$$\mathrm{H} = (\sigma^2\mathrm{g} / \sigma^2\mathrm{ph}) \times 100. \quad (6)$$

3 Results and discussion

3.1 Agronomic characteristics

3.1.1 Variance and means

The individual and combined analysis of variances (Tab. 3) showed that the genotype variance was significant for all the studied traits except seed yield/plant in season 2018.

Table 4. Mean values of yield and related characters as affected by sesame genotypes (combined analysis over 2017 and 2018 seasons.

Parameters	Sesame genotypes						Mean	Range	
	G1 (Control)	G2	G3	G4	G5	G6		Min	Max
Plant height (cm)	170.33^{d}	208.50^{a}	199.17^{ab}	186.33^{c}	208.83^{a}	189.00^{bc}	193.69	170.33	208.83
Length of the fruiting zone (cm)	123.50^{a}	121.67^{a}	115.83^{ab}	105.50^{b}	105.67^{b}	104.00^{b}	112.69	104.00	123.50
Number of branches/plant	1.00^{c}	3.83^{a}	3.00^{ab}	2.67^{b}	3.50^{ab}	3.33^{ab}	2.89	1.00	3.83
Number of capsules/plant	144.50^{b}	153.33^{a}	127.50^{c}	97.67^{e}	106.83^{d}	83.00^{f}	118.81	83.00	153.33
Seed yield/plant (g)	29.78^{bc}	32.60^{a}	30.83^{b}	27.70^{d}	30.30^{b}	28.83^{c}	30.01	27.7	32.60
Seed yield (ton/ha)	1.91^{a}	1.86^{a}	1.56^{c}	1.95^{a}	1.73^{b}	1.75^{b}	1.75	1.56	1.95
Seed index (1000 seed weight in g)	3.75^{c}	4.24^{a}	3.59^{d}	4.24^{a}	3.99^{b}	3.19^{e}	3.84	3.19	4.24
Oil yield (ton/ha)	0.814^{b}	0.858^{ab}	0.610^{c}	0.964^{a}	0.966^{a}	0.945^{a}	0.859	0.610	0.966

Values in the same row followed by different letters are statistically different at the 95% confidence level.

Moreover, the difference between years was significant for all the studied traits except seed index. The genotypes/year interaction was highly significant for all studied traits except length of fruiting zone, seed index, seed yield/ha and oil yield/ha which was not significant. These results reflect the importance of genotypes as a source of variance. Many researchers observed high variance for yield component traits among sesame genotypes, in addition they found an important role of sesame genotypes as a main source of variance (Sankar and Kumar, 2003; Gnanasekaran *et al.*, 2008). In addition, the genotype and climate changes (rainfall and temperature) could have played an effect, for example, unusually high temperatures through short intervals of time could significantly negatively affect crop growth and yield (Wheeler *et al.*, 2000).

3.1.2 Morphological characteristics

Wide range of variability was recorded for some morphological characters in Table 3. The differences among genotypes were significant for plant height; length of fruiting zone; the number of branches/plant, and number of capsules/plant. The overall averages of plant height, Length of the fruiting zone number of branches/plant and the number of capsules/plant were 193.69, 112.69, 2.89 and 118.81 respectively. The range of plant height was from 170.33 for G1 to 208.83 for G5. All genotypes were taller than that of G1. Results showed that G1 and G2 had significantly higher length of fruiting zones compared with G4, G5 and G6 whereas there were no statistical differences between G3 and the rest of the genotypes (Tab. 4). With respect to a number of branches/plant ranged from 1.00 for G1 to 3.83 for G2. The results revealed that there was a wide range in a number of capsules/plant varied from 83.00 to 153.33 with an average of 118.81. The G2 produced the highest number of capsules/plant (153.33) followed by G1 (144.50) whereas G6 gave the lowest number of capsules/plant being 83.00.

Similar results have been reported by Hassan and Sedeck (2015); Abd El-Rhman and Shafi (2016) for seed yield/plant, oil yield/plant, number of capsules/plant and number of branches/plant, Hika *et al.* (2015) for biological yield per plant.

3.1.3 Yield contributing characteristics

Mean performances and range for seed yield/ha, seed yield/plant, the seed index and oil yield/ha of six sesame genotypes over the two seasons are presented in Table 4. Results in Table 4 revealed that all genotypes had significantly seed yield/plant whereas no statistical differences were found between G1, G3 and G5. The data presented in Table 4 showed that seed yield was high in G2, G3 and G5, could it be explained by the high plant height, number of branches/plant and numbers of capsules/plant (Abd-Elsaber and Teileb, 2019).

Significant difference in oil yield/ha was detected among sesame entries over two seasons. Seed yield/ha ranged from 1.56 ton for G3 to 1.95 ton for G4. The G4 significantly exceeded the yield of G1 by about 1.7%; it ranked the first in seed yield/plant, number of branches/plant, number of capsules/plant and seed index, and the second-highest genotype in the length of the fruiting zone and oil yield/ha. Results showed that G5, G4 and G6 had significantly higher oil yield compared with G2 and G6, whereas while G3 recorded the lowest oil yield by 0.61 ton/ha (Tab. 4). The obtained results by Hassan and Sedeck (2015), Abd El-Rhman and Shafi (2016), Abd-Elsaber *et al.* (2018) were in same manner of most studied traits.

3.1.4 Genetic effect

The estimates of genetic variance (σ^2g), phenotypic (σ^2ph) and environment (σ^2e) variance, genotypic (GCV) and phenotypic (PCV) coefficient of variability broad-sense heritability and expected genetic advance (GS) under 5% selection on the intensity and as a percentage of the general mean (GS%) are presented in Table 4. The highest values of phenotypic, genotypic and environment variances ware 834.96, 679.07 and 155.89 for the number of capsules/plant and 215.88, 207.96 and 7.93 for plant height. On the other hand, seed yield/ha had the lowest value of phenotypic, genotypic and environment variances were 0.021, 0.021 and 0.0, respectively. These results are in confirmatory with these of Kumar and Sasivannan (2006), El-Shakhess *et al.* (2008), Abd-Elsaber and Teileb (2019).

The extent of the coefficient of variation indicated that high estimates of (PCV) and (GCV) were exhibited for the number of branches/plant and number of capsules/plant. The GCV for the number of branches/plant and number of capsules/plant were 29.19 and 21.93 respectively, suggesting a wide spectrum of genotypic variation for these traits. Low magnitude GCV and PCV were observed for seed yield/plant, plant height and length of the fruiting zone.

Table 5. The genetic effects on yields and some agronomic characters of six sesame genotypes over 2017 and 2018 seasons.

Characters	Component of variance			Genetic variability		$h^2b\%$	Genetic advance	
	σ^2g	σ^2ph	σ^2e	PCV	GCV		GS	GSM
Plant height	207.96	215.88	7.93	7.59	7.45	96.33	29.20	15.07
Length of fruiting zone	59.58	76.25	16.67	7.75	6.85	78.13	14.08	12.49
Number of branches/plant	0.71	1.21	0.50	38.09	29.19	58.72	1.33	46.14
Number of capsules/plant	679.07	834.96	155.89	24.32	21.93	81.33	48.48	40.81
Seed yield/plant	2.32	2.96	0.65	5.74	5.07	78.19	2.78	9.26
Seed yield/ha	0.021	0.021	0.00	8.155	8.108	98.833	0.297	16.628
Seed index (1000 seed weight)	0.16	0.17	0.02	10.90	10.34	90.03	0.78	20.25
Oil yield/ha	0.016	0.016	0.000	14.91	14.88	99.56	0.26	30.63

σ^2g = genetic variance; σ^2ph = phenotypic variance; σ^2e = environmental variance.

Table 6. Gross chemical composition of sesame genotypes.

Parameters	Sesame genotypes					
	G1 (control)	G2	G3	G4	G5	G6
Moisture content (%)	$5.83^{a} \pm 0.11$	$4.51^{d} \pm 0.12$	$5.27^{c} \pm 0.15$	$5.66^{b} \pm 0.34$	$5.82^{a} \pm 0.31$	$5.15^{d} \pm 0.17$
Oil content (%)	$41.12^{d} \pm 2.20$	$45.65^{c} \pm 1.94$	$39.56^{de} \pm 1.23$	$47.58^{b} \pm 1.74$	$54.64^{a} \pm 3.87$	$54.13^{a} \pm 0.29$
Protein (%)	$27.33^{a} \pm 0.58$	$26.16^{b} \pm 0.22$	$24.2^{d} \pm 0.44$	$25.07^{c} \pm 0.15$	$26.56^{b} \pm 0.15$	$26.22^{b} \pm 0.15$
Ash (%)	$4.80^{b} \pm 0.10$	$4.78^{b} \pm 0.06$	$5.07^{a} \pm 0.05$	$4.11^{b} \pm 0.06$	$5.72^{a} \pm 0.17$	$5.15^{a} \pm 0.17$
Crude fibre (%)	$3.31^{c} \pm 1.53$	$4.01^{b} \pm 1.32$	$4.33^{ab} \pm 0.51$	$3.93^{c} \pm 0.58$	$4.17^{b} \pm 0.55$	$4.67^{a} \pm 0.55$
Carbohydrate (%)*	$26.75^{b} \pm 1.03$	$23.41^{c} \pm 0.49$	$31.17^{a} \pm 0.29$	$23.24^{c} \pm 0.38$	$13.08^{d} \pm 1.08$	$14.5^{d} \pm 1.08$

*Calculated by difference; the values followed by the same letter (in each row) are not significantly variance ($p \leq 0.05$).

For heritability estimates, data in (Tab. 5) indicated that four traits out of eight recorded the highest heritability values over 90%. These traits were oil yield/ha (99.56%), seed yield ton/ha (98.83%), plant height (96.33%) and seed index (90.03%). Meanwhile, the rest of the studied characters showed relatively medium intermediate heritability percentage such as the number of branches/plant (58.72%).

The number of capsules plant had the highest estimated of genetic advance coupled with high broad-sense heritability thus, these characters seem to be highly heritable, points to the predominance of additive gene effect, easily fixable and can be taken as unit characters for effective selection. Length of fruiting zone and seed yield/plant expressed moderate heritability and low genetic advance, indicating the role of non-fixable genetic variance in the expression of these traits. These results were in harmony with that obtained by Kumar and Sasivannan (2006), Iwo *et al.* (2007), Ahmed *et al.* (2013), and Abd-Elsaber and Teileb (2019).

3.2 Approximate chemical composition of sesame genotypes

The proximate chemical composition of different sesame genotypes was shown in Table 6. The results obtained in Table 6 showed that there are slight differences between all the different sesame genotypes in moisture content, where the results revealed that the G2 is the lowest in moisture content (4.51%), while the control sample showed the highest moisture content (5.83%). Alege and Mustapha (2013) reported, in the study of 23 genotypes of Nigerian sesame, that moisture contents ranged from 0.25 to 3.00%. Whereas, they are less than the ratios obtained in our samples, this difference may be due to the genetic variation, weather, location and the environment. The crude oil content of sesame genotypes ranged from 39.56 to 54.64% of dry weight. Significant differences in sesame oil content were observed among the genotypes. G5 showed the highest content of oil followed by G6, G4 and G2, while G3 was the lowest in oil contents. The composition of the sesame seed is dependent on genetic, environmental factors, genotype, cultivation, climate, ripening stage, the harvesting time of the seeds and the analytical method used (Yasothai 2014; Rababah *et al.*, 2017; Ahmed *et al.*, 2018). G5 was characterized by its higher protein content (26.56%) after G1 (control) and G6 recorded 26.22% followed by G2 (26.16%) then G4 (25.07%), and finally G3 (24.20%), respectively. The tested genotypes G2, G3, G4, G5 and G6 showed no significant ($p \leq 0.05$) difference content in ash (4.78, 5.07, 4.11, 5.72 and 5.15%, respectively) as compared with control (4.80%). The fibre content of the G6 sample increased significantly to the highest level (4.67%) and decreased to the lowest level (3.31%) in control genotype. Finally, Carbohydrate content calculated by difference and the results clarified that G5 genotype recorded the lowest level (13.08%) while the sample of G3 genotype recorded the highest level (31.17%). These results are approached with that obtained by Onsaard (2012), Prakash and Naik (2014), Yasothai (2014), and Rababah *et al.* (2017).

Table 7. Physicochemical properties of oil extracted from different sesame genotypes.

Properties	Sesame oil					
	G1 (control)	G2	G3	G4	G5	G6
Refractive index	$1.4661^{b} \pm 0.001$	$1.4711^{a} \pm 0.001$	$1.4711^{a} \pm 0.001$	$1.4692^{b} \pm 0.001$	$1.4707^{a} \pm 0.001$	$1.4677^{b} \pm 0.001$
Acidity % (as oleic acid)	$0.33^{c} \pm 0.02$	$0.35^{b} \pm 0.02$	$0.32^{d} \pm 0.01$	$0.37^{a} \pm 0.02$	$0.28^{e} \pm 0.01$	$0.31^{d} \pm 0.01$
Peroxide value (mEq./kg)	$1.34^{b} \pm 0.12$	$1.12^{b} \pm 0.09$	$1.17^{b} \pm 0.16$	$2.87^{a} \pm 0.32$	$1.01^{b} \pm 0.03$	$1.67^{b} \pm 0.11$
Iodine value (g/100g)	$106.53^{b} \pm 0.32$	$105.95^{bc} \pm 0.18$	$105.38^{bc} \pm 0.13$	$108.39^{a} \pm 0.08$	$106.92^{b} \pm 0.67$	$104.95^{c} \pm 0.38$
Unsaponifiable matter (g/100g)	$1.22^{c} \pm 0.13$	$1.18^{b} \pm 0.14$	$1.11^{b} \pm 0.12$	$0.92^{a} \pm 0.17$	$1.65^{d} \pm 0.15$	$0.99^{a} \pm 0.35$
Total phenolic content, TPC (mg/g)	$13.66^{b} \pm 0.88$	$2.80^{d} \pm 0.44$	$13.98^{b} \pm 0.44$	$4.97^{d} \pm 0.89$	$18.32^{a} \pm 0.40$	$11.49^{c} \pm 0.31$

The values followed by the same letter (in each row) are not significantly variance ($p \leq 0.05$).

3.3 Physicochemical properties of oil extracted from different sesame genotypes

3.3.1 Oil characteristics

The results obtained from the study are presented in Table 7. The Data shows the values of the oil properties measured from the extracted oil from different sesame genotypes. Refractive indices (RI) of sesame oil extracted from different genotypes were slightly significantly varied. The values of RI obtained from sesame oil samples are similar to those of a wide range of vegetable oils. The higher values of the characteristics reported for the crude oils revealed the necessity to purify the oils. As reported by Bello and Olawore (2012) and Aniołowska *et al.* (2016) the high RI values of oil due to the presence of long-chain fatty acids.

Acid value can catalyse oxidative decay of oils by enzymatic and chemical hydrolysis to form off volatile components. The free fatty acid percent refers to the possible hydrolytic retrogression of the oil (Zahran and Tawfeuk, 2019). The acidity % (as oleic acid) of the sesame oil samples ranged from 0.28 to 0.37% (Tab. 7), the data revealed that there are low significance variations between sesame samples. Based on the foregoing, we have noticed that the difference in the content of free fatty acids of different samples may not be related to the genotype, but it may be accidental.

Peroxide value is an indicator of peroxidation, and therefore the high peroxide value of the oil is a hint to a weak oil resistance to peroxidation during storage and signals to a deterioration level (Adebayo *et al.*, 2012; Mohamed *et al.*, 2018). The peroxide number of different genotypes of sesame oil have significantly the highest value of 2.87 mEq./kg for G4, while found the lowest value of 1.01 mEq./kg for G5 (Tab. 7). The peroxide value of all genotypes was in acceptable values (maximum acceptable value of 10 mEq./Kg set by the Codex Alimentarius Commission (1999).

The data in Table 7 showed that the iodine value of sesame genotypes ranged from 104.95 to 108.39 g/100g oil in all genotypes. The highest iodine value was found in G4 and the lowest in G6. The iodine number was used to define the degree of unsaturation and stability of sesame oil samples (Naeem *et al.*, 2019). Earlier, it was suggested that the iodine value should not be too high because it will increase the rate of oxidation and it should also not be too low, because it will affect its physical property (Sher and Hussain, 2009).

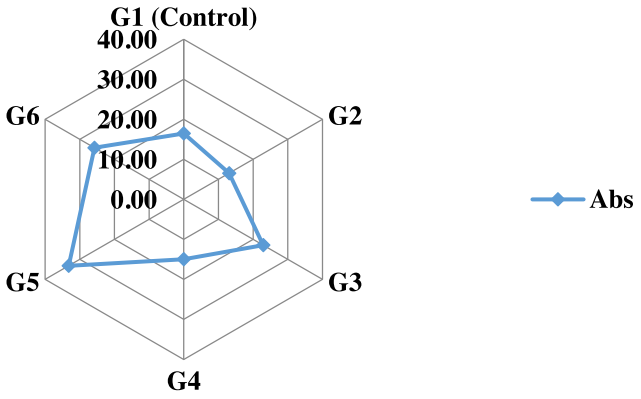

Fig. 1. Photometric colour index of different sesame oil samples.

The presence of unsaponifiable matter directly affected the oxidative stability of vegetable oils (Abou-Gharbia *et al.*, 2000). Unsaponifiable matter content of sesame oil samples ranged from 0.92 to 1.65 g/100g, the highest value of unsaponifiable matter was found in G5 (1.65 g/100g) followed by G1 (control), G2 and G3, however, G6 and G4 were in lowest levels of unsaponifiable matter content. The unsaponifiable matter content varied significantly ($p \leq 0.05$) in all genotypes.

Photometric color index (PCI) of sesame oil samples was shown in Figure 1. The spectrophotometric measurement has been proposed to establish a method to control the decolorization of oils. The absorption spectrum changes considerably as a function of the relative percentages of pigments occurring in them (Borello and Domenici, 2019). A large part of fluorescence in vegetable oils is caused by the presence of chlorophyll groups, β-carotene and tocopherols. (Nikolova *et al.*, 2012). From the results in Figure 1, G5 has the highest absorption, as well as the highest oxidative stability (IP = 26.57 ± 0.27 h) in comparison with the other samples, this is maybe due to the presence of β-carotene and tocopherols.

3.3.2 Total phenolic content (TPC)

The obtained data revealed that the level of total phenolic content (TPC) of sesame oil samples was shown in Table 7. The TPC of different samples was varied significantly ($p \leq 0.05$) and ranging from 2.80 ± 0.44 to 18.32 ± 0.40 mg GAE g^{-1}. G5 showed the highest in TPC (18.32 ± 0.40 mg

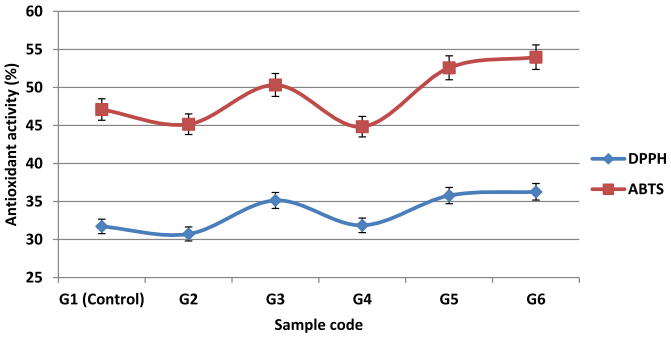

Fig. 2. Means antioxidant activities and standard errors ($n = 3$) of sesame oil samples by DPPH and ABTS radical scavenging activity.

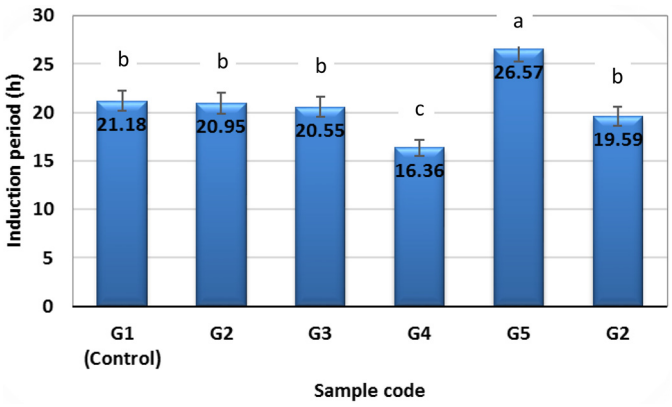

Fig. 3. Means induction time (h) and standard errors ($n = 3$) of sesame oil samples by Rancimat test.

Table 8. Fatty acid profile of sesame oil genotypes.

Fatty acids	Area (%)					
	G1 (control)	G2	G3	G4	G5	G6
Palmitic acid ($C_{16:0}$)	9.15^{a}	8.87^{b}	8.79^{b}	8.69^{bc}	8.32^{d}	8.47^{c}
Palmitoleic acid ($C_{16:1}$)	0.49^{b}	0.10^{c}	0.18^{c}	1.11^{a}	0.14^{c}	0.13^{c}
Stearic acid ($C_{18:0}$)	6.36^{c}	6.72^{b}	6.57^{b}	7.27^{a}	6.59^{b}	6.65^{b}
Oleic acid ($C_{18:1}$)	43.24^{b}	42.67^{b}	45.33^{a}	37.15^{c}	45.49^{a}	46.61^{a}
Linoleic acid ($C_{18:2}$)	40.76^{b}	41.03^{b}	38.40^{c}	44.33^{a}	38.82^{c}	37.49^{d}
Linolenic acid ($C_{18:3}$)	ND	ND	ND	0.91^{a}	ND	ND
Arachidic acid ($C_{20:0}$)	ND	0.61^{bc}	0.74^{a}	0.55^{c}	0.64^{b}	0.66^{b}
$\sum$ of Saturated fatty acids (%) (SFA)	15.51^{c}	16.20^{ab}	16.09^{b}	16.51^{a}	15.55^{c}	15.78^{bc}
$\sum$ of Unsaturated fatty acids (%) (USFA)	84.49^{a}	83.80^{bc}	83.91^{b}	83.50^{c}	84.45^{a}	84.22^{ab}
MUFA	43.73^{b}	42.77^{b}	45.51^{a}	38.26^{c}	45.63^{a}	46.73^{a}
PUFA	40.76^{b}	41.03^{b}	38.40^{c}	45.24^{a}	38.82^{c}	37.49^{c}
USFA/SFA	5.45	5.17	5.21	5.06	5.43	5.34

**Nd = Not detectable; the values followed by the same letter (in each row) are not significantly variance ($p \leq 0.05$).

GAE g^{-1}), while the lowest was observed in oil G2 (2.80 ± 0.44 mg GAE g^{-1}), which has a significant difference ($p \leq 0.05$) is compared with other samples (Tab. 7). This study showed that sesame oil samples of different genotypes varied phenolic contents. Many scientists concluded that there is a positive correlation between the antioxidant activity and content of phenolics (Wang *et al.*, 2017).

3.3.3 Antioxidant activity by DPPH and ABTS method

The effect of sesame genotype on antioxidant activity of sesame oil whether using DPPH or ABTS free radical scavenging activity (Fig. 2). The results showed that G6 exhibited the highest DPPH and ABTS scavenging activity (36.27 and 53.98%, respectively) followed by G5 with DPPH and ABTS radical scavenging activity by 35.78 and 52.58%, respectively. From the graph in Figure 2, we notice that the variation of genotypes affected significantly the antioxidant activity of sesame extracted oil. Elhussein *et al.* (2018) concluded that lipid oxidation of sesame oil is greatly affected by the presence of phytonutrients, as well as its origin. When these appropriate correlations hold, we could conclude that phenolic compounds in sesame oil are predominantly responsible for its antioxidant activity.

3.4 Fatty acid composition

The variances among the sesame genotypes were statistically significant (at level $p \leq 0.05$) for saturated fatty acids such as palmitic ($C_{16:0}$), stearic ($C_{18:0}$) and arachidic ($C_{20:0}$) acids in all genotypes. The ranges of fatty acids differ from 8.32 to 9.15% of palmitic acid ($C_{16:0}$), 6.36 to 7.27% of stearic acid ($C_{18:0}$) and 0.55 to 0.74% of arachidic acid ($C_{20:0}$) but we found that arachidic acid was not detected in control genotype (Tab. 8). Statistically little significant variances between sesame genotypes were showed for saturated fatty acids in all sesame genotypes under study. The chief saturated fatty acids are palmitic acid (7–12%) and stearic acid (3.5–6%). The data obtained by Mehta (2000) was in the same manner of our obtained data.

For unsaturated fatty acids, statistically significant variances ($p \leq 0.05$) were found between sesame genotypes for the major unsaturated fatty acids such as oleic ($C_{18:1}$) and

linoleic acid ($C_{18:2}$) percentage in all genotypes. According to different species, the palmitoleic acid ($C_{16:1}$) percentage ranged from 0.10 to 0.49%, the oleic acid ($C_{18:1}$) percentage ranged from 37.15 to 46.61%, linoleic acid ($C_{18:2}$) content ranged from 37.49 to 44.33%, and linolenic acid ($C_{18:3}$) were not detected in all genotypes except in G4 was 0.91% (Tab. 8). In this investigation, a variation among the sesame species was in observed for oleic acid ($C_{18:1}$) and linoleic acid ($C_{18:2}$) percent. The predominant unsaturated fatty acids are oleic (35–50%) and linoleic acid (35.5–41.2%) (Mehta, 2000). Unsaturated fatty acids have a favourable effect and positive health benefit than saturated fatty acids (Soliman *et al.*, 2019), The fatty acid composition of sesame oil was within the range of the results reported by Elleuch *et al.* (2007) and Uzun *et al.* (2002). Total of saturated fatty acids (SFA) ranged from 15.51 to 16.51%, on the other hand, a total of unsaturated fatty acids (USFA) ranged from 83.50 to 84.49%.

3.5 Oxidative stability of sesame oil samples

The oxidative stability of the vegetable oil is a marker of quality and integrity for their potential applications and utilization in foods, and it depends especially on the fatty acid composition, as well as the content of antioxidant of these oils (Abdelazim *et al.*, 2013; Zahran and Soliman, 2018). According to the results of oxidative stability, it was found that the sesame samples have a wide range of induction period (IP), which ranged from 16.36 ± 0.32 to 26.57 ± 0.27 h (Fig. 3), as measured by Rancimat at 110 °C. Sesame oil extracted from G5 (Imported 554) had the highest IP (26.57 ± 0.27 h), followed by G1, G2, G3 and G6 with IP 21.18 ± 0.24, 20.95 ± 0.61, 20.55 ± 0.12 and 19.59 ± 0.19 h, respectively. However, the G4 had the lowest IP (16.36 ± 0.32 h). The variation of stability in sesame oil samples may be due to the presence of unique unsaponifiable constituents namely lignans and tocopherols (Abou-Gharbia *et al.*, 2000).

4 Conclusion

This investigation was carried out to characterize six sesame genotypes during two successive seasons, 2017 and 2018. The results indicated that G4 was the highest in most traits under study. High estimates of (PCV) and (GCV) were exhibited for the number of branches/plant and number of capsules/plant. The high heritability was exhibited for seed yield/ha, plant height, oil yield/ha, and seed index. The number of capsules/plants that had the highest estimated of genetic advance coupled with high broad-sense heritability thus, these characters seem to be highly heritable, points to the predominance of the additive gene effect, easily fixable and can be taken as a unit character for effective selection. From this study, it could be concluded that the oil extracted from different sesame genotypes meet the international quality standards in terms of oil content and fatty acid composition. The sesame oil in particular G5 had the highest oxidative stability due to the presence of the high amount of unsaponifiable matter. The existence of high amounts of unsaturated fatty acids (oleic & linoleic acids) as compared to saturated fatty acids, support the convenience of the investigated sesame genotypes for nutritional applications.

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