

Performance and genetic diversity of some sesame (*Sesamum indicum* L.) accessions based on morpho-agronomic traits and seed proximate composition in Kwara State of Nigeria

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Performance and genetic diversity of some sesame (*Sesamum indicum* L.) accessions based on morpho-agronomic traits and seed proximate composition in Kwara State of Nigeria

Abstract: This study evaluates eleven sesame accessions in Nigeria for performance and genetic diversity using morpho-agronomic traits, chlorophyll contents and nutrient composition in a complete randomized experimental design with five replicates. The results showed 'Igboho Black', '02M' and 'Kenan 4' had the best growth attributes. Although 'NGB0090' and 'Exsudan' matured early, 'E8', 'Bogoro Local' and 'Kenan 4' had the best yield attributes. Seeds produced were predominantly milky-white, an accession had black seeds, while three produced white seeds. Plant height positively correlated with number of leaves and leaf area as well as peduncle length. Days to 50 % flowering positively correlates with days to maturity. So also the number of capsule per plant, capsule dimension and seeds per capsule. The moisture content in seeds of the accessions was < 3.5 %, ash (4.5-5.9 %), crude protein (5.3-7.4 %), fat and oil (53.6-60.5 %), and carbohydrate < 30 %. Out of the eight components that accounted for the observed variations, the PC-1 and PC-2 contributed 65.42 %. The dendrogram revealed that 'NGB00960' and 'NGB00963' which had 'Kenan 4' as a distant member are the closest relatives, while 'NGB00390' and '01M' are the most diverse. The study concludes that the accessions are genetically and phenotypically varied and the existing diversity can be harnessed for selecting high yielding and adaptable variety for the development of improved cultivars.

Key words: chlorophyll content; genetic diversity; morphometric attributes; oilseed

Preučevanje uspevanja in genetske raznolikosti nekaterih akcesij sezama (*Sesamum indicum* L.) na osnovi morfoloških in agronomskih lastnosti ter zgradbe semen v državi Kwara, Nigerija

Izvleček: V raziskavi je bilo ovrednoteno sedem akcesij sezama iz Nigerije glede na uspevanje in genetsko raznolikost z uporabo morfološko-agronomskih lastnosti, vsebnosti klorofila in hranil v popolnem naključnem bločnem poskusu s petimi ponovitvami. Rezultati so pokazali da so imele akcesije 'Igboho Black', '02M' in 'Kenan 4' najboljše lastnosti. Čeprav sta 'NGB0090' in 'Exsudan' dozorevali zgodaj, so imele 'E8', 'Bogoro Local' in 'Kenan 4' najboljše lastnosti pridelka. Semena so bila pretežno mlečno bela, ena akcesija je imela črna semena, tri pa popolnoma bela. Višina rastlin je bila v pozitivni korelaciji s številom listov kot tudi z dolžino cvetnih pecljev. Dnevi potrebni do 50 % cvetenja so bili v pozitivni povezavi z dnevi do zrelosti. V podobni povezavi je bilo tudi število plodov na rastlino, dimenzija glavic in število semen na glavico. Vsebnost vlage v semenih je bila večja od 3,5 %, vsebnost pepela 4,5-5,9 %, celokupnih beljakovin 5,3-7,4 %, maščob in olj 53,6-60,5 % in ogljikovih hidratov več kot 30 %. Od osmih komponent, ki so pripispevale k ugotovljeni raznolikosti sta komponenti PC-1 in PC-2 priležali 65,42 %. Dendrogram je pokazal, da so 'NGB00960' in 'NGB00963', ki vključujeta oddaljeno akcesijo 'Kenan 4' najožji sorodniki, med tem, ko sta 'NGB00390' in '01M' najbolj raznoliki. Na osnovi raziskave je bilo ugotovljeno, da so akcesije genetsko in fenotipsko različne in da bi se njihova raznolikost lahko izkoristila za izbor visoko donosnih in prilagodljivih različic pri razvoju izboljšanih sort.

Gljučne besede: vsebnost klorofila; genetska raznolikost; morfometrične lastnosti; vsebnost olja v semenih

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1 INTRODUCTION

Sesame (*Sesamum indicum* L.) also known as 'ben-niseed' is an important member of the Pedaliaceae family. It is an ancient tropical crop of high economic importance, widely known for its seed edible oil. The origin of the cultivated sesame is controversial. There are claims that it originated in the Savannah of tropical Africa and was introduced into India and China by early humans (Purseglove, 1977; Naturland, 2002; Bedigian, 2004; Behera et al., 2017). There is also a concept of Indo-Asian centre of origin and diversity of sesame. While the presence of wild types and abundance supports Africa as the centre of origin (Ram et al., 1990), interspecific crosses and lignan analyses refuted the same (Bedigian et al., 1985; Bedigian & Harlan, 1986) and pointed at Indo-Asia origin of progenitor sesame.

The world sesame production is approximately 5.5 million metric tonnes, of which 70 % are produced in Asia while Africa accounted for about 26 %. African major producers include Ethiopia, Sudan, Uganda and Nigeria (FAOSTAT, 2011; Pathak et al., 2014). India ranks top in global sesame production followed by China (Anthony et al., 2015). However, the average yield per hectare is highest in China, followed by India, and Tanzania. Meanwhile, China is the world's largest consumer of sesame (FAOSTAT, 2020). Despite the peachy production of sesame in Nigeria, productivity is comparatively low. There is a need to accelerate its production through the use of improved genotypes and farming practices.

Sesame is a herbaceous annual plant that can grow up to 1.5 m in height. The fruit has many seeds enclosed in a capsule. The seeds are small, oval, and almost oblate in shape. They vary from cream-white to charcoal-black but often white or black and may also be, yellow, red or brown depending on the variety (Naturland, 2002; Bennet, 2011). Although sesame is adapted to various ecological conditions, it thrives better on well-drained, fertile soils. The temperature requirement is between 20-35 °C (Misganaw et al., 2015). Most varieties are drought and insect resistant with negligible economic loss from pests (Langham et al., 2008). The seed oil is rich in sesamol which is an important anti-oxidant, and polyunsaturated fatty acid that is safe for human and animal consumption (Ashri, 1998). Also, the oil is used majorly for cooking, for making margarine, soap, paints, lubricants and lamp fuel. The seeds are equally nutritious, containing protein (18–25 %), carbohydrate (about 13 %), calcium, phosphorus, iron, essential minerals and vitamins (Bedigian et al., 1985; Bedigian, 2004). Sesame seed contains more oil than major oilseed crops such as peanut and soybean (Ashri, 1998). However, seed oil quantity and quality may vary, depending on the genotype and growth condi-

tions (Myint et al., 2020). The medicinal usage of sesame oil as an anti-oxidant, anti-tumour, anti-cholesterol and anti-microbial agent have been reported (Sankar et al., 2005; Costa et al., 2007).

Sesame improvement to meet the growing demand for seed oil requires adequate knowledge of the genetic diversity and relationship among the available germplasm. The genetic diversity among sesame accessions and genotypes based on morphological parameters has been established from different studies conducted over the years (Bisht et al., 1998; Baydar, 2005; Arriel et al., 2007; Furat & Uzun, 2010; Parameshwarappa et al., 2010; Frary et al., 2015; Kiranmayi et al., 2016; Azeez et al., 2017; Iqbal et al., 2018). The authors reported significant variations among the genotypes studied and elucidated the genetic relationship among the accessions. Furthermore, more recently, Adu-Gyamfi et al. (2019) employed morphological traits in the assessment of the diversity of selected sesame genotypes cultivated in Northern Ghana. However, Nigerian accessions of sesame have not been well characterised, more so, the number of available accessions cannot be accurately ascertained. So there is a need to characterise as many accessions that are available to generate basal information that could be used for the crop cultivation and improvement

Although Nigeria is one of the leading producers of sesame in Africa, there is insufficient information on the diversity of sesame accessions in cultivation, hence only a little progress is made on sesame breeding and the development of elite cultivars in the country. To improve sesame production for seed and oil yield in Nigeria, there is a need for characterization, performance evaluation and assessment of genetic diversity of the available genotypes. To this end, the present study assessed the performance, morphometric variation, and proximate composition of eleven accessions of cultivated sesame (*S. indicum*) in the Kwara State of Nigeria with the view of identifying and selecting the best and promising accessions in terms of yield and nutritional quality that could be improved for higher productivity.

2 MATERIALS AND METHODS

2.1 COLLECTION OF THE SESAME ACCESSION

Eleven accessions of *Sesamum indicum* L. collected from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Oyo State, Nigeria were used for the study. NACGAB is the National Agency responsible for the collection, evaluation and conservation of genetic resources in Nigeria. The accessions (Igboho black, 02M, 03M, E8, 01M, Exsudan, Kenan 4,

NGB00960, NGB00963, Bogoro local and NGB00390) are part of the mini-core collection of cultivated sesame from the growing regions of Nigeria. The collections are maintained at NACGRAB genebank facility (All information and details of the accessions are available at NACGRAB, Nigeria).

2.2 THE EXPERIMENTAL SITE

The pot experiment was conducted at the University of Ilorin Botanical Garden, Ilorin, Kwara State, Nigeria. The garden is at the Latitude 8° 24'N - 8° 36'N and Longitude 4° 10'E - 4° 36'E in the Guinea savanna zone of Nigeria. The annual rainfall is 990-1200 mm and the temperature is between 33 – 37 °C (Olaniran, 1988; Ajadi et al., 2011). The relative humidity is about 75 % during the rainy season, and 65 % during the dry season. During the dry season (November – May), the sun shines for 6.5 - 7.5 hours per day (NIMET, 2018)

Ten clean and healthy seeds of each accession were sown separately into a pot (30 × 25 cm), filled with loose soil taken from 0-15 cm soil depth, from a location with distinct textural characteristics of sandy-loamy in the garden. The experiment was laid out in a complete randomized design (CRD) with 0.5 m between the pots in five replicates for each accession in a screen house facility. On germination, the seedlings were thinned to 2 plants per pot. Adequate watering and weeding practices were carried out as required. Meanwhile, no fertilizer or nutrient supplement was added to the plant through the weeks of evaluation. The performance of the accessions was evaluated at two-week intervals until 14 weeks after sowing (WAS) using the International Plant Genetic Resources (IPGRI, 2004) descriptors for sesame. The growth variables evaluated include; plant height, number of leaves per plant, leaf dimension, petiole length, number of primary branches and stem girth. Furthermore, at maturity data were collected on the flowers and seed related characters such as days to 50 % flowering, the number of flowers per plant, number of capsules per plant, capsule length and width, 1000-seed mass and mass of seeds per plant. Qualitative characters such as stem base colour, leaf and flower colour, seed colour and shape were also recorded.

2.3 CHLOROPHYLL AND CAROTENOID DETERMINATION

The photosynthetic pigment extraction and quantification were carried out as described by Porra et al. (1989). Fresh leaf samples collected from the accessions early in the morning were used for the pigment analy-

sis. In brief, chlorophyll extraction was performed by dipping 12.5 mg of each leaf sample into a sample bottle containing 3.5 ml acetone in five replicates. The set-up was left for 72 hours in a dark cupboard at room temperature, after 72 hours, the bottle was vigorously shaken, and then the bleached leaf was removed, leaving behind the leaf homogenates in the bottle. The chlorophyll and carotenoid contents were quantified using a spectrophotometer (Jenway, Model 6305, Bibby Scientific, USA). The amount of chlorophylls a, b, carotenoid, and total chlorophyll was calculated using the Porra et al. (1998) equations:

$$\text{- Chlorophyll a (mg ml}^{-1}\text{)} = [(12.21 \times A_{663}) - (2.81 \times A_{646})]$$

$$\text{- Chlorophyll b (mg ml}^{-1}\text{)} = [(20.13 \times A_{646}) - (5.03 \times A_{663})]$$

$$\text{- Total chlorophyll} = \text{Chlorophyll a} + \text{Chlorophyll b}$$

$$\text{- Carotenoids} = [(1000 \times A_{470}) - (3.27 \times \text{Chl.a}) - (104 \times \text{Chl.b})] / 198$$

Where *A* is the absorbance wavelength read from the Spectrophotometer.

2.4 DETERMINATION OF THE PROXIMATE COMPOSITION OF SESAME SEED

The proximate analysis followed the standard protocol of AOAC (2000). The moisture content was determined by oven-drying the seeds at 105 °C for 24 hours. The dried seeds were grounded and the moisture content was estimated. Crude lipid was extracted from the samples with petroleum ether as solvent using the Soxhlet apparatus technique, then the percentage crude lipid was determined as described in the protocol (AOAC, 2000). The nitrogen composition was determined by Micro-Kjeldahl's method using Electrothermal (Model MQ3868B/E, Fisher Scientific, Austria). The total nitrogen was estimated using the relationship $N \times 5.95$, and the resultant values are taken as the percentage crude protein of the seeds. The percentage of fibre and ash contents (% minerals) was also obtained using a standard procedure (AOAC, 2000). The total carbohydrate present in the seeds was derived by the differential method as:

$$\% \text{ Total carbohydrate} = 100 - (\% \text{ moisture} + \% \text{ crude protein} + \% \text{ crude lipid} + \% \text{ ash} + \% \text{ crude fibre})$$

2.5 STATISTICAL ANALYSIS

Data collected were subjected to Analysis of Variance (ANOVA) using SPSS statistical package version 21. The means were separated by New Duncan's Multiple Range Test (N-DMRT), and the probability value of 0.05

was used as a benchmark for separating a significant difference in the means. Growth and yield parameters were correlated using Genstat 19th Edition (Payne et al., 2007). Genetic relationship and cluster analysis were conducted, based on the agglomerative technique of the unweighted pair group of arithmetic average (UPGMA) method. The genetic relationships of the accessions were graphically presented as a dendrogram.

3 RESULTS

3.1 QUANTITATIVE GROWTH PARAMETERS OF THE ACCESSIONS

The plant height varied across the weeks of evalua-

tion (Fig. 1). The average plant height for the accessions are 2.45, 7.85, 21.11, 43.79, 57.61 and 61.03 cm for 2, 4, 6, 8, 10 and 12 WAS respectively. Accessions 02M, Kenan 4 and 01M had the best growth performance across the weeks. Four accessions (Igboho Black, 03M, E8 and Eksudan) recorded plant height below the average over the period (Figure 1a). At 2 WAS, 'Bogoro Local' had a 6.0 mean number of leaves per plant which is far higher than the average of 3.60 leaves per accession (Fig 1b). At the same time, 'Eksudan' had 1.60 leaves per plant. Similarly, at 4-12 WAS, 'Bogoro Local' maintained the best performance in terms of leaf formation while 'Eksudan' showed the least. Other accessions that exhibit good leaf formation are; Igoho Black, NGB00390 and 01M. Meanwhile, 03M, E8 and NGB00963 had the number of leaves less than the average. However, a fall was recorded for most

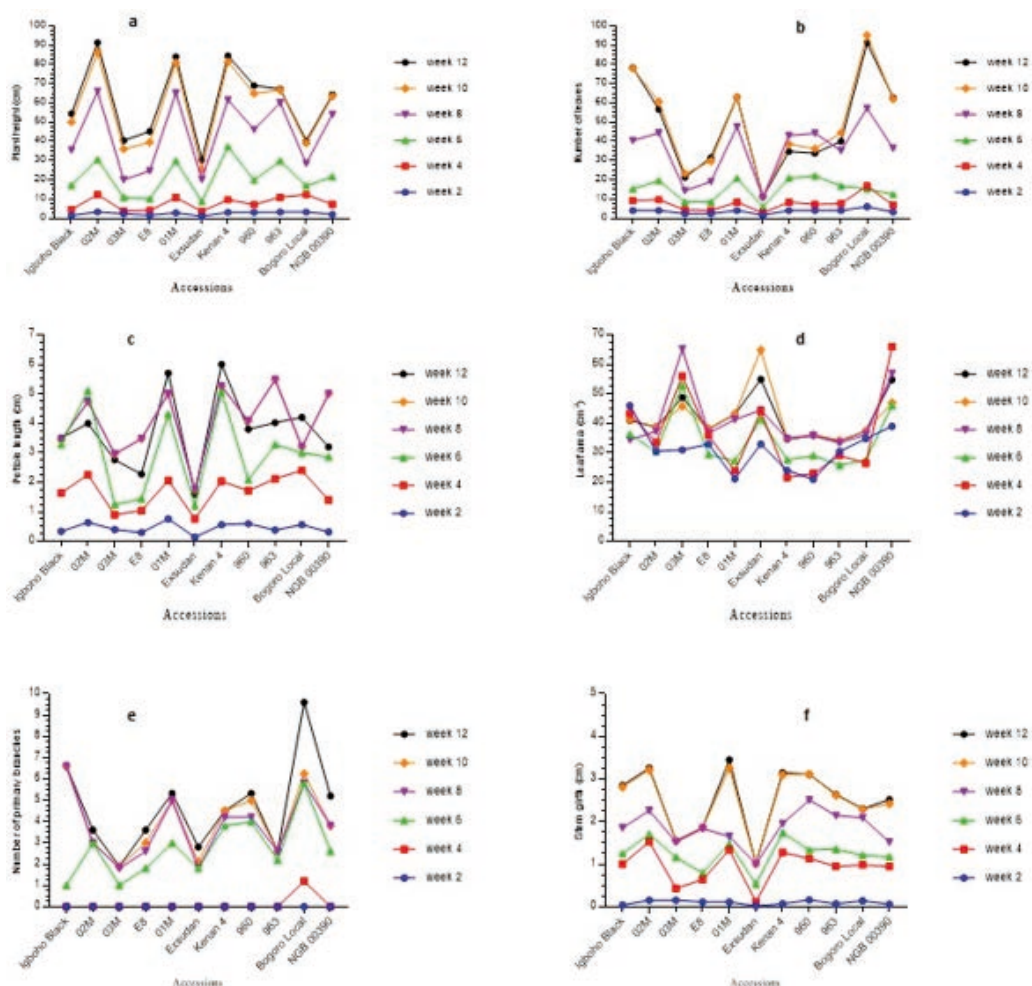


Figure 1: Growth parameters (2 – 12 weeks after sowing) of the eleven accessions of *Sesamum indicum* evaluated for variability and genetic diversity of accessions. Kenan 4 and 00960 were the first to begin senescence, observed from the 10 WAS, followed by six accessions (Bogoro Local, 00963, Kenan 4, 02M, NGB00960 and 03M) at 12 WAS with a corresponding decrease in stem girth. Bogoro Local had the highest number of primary branches, an average of 9.60, closely followed by Igboho black (6.65), 01M and NGB00960 both having 5.33. Altogether, Eksudan and 03M had the poorest performance in quantitative characters observed

accessions at 10-12 WAS, indicating the inception of senescence.

The petiole length was progressive till 10 WAS (Fig 1c). Five accessions (01M, 02M, Kena 4, NGB00960 and NGB00963) consistently had petiole length higher than the average. Worthy of mention is that 'Exsudant' which had the least number of leaves per plant also had the shortest petiole. The accessions were diverse in leaf area which did not follow a definite trend, though most accessions' leaf area was above the average (Fig 1d). However, at 8-12 WAS, '01M' had the largest assimilative surface followed by '02M' and 'Bogoro Local'. The least leaf area occurred in 'Exsudant' over the period. No branching occurred in the accessions at 2-4 WAS except 'Bogoro Local' that had 1.20 branches per plant. Only two accessions (NGB00960 and Bogoro Local) had the number of branches ≥ 4.0 per plant at 6 WAS, even at 8 WAS, only 1.80 branches were found on 'Exsudant' and 03M. More branches were observed in 'Igboho' black at 6-8 WAS reaching its peak in week 8 (6.60). Generally, the average number of branches for the accession was low across the weeks of evaluation (Fig 1e). Most accessions fell below the average, only four (Igboho Black, 01M, NGB00960 and Bogoro Local) had a higher number of branches. The stem diameter of the accessions progressed with the week of evaluation, with most accessions recording stem diameter above average, the least occurred in 'Exsudant' (Fig 1f).

At maturity, growth parameters varied significantly ($p < 0.05$) for the accessions (Table 1). The average plant height of the accessions was 62.19 cm, 'Igboho Black', '03M', 'E8', 'Exsudant', and 'Bogoro Local' plants are significantly short. The tallest accession (94.84 cm) was 02 M, while the Exsudant was the shortest (27.76 cm). Whereas 'Bogoro Local' was the best in terms of leaf formation with over 78 leaves per plant which is significantly higher than the accessions' average (31.54). In contrast, 'Exsudant' showed poor performance with just 8.66 leaves per plant. The accessions petiole length ranged from 1.60 to 6.01 cm, five accessions had petiole lengths greater than the average (3.85 cm), and the longest occurred in 'NGB00390'. Accession 01M produced leaves with the highest surface area (43.06 cm²). The 'Exsudant' which had the least number of leaves and shortest petiole also produced the smallest assimilatory surface (14.91 cm²). The most branched of the accession is Goboro Local with over 9 branches per plant. There are other five accessions (Igboho Black, 01M, Kenan 4, 00960 and NGB00390) with more than 4 branches per plant. Branch formation remained poor in '03M', attaining only 1.90 primary branches per plant at maturity which is well below the average of all accessions (4.65). The stem girth of the accessions was between 1.76 and 3.41 cm, while nine ac-

cessions had stem girth > 2 cm, two accessions (03M and Exsudant) had less (Table 1).

3.2 YIELD ATTRIBUTES PERFORMANCE

There are significant differences ($p < 0.05$) in the performance of the yield attributes of the sesame accessions. Among the accessions, E8 showed superior yield features (Table 2). Flowering was delayed in 'NGB00390' and 'Exsudant', both took longer days to attain 50 % flowering (54.25 and 50.11 days respectively). 'E8', 'Bogoro Local' and 'Kenan 4' attained 50 % flowering in 36.33, 37.35 and 39.56 days respectively, about a week earlier than the average (43.14 days) for the accessions. The average number of days to attain physiological maturity for the accessions was 100.96 days which was not significantly different. Whereas, 'NGB00390' matured much earlier at 89.33 days. The last accession to reach maturity was 02M (108.66 days), followed by 03M (105.54 days) and NGB00960 (104.28 days). The highest number of capsules per plant (56.66) occurred in 'E8', followed by 'Bogoro Local' (54.02 capsules). Although the average number of capsules per plant for the accessions was 40.84, however, seven accessions (Igboho Black, 03M, 01M, NGB00960, NGB00963, Exsudant and NGB00390) produced less, and the least occurred in 'NGB00390' which produced 24.08 capsules per plant.

Furthermore, the number of seeds per plant varied significantly ($p \leq 0.05$) among the accessions. All accessions had more than 30 seeds in each capsule, with an average of 42.08 seeds per capsule. The highest seeds per capsule were recorded in 'Bogoro Local' (58.2 seeds), 10 seeds more than 02M (47.01 seeds) which is the second in the ranking. Fewer seeds per capsule were found in 'NGB00390' (34.10) which is not statistically different from 'Exsudant' (36.02). The average mass of a thousand seeds (MTS) of the accessions was 2.48 g. Three accessions (03M, Exsudant and NGB 00390) had MTS less than 2.00 g and the least obtained in '03M' (1.22 g). Nevertheless, 'E8' produced the heaviest seeds (4.31 g), about 2.0 g more than the average for the accession. Besides, 'E8' had the highest (8.52 g) total mass of seeds per plant (TMSP), which means the accessions is superior in term of seed mass. Next to 'E8' was 'Bogoro Local' with 6.28 g TMSP. Both accessions also recorded the best capsule features, having capsules lengths of 2.23 and 2.58 cm, capsules width 0.64 and 0.92 cm respectively. In contrast, three accessions (03M, Exsudant and NGB00390) performed poorly for MTS and TMSP. Whereas the three accessions had capsule length and width below average, 'NGB00390' had the least capsule length of all the acces-

Table 1: Vegetative growth variables of eleven accessions of *Sesamum indicum* at physiological maturity

Accessions	Plant height (cm)	Number of leaves	Petiole length (cm)	Leaf Area (cm ²)	Number of primary branches	Stem girth (cm)
Igboho Black	56.80e	68.81b	3.12de	41.02a	6.65b	2.87cd
02M	94.84a	37.47d	5.01ab	38.74ab	3.60e	3.25ab
03M	41.28fg	12.80gh	3.33de	15.84f	1.90g	1.94f
E8	44.84f	23.20ef	2.28ef	38.12ab	3.60e	2.09ef
01M	88.04ab	41.83c	5.51ab	43.06a	5.33bc	3.41a
Exsudant	27.76h	8.66i	1.60g	14.91f	2.80ef	1.76f
Kenan 4	84.24b	14.42g	3.50d	34.63cd	4.50de	3.02ab
NGB960	69.84c	22.25ef	3.01e	36.02bc	5.33bc	3.01ab
NGB963	68.20c	13.80g	4.50bc	34.10cd	2.60ef	2.29de
Bogoro Local	41.72fg	78.45a	4.51bc	37.40bc	9.60a	2.49de
NGB 00390	66.48cd	25.25ef	6.01a	24.87e	5.20bc	2.53cd
Mean	62.19	31.54	3.85	32.61	4.65	2.61
Max	94.84	78.45	6.01	43.06	9.60	3.41
Min	27.76	8.66	1.60	14.91	1.90	1.76

Values with the same letter(s) along a column are not significantly different at $p < 0.05$. The mean is the average for all the accessions, the Max is the maximum value and the Min is the minimum value for each parameter

sions (1.68 cm), and 'Exsudant' with the least apicule width (0.58 cm) as presented in Table 2.

The boxplot analysis (Fig. 2) revealed that the plant height of the accessions lies closer to the average (62.19 cm), the little deviation was accounted for greatly by 'Exsudant'. The plots also showed that most accessions performed above the average in leaf formation, petiole length, the number of days to 50 % flowering, number of capsules per plant and number of seeds per capsule. The accessions' performance aligned on the median values for stem girth, days to maturity and the total mass of seeds per plant. For other characters such as the number of primary branches, leaf areas, capsule length and breadth, most of the accessions performed below the average. This indicates the presence of significant variation in both growth and yield characters of the accessions.

3.3 QUALITATIVE CHARACTERS

The summary of the qualitative characters of the sesame accessions observed at maturity is presented in Table 3. The accessions leaf colour was either dark or light green. Only three accessions (Igboho Black, 02M and E8) exhibited dark-green leaves, others produced pale or light green leaves. The basal stem colour varied from greenish-brown, dark-green, pale green and green with specks of yellow. '03M', '01M', 'Exsudant' and

'Kenan 4', produced white flowers, 'Bogoro Local' and 'Igboho Black' had purple, '02M', 'E8', 'NGB00960' and 'NGB00963' had milky-white while 'NGB00390' flowers are brownish white. The accessions' capsules were elongated in shape and predominantly brown, enclosing numerous oval seeds which are either white, milky, brown or black (Table 3).

3.4 THE PRINCIPAL BIPLLOT AND CORRELATION ANALYSES

The principal biplot analysis of the agro-morphological and seed related characters revealed that eight components (PC) contributed significantly to the observed variations among the sesame accessions. Out of the components, PC-1 and PC-2 which accounted for 45.17 and 20.25 % respectively, and cumulated to 65.42 % of the variables are the most important (Fig. 3). In the PC-1, plant height, the number of leaves per plant, number of primary branches, leaf areas, number of capsules per plant, number of seeds per capsule and a thousand seed mass are the main sources of variation of the accessions under PC-1. The variables that significantly contributed to the observed variation in the PC-2 are; plant height, petiole length, leaf area and the number of seeds per capsule. On the contrary, stem girth, number of days to 50 % flowering, days to maturity, capsule length and

Table 2: Yield attributes of seed related characters of eleven accessions of *Sesamum indicum* evaluated for variability and genetic diversity study at maturity

Accession	DT 50 % F	DTM	NCP	NSC	CL (cm)	CD (cm)	MTS (g)	TMSP (g)
Igboho Black	42.02b	98.45ab	37.10c	39.02b	2.01bc	0.62de	2.24bc	3.48d
02M	46.25ab	108.66a	44.21b	47.01ab	2.22ab	0.79b	2.76b	5.52ab
03M	42.05b	105.54a	39.33c	37.99b	1.89cd	0.68cd	1.22d	2.45de
E8	36.33c	100.45a	56.66a	42.01ab	2.23ab	0.64d	4.31a	8.52a
01M	42.06b	101.25a	37.25c	38.02b	2.12bc	0.61de	2.20bc	4.42bc
Exsudana	50.11a	98.28ab	28.44d	36.02c	2.02bc	0.58e	1.24d	2.01e
Kenan 4	39.56bc	101.58a	51.33a	43.01ab	2.21ab	0.72bc	2.92ab	5.82a
NGB00960	42.25b	104.28a	38.55c	38.02b	2.11bc	0.67cd	2.70b	3.95c
NGB00963	42.33b	100.56a	38.25c	42.02ab	2.21ab	0.66cd	2.72b	4.02c
Bogoro Local	37.35c	102.20a	54.02a	58.20a	2.58a	0.92a	2.96ab	6.28a
NGB 00390	54.25a	89.33b	24.08d	34.10c	1.68d	0.72bc	1.96c	2.08e
Average	43.45	100.68	40.77	42.08	2.12	0.70	2.52	4.54
Max	54.25	108.66	56.66	58.20	2.58	0.92	4.31	8.52
Min	36.33	89.33	24.08	34.10	1.68	0.58	1.22	2.01

Values with the same letter(s) along a column are not significantly different at $p < 0.05$. The mean is the average for all the accessions, the Max is the maximum value and the Min is the minimum value for each parameter. DT 50 % F: Days to 50 % flowering; DTM: Days to physiological maturity; NCP: Number of capsules per plant; NSC: Number of seeds per capsule; CL: capsule length; CW: capsule width; MTS: Mass of a thousand seeds per plant; TMSP: Total mass of seeds per plant

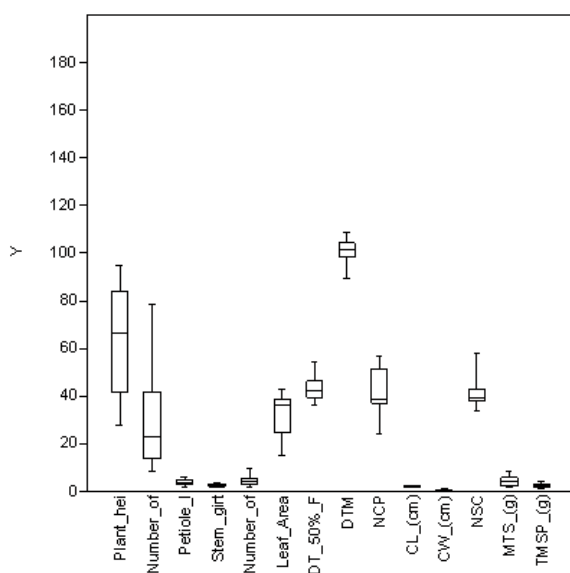


Fig 2: The boxplot of the growth and reproductive characters of eleven accessions of *Sesamum indicum* evaluated for performance and genetic diversity. The boxes revealed the skewness of the data from the mean proportion of the studied accessions with values below or above the mean. The y-axis shows the magnitude of the measured characters while the x-axis contains the characters

breadth are without significant effect. Thus, plant height,

number of leaves, leaf area, days to flowering, days to maturity, number of capsules per plant, seeds per capsule and seed mass are the major factors of variation in the sesame accessions.

The matrix of correlations between the vegetative and reproductive characters of the sesame accessions is presented in Figure 4. At a significant level of $p < 0.01$, the number of leaves is associated with the number of primary branches ($r = 0.8701$). Also, a strong positive correlation occurred between capsule length and the number of seeds per capsule ($r = 0.8869$); the number of capsules per plant, capsule width, and the number of seeds per capsules ($r = 0.8393$). Besides, the mass of a thousand seeds strongly related to the total mass of seeds per plant, and the total mass of seeds per plant was strongly linked with the number of capsules per plant ($r = 0.9192$). So also, is the number of primary branches and number of leaves ($r = 0.8700$); stem girth and plant height ($r = 0.8803$). Furthermore, at $p < 0.05$, plant height and leaf area ($r = 0.5876$), days to maturity and number of capsules per plant, the number of seeds per capsule and days to maturity, capsule length and days to maturity are linked (with r values above 0.4 and less than 0.8). Likewise, leaf area correlated with plant height, number of primary branches, number of leaves, number of capsules per plant and seed mass parameters. Other correlated characters are; the number of capsules per plant, number of seeds per

Table 3: Summary of the qualitative characters of eleven accessions of sesame for similarities and differences in their morphological features at maturity

Accession	Leaf colour	Stem base colour	Flower colour	Capsule colour	Capsule shape	Seed shape	Seed colour
Igboho Black	Dark green	Greenish brown	Whitish purple	Brown	Elongated	Oval	Black
02M	Dark green	Yellowish green	Milky white	Brown	Elongated	Oval	Milky white
03M	Light green	Dark green	White	Brown	Elongated	Oval	Milky white
E8	Dark green	Dark green	Milky white	Brown	Elongated	Oval	Milky white
01M	Light green	Light green	White	Brown	Elongated	Oval	White
Exsudana	Light green	Light green	White	Greenish brown	Elongated	Oval	White
Kenan 4	Light green	Greenish white	White	Greenish brown	Elongated	Oval	White
NGB00960	Light green	Greenish white	Milky white	Greenish brown	Elongated	Oval	Milky white
NGB00963	Light green	Light green	Milky white	Brown	Elongated	Oval	Milky white
Bogoro Local	Light green	Greenish-white	Purple	Yellowish-brown	Elongated	Oval	Brownish-yellow
NGB00390	Yellowish green	Yellowish green	Brownish white	Brown	Elongated	Oval	Brownish-yellow

Values with the same letter(s) along a column are not significantly different at $p < 0.05$. The mean is the average for all the accessions, the Max is the maximum value and the Min is the minimum value for each parameter

plant and capsule dimension. More associations of significant interaction between the morphometric and seed related characters are shown in Figure 5. However, a negative correlation ($r < 0$) existed between the number of days to 50 % flowering and the number of seeds, capsules per plant, capsule length, and mass of seeds. There was approximately no correlation between plant height and the number of seeds per plant, number of leaves and the number of primary branches.

3.5 PHOTOSYNTHETIC PIGMENTS CONTENT

Chlorophyll analysis was conducted on each accession every four (4) weeks till maturity to determine the quantity and variations in chlorophyll a, b, and carotenoids contents. Over the period of vegetative growth (2-12 WAS), chlorophyll-a was relatively more abundant in the leaf compared to other photosynthetic pigments (Fig. 5). At 4 WAS, 'Exsudana' had the highest chlorophyll-a (4.78 mg l⁻¹) and chlorophyll-b (1.54 mg l⁻¹), same for the

total chlorophyll (6.32 mg l⁻¹) (Fig. 5), followed by 'Bogoro Local', 'NGB00390', 'NGB00960', and '02M' which all had chlorophyll-a > 3.00 mg l⁻¹ and chlorophyll-b > 4.00 mg l⁻¹. At the same period, '01M' had the least total chlorophyll (1.65 mg l⁻¹). Likewise, the highest carotenoid content (1.21 mg l⁻¹) was found in 'Exsudana'. Four accessions (03M, Igboho Black, E8 and 01M) had carotenoid content < 0.70 mg l⁻¹. Chlorophyll-b was generally low at the seedling stage, although notably high in 'Exsudana' (1.54 mg l⁻¹), '01M' recorded the least amount of the pigments.

At 8 WAS, the total chlorophyll content of the accessions increased for some accessions, 'Exsudana' yet had the highest chlorophyll (11.56 mg l⁻¹) (Fig. 5). The carotenoid contents of all the accessions were similar except 'NGB00960' and 'NGB00963' which showed a decline. Carotenoid increased as much as 43 % in '01M', and 'Exsudana' by 25 %, amounting to 1.58 mg l⁻¹ which was the highest recorded while the accession NGB00963 recorded the least carotenoid (0.38 mg l⁻¹). Although, the total chlorophyll contents of the accessions are similar, not-

Table 4: Proximate composition of the eleven accessions of *Sesamum indicum* evaluated for variability and genetic diversity

Accession	Percentage composition (%)					
	Moisture	Ash	Crude protein	Crude fibre	Fat and oil	Carbohydrate
Igboho Black	3.40a	5.98a	5.60g	5.77a	53.61j	27.63b
02M	3.10e	4.84cd	5.33i	4.69e	57.25e	24.79c
03M	3.25b	4.97bc	5.80h	4.75d	59.83b	21.49e
E8	3.38a	5.10b	7.21c	4.99b	60.50a	18.81h
01M	3.20bc	4.92bc	7.35ab	4.81bc	58.76d	21.47e
Exsudan	3.18cd	4.85cd	6.80e	4.78cd	58.95c	21.33f
Kenan 4	2.68g	4.60ef	6.90d	4.49g	60.46a	20.79g
NGB00960	2.74f	4.80d	7.40a	4.62f	56.80f	23.76d
NGB00963	2.03i	4.55ef	5.85g	4.38h	54.47h	28.62a
Bogoro Local	2.04h	4.65e	6.58f	4.47g	54.25i	27.62b
NGB00390	3.15d	4.88cd	6.81e	4.80c	55.58g	24.79c

Values with the same letter(s) along a column are not significantly different at $p < 0.05$

contents of 3.40 % and 3.38 % respectively, followed by '03M' (3.25 %), '01M' (3.20 %), 'Eksudan' (3.18 %), and 'NGB00390' (3.15 %). Whereas moisture contents of '01M', 'Eksudan' and 'NGB00390' are not statistically similar, the least amount of moisture (2.03 %) was found in 'NGB00963'. The ash content which indicates the mineral element composition of the accessions ranged was 4.55- 5.98 %, only two accessions, Igboho Black and 03M had ash composition above 5 %. Like the moisture content, the least percentage of the mineral was found in 'NGB00963'. Generally, all the accessions had a percentage crude protein higher than 5 %, the highest (7.4 %) occurred in '00960' and the lowest (5.33 %) in '02M'. The highest crude fibre content was found in 'Igboho Black' (5.77 %), followed by 'E8' (4.99 %), none of the accessions had crude fibre composition of less than 4 %. Furthermore, there is variation in the fat and oil composition of the accessions. Sesame seeds are mainly used for oil production; therefore, the percentage of oil composition is important. The accession E8 had the highest oil yield (60.5 %) which was not significantly different from the percentage composition of fat and oil in 'Kenan 4' (60.45 %). Meanwhile, none of the accession recorded crude fat and oil percentage less than 50 %, the least (53.61 %) was found in 'Igboho Black'. As an oil-bearing crop, the carbohydrate composition was expectedly low, ranging from 18.81-28.62 %. The accessions E8

and Kenan 4 with high fat and oil had 18.81 and 20.79 % carbohydrate respectively. The percentage of fat and oil composition of the accessions was inversely proportional to the carbohydrate content (Table 4).

3.7 DIVERSITY OF THE ACCESSIONS

The dendrogram partitioned the accessions into two major groups (Fig. 6). Group 1 consisted of two accessions; Igboho black and Bogoro Local which are separated at a genetic distance below 24. Group 2 consisting of 9 accessions was further divided into two sub-groups; 2A and 2B. The sub-group 2A had three accessions separated into two clusters; 2A(i) and 2A(ii) at a genetic distance below 34, a single accession (E8) made the cluster 2A(i) while two accessions (03M and Exsudan) with distance scale of 15 constituted the cluster 2A(ii). On the other hand, the sub-group 2B members were segregated into two distinct clusters; 2B(i) and 2B(ii). The former comprised of four accessions (NGB00390, Kenan 4, NGB00960 and NGB00963), whereas 'NGB00390' was the most distant member, followed by 'Kenan 4' with less genetic distance while the duo of 'NGB00960' and 'NGB00963' are the most related members of the cluster. Besides, two other related accessions, 02M and 01M formed the clustered 2B(ii).

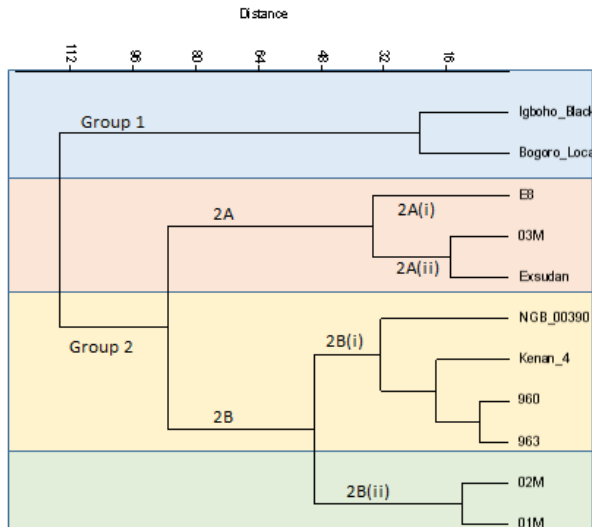


Figure 6: Dendrogram of the genetic relationship of the eleven sesame accessions based on agro-morphometric and yield-related attributes. The dendrogram was constructed using the agglomerative technique of the unweighted pair group of arithmetic average (UPGMA) method

4 DISCUSSION

The qualitative and quantitative traits of the accessions revealed variations in the studied variables, this showed there is existing genetic diversity amidst the accessions. Factors such as genetic drift, natural and artificial selection, exchange of breeding materials could contribute significantly to diversity among the accessions. (Sabesan et al., 2009; Banumathy et al., 2010). The observed variability in the morphological attributes obtained in the present study could provide useful information for the identification and selection of accessions with superior traits that could be used for sesame production, and as parents for breeding programs (Arriel et al., 2007). Significant dissimilarities in parameters such as plant height, leaf attributes, and stem girth as well as yield-related characters are essential for the assessment of variability and genetic divergence in plant genetic resources (Bisht et al., 1998; Baydar, 2005; Sharmila et al., 2007; Furat & Uzun, 2010; Kiranmayi et al., 2016; Animasaun et al., 2017; Azeez et al., 2017; Iqbal et al., 2018; Adu-Gyamfi et al., 2019).

The significant differences in the growth and yield characters of the evaluated *Sesamum indicum* accessions concurred with earlier reports (Adebisi et al., 2005; Parameshwarappa et al., 2010; Pham et al., 2010). The observed differences may be due to the genetic system of

the accessions. The plant height range (27.76-94.84 cm) of the accessions in the current study was lower than 104-161 cm reported for some genotypes in South-East Asia by Pham et al. (2010). In terms of growth attributes, '02M' and 'Kenan 4' are the most promising accessions. Although 'Bogoro Local', 'E8', '03M' and 'Igboho' black had heights below the accessions average, notwithstanding, they had good yield attributes suggesting that vegetative growth and grain yield are under different genetic control systems. The short accessions may not be a complete disadvantage as Baydar (2005), opined that non-branching sesame varieties of medium heights and uniform maturity may be desirable for mechanized cultivation, and development of modern sesame breeding programmes. In addition, shorter canopy might lead to redistribution of assimilate which promotes higher yield.

The ability of the accessions to achieve 50 % flowering between 37 to 54 days showed most of the accessions are elite with regards to maturity. In a similar study, Arriel et al. (2007) reported the commencement of flowering varied from 30 to 48 days in some accessions. Also, the 89-108 days to maturity reported in the current study agreed with the authors' report. Meanwhile, Pham et al. (2010) documented much earlier time (24-31 days) for some accessions. The accession E8 that attained early maturity in this study could be potential mother material for the development of elite sesame cultivars. Since sesame is cultivated mainly for its seed and oil, therefore, seed yield attributes are of great importance in the selection of accession for commercial production. Besides early maturity, accession E8 showed impressive yield-related traits. According to Parameshwarappa et al. (2010), sesame genotypes with delayed maturity may record low seed yields. This is true for this study; 'NGB00390' which attained maturity late also had poor seed yield. Compared to other oilseed crops, sesame yield is low owing to its early senescence and vulnerability to some abiotic stress and photosensitivity (Pathak et al., 2014). Also, legumes generally have low yield, since the construction cost of oil is high compared to that of the carbohydrates in cereals. The high seed mass of 'E8' further reinforced the good quality of its seeds, making it a good parent material for sesame breeding programmes. The variations in the number of capsules per plant and seeds per capsule obtained in this study corroborate the earlier works (Ogbonna & Ukaan, 2012), who demonstrated considerable variation in some sesame seed characters, and this suggest yield component are controlled by multiple genes (Basu et al., 2009).

In green plants, the assimilatory surface is one of the major factors that determine growth and yield (Beheshti & Fard, 2010). Thus, a larger and increased assimilatory surface may translate to higher photosynthate, and ulti-

mately a better growth and yield. Sesame is highly sensitive to day length which coupled with temperature have a significant effect on its flowering rate (Suddhiyam et al. 1992). There is a close correlation between photosynthetic active radiation (PAR) absorption and yield (Yadav et al. 1988). But the reverse is the case for the duo of 'Exsudant' and 'NGB00960', which despite their high chlorophyll contents, they performed poorly in growth and yield. This suggests the two accessions had inherent characters for their non-impressive performance and therefore may not be suitable as raw material for the crop improvement. The gradual decline in chlorophyll contents of the accessions after 10 WAS could be due to increasing senescence, as the plant shift from the vegetative growth phase to the reproductive and maturity stage, this, of course, explains the slight increase recorded in the carotenoid contents. Carotenoids are essential pigments that compliment chlorophyll, it also acts as photoprotectors, antioxidants, colour attractants, and precursors of plant hormones in non-photosynthetic organs of plants. As the plant attains maturity and gene switches from vegetative to reproductive phase, more carotenoids are produced to manage the decrease in the Chlorophyll a and b functionality. In addition, carotenes contribute to photosynthesis by transmitting the light energy they absorb to chlorophyll and protect plant tissues by helping to absorb the energy from singlet oxygen, an exciting form of the oxygen molecule O_2 which is formed during photosynthesis.

Traits that are significantly correlated are highly linked and are possibly controlled by a genetic system. The strong associations between plant height, leaf area and seed yield showed there is a connection between growth and yield components. Significant correlations have been established in crop plants (Kiranmayi et al., 2016; Animasaun, et al., 2021; Azeez et al., 2017; Olorunmaiye et al., 2019), in all cases, it was argued that traits that are correlated are linked, and can be improved simultaneously. Meanwhile, Parameshwarappa et al. (2010), reported a negative relationship between the number of days to 50 % flowering and seed yield, indicating the higher the number of days to flower, the less the seed yield. Characters that showed significant negative association are not genetically linked and may be improved or selected individually. The concept of correlated traits is of great importance to a breeder as it gives concise information on character linkage on which selection could be made.

The nutrient composition of the seeds also varied, oil yield was generally high above 50 % in all accessions, a bit higher than values reported by Kiranmayi et al. (2016). The high oil yield obtained from 'E8' and 'Kenan 4', makes them the potential candidates for improved oil

yield breeding programmes. The low carbohydrate contents of the accessions qualify the seed oil as low calories and safe for human and animal health.

The Principal Component Biplot Analysis enables the plant breeders to sort genotypes and select promising varieties using multivariate methods to estimate the contribution of each trait that constitute an ideal plant (Yan & Rajcan, 2002, Iqbal et al., 2018). Thus, it is an important tool to reveal the degree of similarity or variability among evaluated accessions. The effectiveness of a trait as a morphological marker is measured by its discriminating power among the accessions and its stability of expression (Arriel et al., 2007). The presence of '02M' and '01M' on a plain revealed they had similar morphological traits. They are both tall, with a relatively similar number of leaves per plant. The co-occurrence of three accessions; E8, 03M, and Exsudant in a cluster indicates a shared resemblance in yield characteristics. Relatedness and genetic diversity among the accessions based on growth and yield characters were further established by the dendrogram, which partitioned the accessions into four distinct groups. The higher the genetic distance, the less the relatedness, consequently, accessions having less distance scale are more related. The dendrogram obtained in the present study revealed that 'NGB00960' and 'NGB00963' are the most related accessions, and they are distant relative to 'Kenan 4'. A similar study (Tyagi et al., 2014) also demonstrated heterogeneous genotypes in a cluster, because, genetic relationship is based on related genetic markers and not necessarily the origin of the accessions (Animasaun et al., 2015). The use of cluster analysis to unravel genetic similarity in crop genetic resources have been demonstrated (Adewale et al., 2015; Pandey et al., 2015; Animasaun et al., 2017). The genetic divergence information present by the dendrogram is of great importance because it reveals accessions that are likely from a common progenitor. Besides, such information is a prerequisite for the selection and breeding of improved cultivars with novel alleles mix as well as developing an effective conservation strategy for the genetics (Upadhyay et al., 2011). Since members of a cluster share similar genetic composition regardless of origin, therefore, duplication and misidentification of accessions can be prevented.

5 CONCLUSION

The current study evaluated the performance and assessed the genetic diversity of eleven accessions of cultivated sesame using morpho-agronomic traits, photosynthetic pigment and nutrient composition. The result showed significant variations among the accessions for

growth, seed yield and nutritional composition. In terms of growth attributes, '02M' and 'Kenan 4' are the most promising while 'E8', 'Bogoro Local', and 'Igboho Black' showed good yield attributes. However, 'Kenan 4' showed the optimum performance. The study concludes that the accessions are genetically and phenotypically diverse and the existing diversity could be harnessed for selecting high yielding and adaptable variety as possible parents for the development of improved cultivars for commercial cultivation.

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7 CONFLICT OF INTEREST

The authors declare there is no potential conflict of interest.

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