Print ISSN: 2287-9358 Online ISSN: 2287-9366
Plant Breed. Biotech. 2026 (October) 14.272~290
https://doi.org/10.9787/PBB.2026.14.272

Plant Breeding and Biotechnology

Research Article

Correlation among Morpho-agronomic Traits, Yield Components, and Biochemical Parameters in Sesame (*Sesamum indicum* L.) Genotypes

Ilkham Dj. Kurbanbayev[1], Dilfuza B. Vaisova[1], Alimjon D. Matchanov[2], Azamat K. Ahmedov[4], Navruzbek Khusanov[5], Firuza A. Nazarova[6], Kholikulov Mukhammad[7], and Abdurauf A. Dolimov[1,3*]

[1]Institute of Genetics and Plant Experimental Biology, Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
[2]Institute of Bioorganic Chemistry, Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
[3]Research Institute of Plant Genetic Resources, National Center for Knowledge and Innovation in Agriculture, Kibray district, 111202, Tashkent Region, Uzbekistan
[4]"TIIAME" National Research University, Tashkent, Uzbekistan
[5]National University of Uzbekistan, Tashkent, Uzbekistan
[6]Bukhara State University, Bukhara, Uzbekistan
[7]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers

*Corresponding to
Abdurauf A. Dolimov
TEL. +998942571874
E-mail. dolimovabdurauf1995@gmail.com

Abstract The objective of this study was to evaluate agronomic traits, yield components, seed biochemical characteristics, and their relationships in local and exotic sesame (*Sesamum indicum* L.) genotypes under field conditions in Uzbekistan. Thirteen genotypes were grown in a randomized complete block design with three replications at the Dormon Experimental Station in 2025. Protein, oil content, and fatty acid composition were determined using the Kjeldahl method and gas chromatography-mass spectrometry (GC-MS), respectively. Statistical analyses, including analysis of variance and Pearson's correlation, were performed using SPSS version 26.0. Considerable variation was observed among genotypes. Protein content ranged from 18.23 to 19.45%, while oil content varied from 44.11 to 50.44%. Oleic acid content ranged from 4.7 to 77.75%, indicating substantial diversity. Positive correlations were observed between thousand-seed weight and capsule length (r = 0.79) and between number of capsules per plant and seed weight per plant (r = 0.89). These results identified NC 8756, NC 8998, NC 9050, and NC 9100 as promising genetic resources for future sesame breeding programs.

Key words Sesame (*Sesamum indicum* L.), yield components, correlation, oil content, protein

Introduction

Sesame (*Sesamum indicum* L.) is considered one of the oldest oilseed crops in the world and is mainly cultivated in the tropical and subtropical regions of Asia (Emamgholizadeh et al. 2015). It belongs to the Pedaliaceae family and is a diploid species (2n = 26) with dicotyledonous characteristics. The genus Sesamum comprises 36 species, among which Sesamum indicum L. is the principal cultivated species (Sudha Sundari et al. 2024).

Several hypotheses have been proposed regarding the origin of sesame, suggesting domestication either in Africa or India. However, based on substantial evidence, it has been concluded that sesame was first domesticated on the Indian subcontinent (Ali et al. 2020). Wild relatives of this species can still be found in Africa. Compared to other oilseed crops, sesame is often referred to as the "Queen of Oilseeds" due to its high oil content (Goudappagoudra et al. 2011)

Sesame is cultivated widely across tropical and subtropical regions, and its global production has increased

Received: July 20, 2026. Revised: August 19, 2026. Accepted: September 16, 2026. Published: October 29, 2026.

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considerably over recent decades due to growing demand for edible oil and functional food products. Currently, the major sesame-producing countries include India, China, Sudan, Myanmar, Nigeria, Tanzania, Ethiopia, Pakistan, Uganda, Guatemala, and Türkiye (Wei et al. 2022). According to recent reports of the Food and Agriculture Organization (FAO), global sesame production has exceeded 6 million tons, with Sudan, India, Tanzania, and China remaining among the leading producers. The increasing economic importance of sesame has stimulated research aimed at improving seed yield, oil content, and nutritional quality characteristics (Sudha Sundari et al. 2024)

Recent studies have emphasized that genetic improvement of sesame is increasingly focused not only on yield enhancement but also on seed quality traits, including protein content, oil concentration, fatty acid composition, and nutritional value. Advances in genetic variability studies, multivariate analyses, and biochemical characterization have facilitated the identification of superior genotypes for breeding programs. Furthermore, increasing demand for functional foods and vegetable oils has intensified research efforts aimed at developing sesame cultivars with improved nutritional quality and stress adaptability (Muhammad et al. 2024).

Sesame is one of the most valuable oil-producing crops. Its seeds contain 60-65% oil, 16-22% protein, and approximately 18% soluble carbohydrates (Amanova et al. 2023). Of the total carbohydrate content, 3.2% consists of glucose, 2.6% fructose, and 0.2% sucrose, while the remaining portion is mainly dietary fiber (Anilakumar et al. 2010). Sesame cake (meal) contains about 40% protein and 8% oil and is widely used in the confectionery industry. In addition, it serves as a nutritious feed source for livestock (Kurmanbayeva et al. 2023).

When sesame oil is obtained through cold pressing, it has a light yellow color, a pleasant taste, and is odorless. This oil is widely used in confectionery products, canned foods, and margarine production. Dehulled sesame seeds are used to produce tahini and halva. Oil extracted by traditional pressing methods is directly utilized in the food industry. In contrast, oil obtained through hot pressing is mainly used for technical purposes; it has a darker color and is employed in the manufacture of carbon paper, soap, and various industrial products. Sesame flowers and stems are also used in perfumery and cosmetic production, and high-quality black pencils are produced from its processed materials (Erjigitov et al. 2025; Shokirova et al. 2026).

In addition to its high oil and protein contents, sesame seeds are recognized as a rich source of essential minerals, bioactive compounds, vitamins, and amino acids. Sesame seeds contain considerable amounts of calcium, magnesium, phosphorus, iron, zinc, and potassium, which contribute to bone health, enzymatic functions, and antioxidant defense systems. They are also characterized by the presence of unique lignans, including sesamin, sesamolin, sesamol, and sesaminol, which exhibit antioxidant, anti-inflammatory, and cardioprotective properties. Furthermore, sesame oil contains tocopherols (vitamin E), which improve oxidative stability and enhance nutritional quality. Sesame proteins are rich in essential amino acids, particularly methionine, tryptophan, leucine, and phenylalanine, making sesame an important source of plant-based protein. These nutritional and functional characteristics contribute to the increasing importance of sesame in human nutrition, the food industry, and breeding programs aimed at improving seed quality (Kalaiyarasi et al. 2019a; Mustafa et al. 2023; Umamaheswari et al. 2019).

Cultivated sesame is an annual herbaceous plant characterized by a well-developed taproot system with a thickened upper root portion. The root penetrates up to 120 cm into the soil and produces numerous lateral

branches. The stem grows erect, is either four- or eight-angled, and reaches an average height of 100-110 cm under irrigated conditions. The leaves are petiolate, arranged alternately or oppositely, and covered with fine hairs. Seed color is usually light brown or brown, but may also be white or black (Amanova et al. 2023).

Sesame is a thermophilic crop. Its seeds begin to germinate at temperatures of 15-16℃, while uniform seedling emergence requires 18-20℃. At temperatures of 23-25℃, the period from sowing to emergence is shortened. During the first 20-25 days of the vegetative period, sesame plants grow very slowly. After seedling emergence, it takes approximately 35-40 days for the first flowers to appear (Kodirova et al. 2024).

Seed yield is considered one of the most important quantitative traits in crops (Wang et al. 2024). Previous studies have identified 1000-seed weight (TSW), capsule length (CL), number of seeds per capsule (CNP), and plant height (PH) as the main yield components in sesame, directly influencing seed yield per unit area (Yol et al. 2010). The positive and significant correlations between these traits and seed yield have been scientifically confirmed by several researchers (Akbar et al. 2011; Goudappagoudra et al. 2011).

Previous studies have shown that crop traits are shaped not only by genetic factors but also by interactions with biological communities. Multivariate analyses in mung bean have demonstrated that yield-related morphological traits are quantitatively inherited and often correlated (Norboyeva et al. 2026), while studies in soybean have highlighted that plant-associated microbial communities can enhance stress resilience and stabilize productivity. Local researchers have conducted studies on species-specific protein markers in cotton morpho-agronomic, physiological, and biochemical characteristics of soybean botanical and genetic collections (Abdurazakova et al. 2020; Kurbanbaev et al. 2023) and the content of photosynthetic pigments in rice leaves (Khamraev et al. 2025). However, research conducted in Uzbekistan on sesame has mainly focused on agronomic traits. Comprehensive studies evaluating the biochemical composition of sesame seeds—particularly protein and oil content, as well as the proportion of major fatty acids in the oil—remain insufficient and require deeper investigation

Materials and Methods

Plant Materials

In this study, 13 local and foreign sesame (*Sesamum indicum* L.) genotypes were used:

1. Tashkentskiy-122
2. Qora Shakhzoda
3. Oq Marvarid
4. NC 8756 (Uzbekistan)
5. NC 8946 (Uzbekistan)
6. NC 8998 (Tajikistan)
7. NC 9000 (Tajikistan)
8. NC 9043 (Iran)
9. NC 9050 (Iran)

10. NC 9100 (Uzbekistan)
11. NC 9124 (China)
12. NC 9763 (Syria)
13. NC 9779 (Korea)

Three of these genotypes (Tashkentskiy-122, Qora Shakhzoda, and Oq Marvarid) are locally cultivated sesame varieties widely grown by farmers in Uzbekistan. The remaining ten genotypes were obtained from the "National Genebank" collection of the Research Institute of Plant Genetic Resources (Fig. 1).

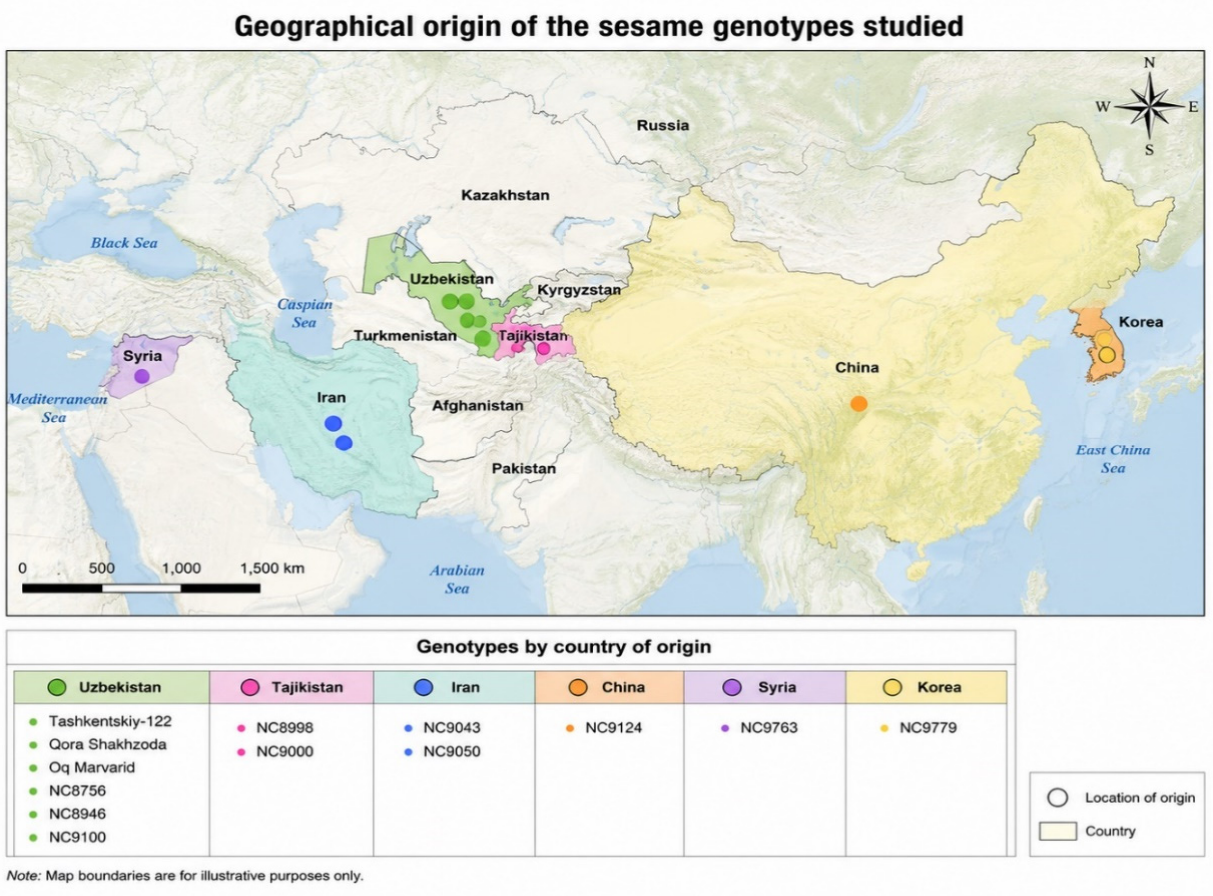


Fig. 1. Geographical distribution and country of origin of the 13 sesame (*Sesamum indicum* L.) genotypes evaluated in this study. Local varieties originated from Uzbekistan, whereas introduced accessions were obtained from Tajikistan, Iran, China, Syria, and Korea.

The selected genotypes represent a moderate level of genetic diversity and were chosen based on their geographical origin and previously observed differences in agronomic and seed quality traits. The objective of this study was not to represent the entire genetic diversity of sesame, but rather to evaluate a diverse set of local and introduced genotypes with contrasting characteristics and potential value for breeding programs.

The genotypes were selected based on their geographical origin and contrasting morpho-agronomic and biochemical characteristics. The objective of this study was not to represent the entire sesame genetic diversity

of Uzbekistan, but to evaluate selected local and exotic genotypes for their potential use in sesame breeding programs.

Experimental Design

In 2025, the 13 sesame genotypes were cultivated at the Dormon Field Experimental Station of the Institute of Genetics and Experimental Plant Biology, Academy of Sciences of the Republic of Uzbekistan.

The experiment was conducted using a randomized complete block design (RCBD) with three replications. For morpho-agronomic and yield-related traits, ten representative plants were randomly selected from each replication for data collection. Protein content, oil content, and fatty acid composition analyses were performed using three biological replicates for each genotype. Pure seeds of each genotype were sown in separate plots measuring 2.0 m × 2.0 m (4 m^2). Each genotype consisted of four rows per replication. The spacing between rows and plants was 60 cm and 10 cm, respectively. All crop management practices, including irrigation, fertilization, weed control, and pest management, were performed according to the standard agronomic recommendations for sesame cultivation in Uzbekistan (Kodirova et al. 2024).

The experiment was conducted under irrigated field conditions in the Tashkent region, Uzbekistan, which is characterized by a continental climate with hot and dry summers. During the growing season, average air temperatures ranged between 28 and 40℃. The field experiment was conducted during the 2025 growing season. Sesame seeds were sown in April and harvested in early September. The experimental period was characterized by hot and dry summer conditions typical of the Tashkent region. These environmental conditions were favorable for the growth and development of sesame genotypes under irrigated field conditions. The soil at the experimental site was classified as non-saline typical sieroz soil with medium fertility and good drainage. Prior to sowing, soil samples were collected from five depth intervals (0-10, 10-20, 20-30, 30-40, and 40-50 cm) and analyzed for available nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), and humus content according to standard agrochemical procedures. The physicochemical characteristics of the experimental soil are presented in Table 1.

Table 1. Physicochemical characteristics of the experimental soil before sowing.

Soil depth (cm)	Available N (mg kg^{-1})	Available P_2O_5 (mg kg^{-1})	Available K_2O (mg kg^{-1})	Humus (%)
0-10	22.8	27.5	165	1.2
10-20	19.2	18.3	187	1.18
20-30	15.6	10.3	220	1.1
30-40	14.3	10	165	1.07
40-50	11.8	9.2	168	1.01

No fertilizers were applied during the experimental period, and the sesame genotypes were evaluated under natural field conditions. Irrigation and other agronomic practices were applied uniformly to all experimental plots to minimize environmental variation among genotypes and ensure reliable comparison among the studied genotypes.

Data Recording

During the study, agronomic traits including days to maturity (DM), plant height (PH), number of branches per plant (BNP), number of capsules per plant (CNP), number of seeds per capsule (SNC), thousand-seed weight (TSW), seed weight per plant (SWP), seed weight per capsule (SWC), and capsule length (CL) were evaluated according to the methods described by (Sudha Sundari et al. 2024). In addition, biochemical traits such as protein content (PC), oil content (OC), and fatty acid composition were analyzed.

For all traits except DM, PC, OC, and fatty acid composition, five plants were randomly selected from each plot, and their mean values were calculated. In the case of DM, data were recorded based on observations of the entire plot.

Statistical Analysis

The experimental data obtained in this study were statistically analyzed using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA). Analysis of variance (ANOVA) was performed to evaluate the significance of genotypic differences among the studied traits. Mean comparisons were conducted using Tukey's honestly significant difference (HSD) test at the 5% probability level ($p<0.05$).

Principal component analysis (PCA) was performed using representative morpho-agronomic, yield-related, and biochemical traits, including plant height (PH), branch number per plant (BNP), capsule length (CL), thousand-seed weight (TSW), seed weight per plant (SWP), capsule number per plant (CNP), seed number per capsule (SNC), seed weight per capsule (SWC), protein content (PC), and oil content (OC). Because the variables were measured on different scales, genotype mean values were standardized to zero mean and unit variance prior to PCA. The first two principal components were used to construct the PCA biplot and visualize relationships among genotypes and traits.

Biochemical Analysis

Determination of total protein content. Total protein content was determined using the Kjeldahl method, which is based on measuring total nitrogen and calculating protein content accordingly. The principle of the method involves hydrolyzing organic substances in the sample with concentrated sulfuric acid, converting nitrogen-containing compounds (including amino groups of proteins) into ammonium sulfate (Guideline R 4.1.1672-03. Moscow: Federal Center of State Sanitary and Epidemiological Surveillance of the Ministry of Health of Russia, 2004).

Determination of oil content in seeds. The oil content of seeds was determined in accordance with the requirements of the Interstate Council for Standardization, Metrology and Certification (ISC) standard "Animal and vegetable fats and oils — Sampling" (GOST ISO 5555—2016), Moscow, Russian Institute of Standardization, 2021, p. 28).

Determination of fatty acid composition in seed oil. The fatty acid composition of sesame seed oil was analyzed using gas chromatography-mass spectrometry (GC-MS) with a "Chromatec-Crystal 5000" system. Fatty acid methyl esters (FAMEs) were prepared according to standard AOAC procedures prior to analysis. The GC-MS system

was equipped with a capillary column, and helium was used as the carrier gas at a constant flow rate of 1.0 mL min-1. The injector temperature was maintained at 250℃, while the oven temperature was programmed from 140℃ to 240℃. Individual fatty acids were identified by comparing their retention times with known standard compounds. The relative fatty acid composition was expressed as a percentage of total identified fatty acids.

Results

This study was conducted on 13 sesame genotypes to evaluate several agronomic traits, yield components, and biochemical characteristics. The analysis of variance (ANOVA) demonstrated significant genotypic differences for most morpho-agronomic, yield-related, and biochemical traits evaluated in this study (Table 2).

Table 2. Analysis of variance (ANOVA) for morpho-agronomic, yield, and biochemical traits in 13 sesame genotypes.

Trait	Df	Mean Square	F value	*p* value
PH	12	4285.61	15.42	<0.001
BNP	12	8.74	8.31	0.002
CL	12	0.42	6.18	0.011
TSW	12	0.37	11.24	<0.001
SWP	12	356.84	18.67	<0.001
CNP	12	12456.33	21.44	<0.001
SNC	12	845.21	9.52	0.003
SWC	12	0.006	4.38	0.019
PC	12	0.48	3.92	0.041
OC	12	7.54	5.67	0.008

Where: PH - plant height; BNP - branch number per plant; CL - capsule length; TSW - thousand-seed weight; SWP - seed weight per plant; CNP - capsule number per plant; SNC - seed number per capsule; SWC - seed weight per capsule; PC - protein content; OC - oil content.

Morpho-agronomic Traits

Morpho-agronomic traits represent a set of external (morphological) and economically important characteristics of plants. These traits are widely used for variety characterization, comparison, and the selection of promising genotypes. According to the results of the study, significant variation was observed among the investigated sesame varieties and accessions for agronomic traits (Fig. 2).

Based on the 2025 harvest data, considerable differences were recorded among local and foreign sesame varieties and accessions in terms of plant height. The highest plant height was observed in the local variety Qora Shakhzoda (230.29 ± 1.98 cm), whereas the lowest value was recorded in the Syrian accession NC 9763 (82.5 ± 1.58 cm). In the remaining varieties and accessions, plant height ranged from 167.86 ± 1.54 cm to 201.14 ± 2.32 cm (Fig. 2a).

Regarding the number of productive branches per plant, the highest value was observed in the Iranian accession NC 9050 (8.80 ± 0.33 branches). The lowest number of branches was recorded in the variety Oq Marvarid

(2.20 ± 0.17 branches). In the other studied genotypes, this trait ranged from 3.00 ± 0.21 to 7.00 ± 0.65 branches (Fig. 2b).

For capsule length, the highest value was recorded in the Tajik accession NC 9000, reaching 3.70 ± 0.03 cm. The lowest capsule length was observed in Oq Marvarid (2.71 ± 0.04 cm). In the remaining varieties and accessions, the average capsule length ranged from 2.95 ± 0.03 cm to 3.60 ± 0.01 cm (Fig. 2c).

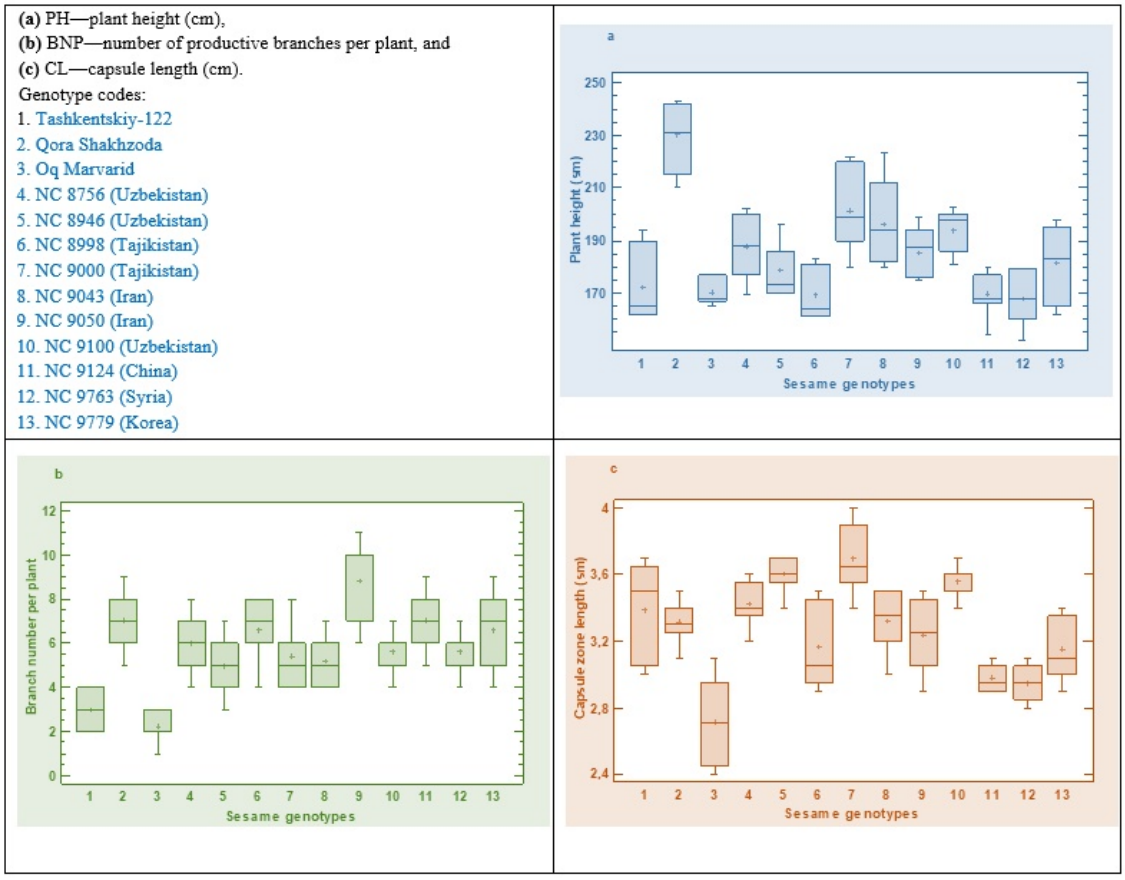


Fig. 2. Box plots of morphological traits in 13 sesame genotypes based on genotype codes.

Yield Components

Yield performance is determined by a series of quantitative traits known as yield components. These components are expressed under the influence of the plant's biological characteristics and growing conditions and ultimately determine final seed yield.

In sesame, the main yield components include the number of capsules per plant (CNP), number of seeds per capsule (SNC), seed weight per capsule (SWC), seed weight per plant (SWP), and 1000-seed weight (TSW) (Fig. 3).

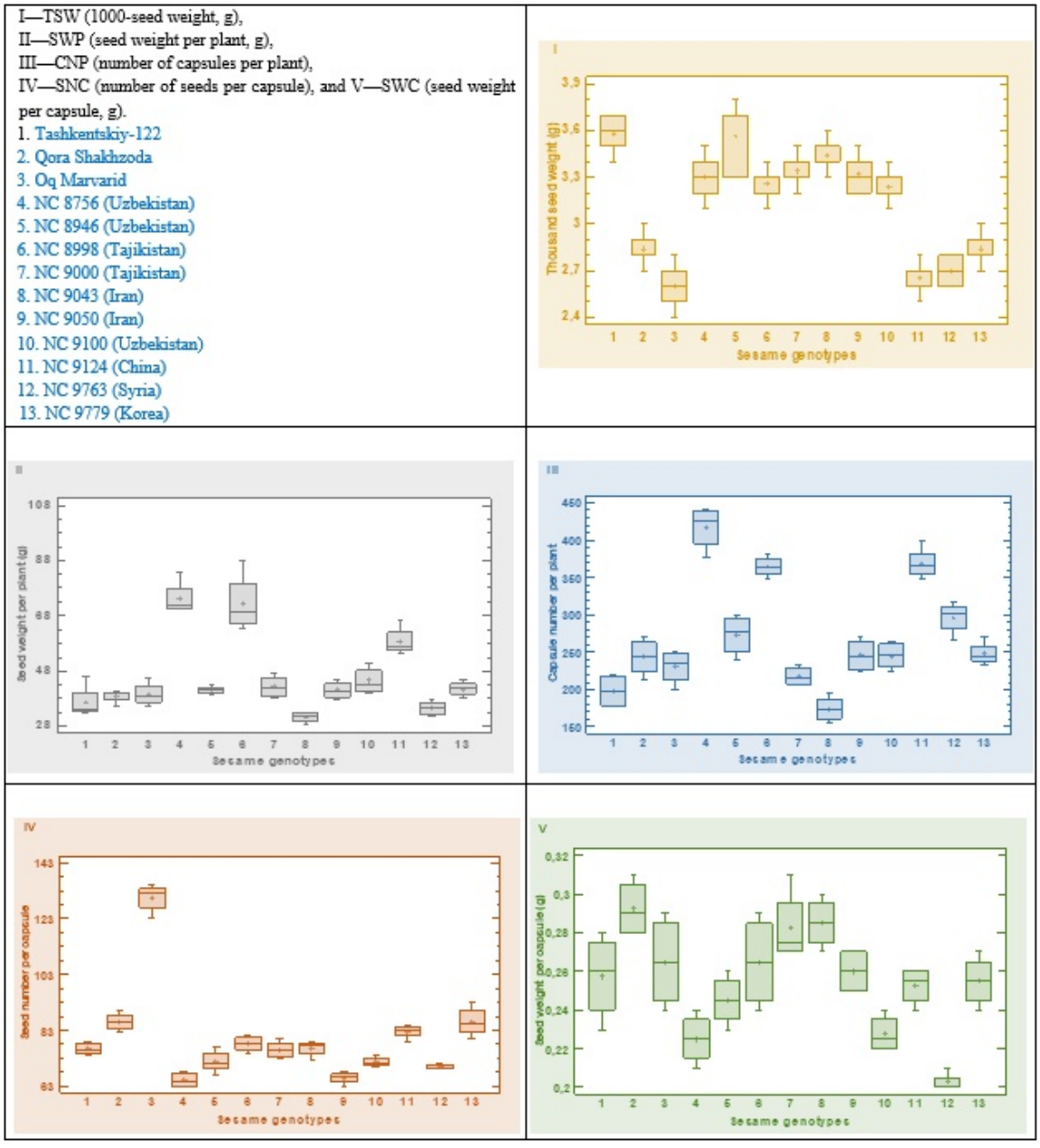


Fig. 3. Box plots of yield-related traits in 13 sesame genotypes based on genotype codes.

Among agricultural crops, 1000-seed weight (TSW) is considered one of the most important indicators of yield potential. In the present study, the highest TSW values were recorded in the local variety Tashkentskiy-122 (3.58 ± 0.02 g) and the accession NC 8946 (Uzbekistan; 3.56 ± 0.04 g), whereas the lowest value was observed in the variety Oq Marvarid (2.60 ± 0.01 g). In the remaining studied varieties and accessions, TSW ranged from 2.66 ± 0.01 g to 3.44 ± 0.02 g (Fig. 3-I).

Regarding seed weight per plant (SWP), the highest values were recorded in NC 8756 (Uzbekistan; 74.20 ± 1.15 g) and NC 8998 (Tajikistan; 72.40 ± 1.64 g). The lowest value was identified in the Iranian accession

NC 9043 (31.28 ± 0.31 g). In the other genotypes, the average SWP ranged between 34.54 ± 0.39 g and 58.58 ± 0.81 g (Fig. 3-II).

For the number of capsules per plant (CNP), the highest value was observed in NC 8756 (Uzbekistan; 417.50 ± 4.15 capsules), while the lowest was recorded in the Iranian accession NC 9043 (173.75 ± 2.82 capsules). In most of the studied varieties and accessions, CNP ranged from 197.75 ± 3.46 to 369.00 ± 3.08 capsules per plant (Fig. 3-III).

With respect to the number of seeds per capsule (SNC), the highest value was observed in the local variety Oq Marvarid (130.50 ± 0.79 seeds), whereas the lowest value was recorded in NC 8756 (Uzbekistan; 65.25 ± 0.40 seeds). In the remaining genotypes, this trait ranged from 66.00 ± 0.33 to 86.00 ± 0.89 seeds per capsule (Fig. 3-IV).

Concerning seed weight per capsule (SWC), the highest values were recorded in the local variety Qora Shakhzoda, as well as in the foreign accessions NC 9000 (Tajikistan) and NC 9043 (Iran), ranging between 0.28 and 0.29 g. The lowest value was observed in NC 9763 (Syria; 0.20 g). In the other varieties and accessions, the average SWC ranged from 0.22 g to 0.26 g (Fig. 3-V).

Protein and Oil Content

Proteins are essential biological substances for the human body, and sesame protein is considered a complete protein because of its balanced amino acid composition. Sesame flour and protein isolates are particularly rich in sulfur-containing amino acids, which distinguish them from many other plant proteins (Mustafa et al. 2023). Protein content varies among plant species and represents an important nutritional quality trait (Kodirova et al. 2024).

According to the experimental results, no substantial variation was observed in protein content among the studied sesame genotypes, with values ranging from 18.23% to 19.45% (Table 2). The highest protein content was recorded in genotype NC 8998 (Tajikistan), reaching 19.45%. The lowest values were observed in Tashkentskiy-122 and NC 9100 (Uzbekistan), both containing 18.23% protein. In the remaining genotypes, protein content ranged from 18.25% to 19.16%.

Sesame (*Sesamum indicum* L.) is one of the most important local oilseed crops, with seed oil content typically ranging from 46% to 56%. It is primarily cultivated for its seeds and is considered a major source of high-quality edible oil. Sesame oil contains natural antioxidants such as sesamin and sesamolin, which contribute to its nutritional and functional value (Umamaheswari et al. 2019).

Since sesame is an oilseed crop, the oil content of its seeds is an economically important trait. To determine oil content, ground plant samples were dried under laboratory conditions and subjected to solvent extraction. Various organic solvents such as diethyl ether, petroleum ether, gasoline, benzene, chloroform, and others are commonly used for lipid extraction. The lower the boiling point of the solvent, the easier it is to remove after oil extraction. In laboratory practice, diethyl (sulfur-containing) ether is frequently used for oil extraction. After extraction, the crude oil is separated from the solvent and weighed.

According to the obtained results, the highest oil content among the sesame genotypes was observed in NC

9050 (Iran; 50.44%) and NC 9100 (Uzbekistan; 50.14%). The lowest values were recorded in Oq Marvarid (44.11%) and NC 9779 (Korea; 44.97%). In the remaining genotypes, oil content ranged from 45.17% to 49.78% (Table 3).

Table 3. Protein and oil content (%) in seeds of sesame genotypes.

№	Sesame Genotypes (*Sesamum indicum* L.)	Nitrogen (%)	Protein (%)	Oil (%)
1	Tashkentskiy-122 (Local variety, Uzbekistan)	2.85 ± 1.61A	18.23 ± 1.45A	46.06 ± 0.51AB
2	Qora Shakhzoda (Local variety, Uzbekistan)	3.00 ± 1.87C	19.16 ± 1.30CE	45.56 ± 0.58A
3	Oq Marvarid (Local variety, Uzbekistan)	2.95 ± 1.55BC	18.85 ± 1.66C	44.11 ± 1.31A
4	NC 8756 (Uzbekistan)	2.86 ± 0.91A	18.25 ± 1.62A	48.47 ± 1.16C
5	NC 8946 (Uzbekistan)	2.89 ± 1.64AB	18.46 ± 1.18AB	45.17 ± 1.26A
6	NC 8998 (Tajikistan)	3.05 ± 1.80D	19.45 ± 1.68E	48.36 ± 0.90C
7	NC 9000 (Tajikistan)	2.99 ± 1.27C	19.11 ± 1.19CE	49.78 ± 1.38 CD
8	NC 9043 (Iran)	2.91 ± 1.45B	18.55 ± 1.85B	47.07 ± 1.61B
9	NC 9050 (Iran)	2.90 ± 1.82B	18.49 ± 1.76AB	50.44 ± 0.66D
10	NC 9100 (Uzbekistan)	2.86 ± 1.72A	18.23 ± 1.44A	50.14 ± 0.75D
11	NC 9124 (China)	2.89 ± 1.74AB	18.44 ± 1.83AB	47.71 ± 0.61B
12	NC 9763 (Syria)	2.95 ± 1.42BC	18.85 ± 0.90C	47.41 ± 1.50B
13	NC 9779 (Korea)	2.99 ± 0.60C	19.13 ± 1.48CE	44.97 ± 0.64A

Means followed by different letters within the same column are significantly different at $p<0.05$ according to Tukey's HSD test.

Fatty Acid Composition

Sesame oil consists of various fatty acids and non-lipid antioxidants. The seeds contain approximately 20% protein and a high proportion (83-90%) of unsaturated fatty acids, mainly linoleic acid (37-47%) and oleic acid (35-43%), along with palmitic acid (9-11%) and stearic acid (5-10%). Minor amounts of linolenic acid are also present. In addition, sesame seeds contain a high oil content (46-50%), about 20% protein, and carbohydrates (Kalaiyarasi et al. 2019a).

Besides these components, sesame oil contains a group of health-promoting compounds, including lignans (sesamin, sesamolin, sesaminol, and sesamolinol), tocopherols, phytosterols, and various micronutrients (Kalaiyarasi et al. 2019b).

In the present study, the fatty acid composition of oil extracted from seeds of 13 sesame genotypes was determined in the form of fatty acid methyl esters (FAMEs) using gas chromatography-mass spectrometry (GC-MS) with a "Chromatec-Crystal 5000" system (Table 4).

Based on the obtained results, considerable variability was observed in the fatty acid composition of sesame genotypes. Oleic acid, the principal monounsaturated fatty acid in sesame oil, ranged widely from 4.7% to 77.75% in seed samples. The highest levels were recorded in Tashkentskiy-122 and NC 9124 (China), reaching 77-77.75%. The lowest value (4.7%) was observed in the Oq Marvarid genotype. In the remaining genotypes, oleic acid content varied from 23% to 52.3%.

Linoleic acid showed the highest value in NC 9763 (Syria), reaching 40.44%. In NC 8998 (Tajikistan) and NC 9050 (Iran), linoleic acid content ranged from 37.27% to 37.7%. The lowest value (0.067%) was recorded in NC 9043 (Iran). In several genotypes (Tashkentskiy-122, Qora Shakhzoda, Oq Marvarid, NC 8756, NC 8946,

Table 4. Fatty acid composition (%) of sesame (*Sesamum indicum* L.) genotypes determined by GC-MS analysis.

No.	Sesame Genotypes (*Sesamum indicum* L.)	Oleic acid (Methyl oleate)	Linoleic acid (Methyl linolelaidate)	Palmitic acid (Hexadecanoic acid)	trans-9-Octadecenoic	Stearic acid (Octadecanoic acid)	Arachidic acid (Methyl arachidonate)	Hexanoic acid	Cis-10-Pentadecenoic acid
1	Tashkentskiy-122 (Local variety, Uzbekistan)	77.75	-	14.3	1.58	5.17	-	0.4	-
2	Qora Shakhzoda (Local variety, Uzbekistan)	31.33	-	9.7	34.8	4.46	4.3	6.2	8.57
3	Oq Marvarid (Local variety, Uzbekistan)	4.7	-	1.6	8.7	1.96	-	-	1.9
4	NC 8756 (Uzbekistan)	28.7	-	8.2	35	3.5	-	-	4.66
5	NC 8946 (Uzbekistan)	28.8	-	7.73	38.4	2.5	2.5	3.8	6.2
6	NC 8998 (Tajikistan)	42.62	37.27	13.12	0.95	4.3	0.2	0.12	-
7	NC 9000 (Tajikistan)	23	2	7	29.2	3	4.74	2.9	-
8	NC 9043 (Iran)	39.55	0.067	9.94	44.4	4.77	-	-	-
9	NC 9050 (Iran)	47.5	37.7	9.93	0.79	3.27	-	0.3	-
10	NC 9100 (Uzbekistan)	52.13	34.86	8.12	0.14	3.46	-	0.33	-
11	NC 9124 (China)	77	-	15.3	1.8	5	0.1	0.25	-
12	NC 9763 (Syria)	52.3	40.44	-	1	3.6	0.5	0.24	-
13	NC 9779 (Korea)	32.5	-	9.6	48	3.33	-	5.4	-
	Mean	41.38	11.72	8.81	18.83	3.72	0.95	1.53	1.64
	Range	4.7-77.7	0-40.4	0-15.3	0.14-48	1.96-5.1	0-4.74	0-6.2	0-8.57

and NC 9124), linoleic acid was not detected in the seed oil.

Palmitic acid, one of the main saturated fatty acids in sesame oil, reached its highest level in NC 9124 (China; 15.3%), while the lowest value (1.6%) was recorded in Oq Marvarid. In other genotypes, palmitic acid content ranged between 7% and 14.3%. It was not detected in NC 9763 (Syria).

Trans-9-octadecenoic acid was detected in the highest proportion (48%) in NC 9779 (Korea). The lowest levels were recorded in NC 9100 (Uzbekistan; 0.14%), NC 9050 (Iran; 0.79%), and NC 8998 (Tajikistan; 0.95%). In other genotypes, its content ranged from 1.5% to 44.4%.

Stearic acid, another important saturated fatty acid in sesame oil, was highest in Tashkentskiy-122 (5.17%) and lowest in Oq Marvarid (1.96%). In the remaining genotypes, stearic acid content ranged from 2.5% to 4.77%.

Arachidonic acid is generally present in very low amounts or absent in sesame oil. In this study, it was not detected in more than 50% of the evaluated genotypes. Small amounts (0.1-0.5%) were observed in foreign genotypes such as NC 9124, NC 8998, and NC 9763. Relatively higher levels (2.5-4.74%) were recorded in NC 8946, Qora Shakhzoda, and NC 9000.

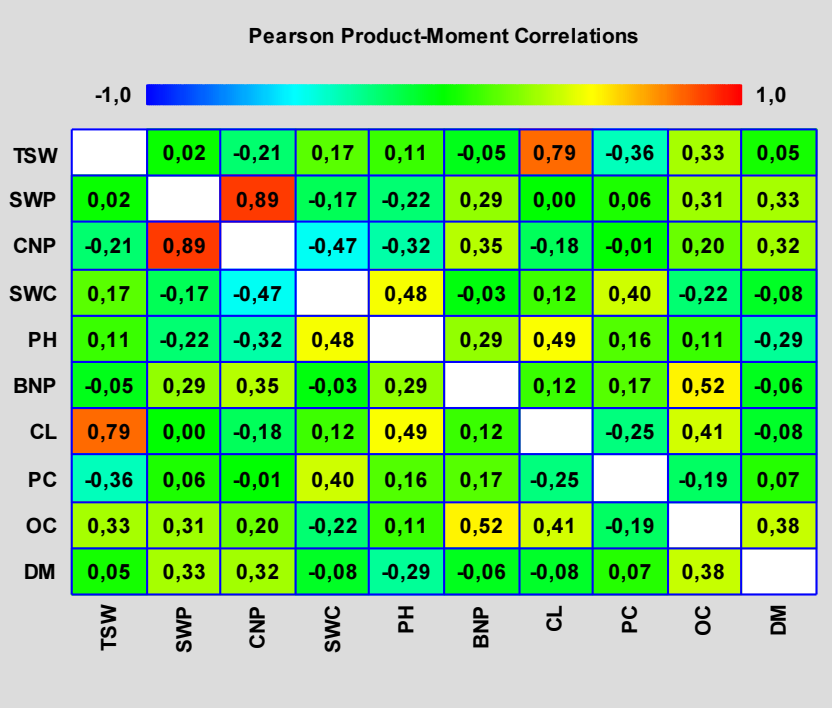
Hexanoic acid was detected in the highest amounts in Qora Shakhzoda (6.2%) and NC 9779 (5.4%). The lowest value (0.12%) was observed in NC 8998. This acid was not detected in Oq Marvarid, NC 8756, and NC 9043. In other genotypes, hexanoic acid content ranged from 0.24% to 3.8%.

Cis-10-pentadecenoic acid was detected only in 4 out of the 13 studied genotypes. The highest value (8.57%) was recorded in Qora Shakhzoda, while the lowest (1.9%) was observed in Oq Marvarid.

Correlation Analysis

During the course of the study, the relationships among several traits in sesame—including agronomic traits, yield components, and biochemical parameters—were analyzed to determine the presence and strength of associations (Fig. 4).

To determine the relationships among the studied morpho-agronomic traits and yield components, Pearson's correlation analysis was performed. The results revealed the presence of both positive and negative correlations of varying magnitudes among the evaluated traits.



Where: TSW - 1000-seed weight, SWP - seed weight per plant, CNP - number of capsules per plant, SNC - number of seeds per capsule, SWC - seed weight per capsule, PH - plant height, BNP - number of productive branches per plant, CL - capsule length, PC - protein content, OC - oil content, and DM - days to maturity.

Fig. 4. Correlation coefficients among yield components, morpho-agronomic traits, and biochemical parameters (protein and oil content) in sesame (*Sesamum indicum* L.).

According to the analysis, a strong positive correlation was observed between 1000-seed weight (TSW) and capsule length (CL; r = 0.79), as well as between the number of productive branches and seed weight per plant (SWP; r = 0.89). These findings are biologically reasonable, as longer capsules generally allow better seed development, which may increase 1000-seed weight. Likewise, a greater number of productive branches can lead to higher seed production per plant, ultimately increasing seed weight per plant.

Moderate positive correlations were identified between plant height (PH) and capsule length (CL; r = 0.49), and between plant height (PH) and seed weight per capsule (SWC; r = 0.48). These results suggest that vegetative

growth may influence the development of generative organs to a certain extent.

Negative correlations were also recorded. A moderate negative association was found between the number of capsules per plant (CNP) and seed weight per capsule (SWC; r = -0.47). Additionally, a moderate negative correlation was observed between 1000-seed weight (TSW) and protein content (PC; r = -0.36). The negative relationship between total protein content and 1000-seed weight may be explained by the "dilution effect," whereby an increase in seed mass is accompanied by a relative decrease in protein concentration.

For some traits, very weak or nearly absent correlations (r ≈ 0) were detected, indicating their independent inheritance and expression.

Overall, the results demonstrate that the selection of certain morpho-agronomic traits may indirectly contribute to improvements in yield-related characteristics.

Integrated Principal Component Analysis (PCA) of Morpho-Agronomic, Yield-Related, and Biochemical Traits

An integrated principal component analysis was performed to evaluate the multivariate relationships among the 13 sesame genotypes using representative morpho-agronomic, yield-related, and biochemical traits. The first two principal components explained 56.91% of the total variation, with PC1 accounting for 31.65% and PC2 for 25.26% (Fig. 5). The PCA biplot revealed clear differentiation among genotypes according to their combined

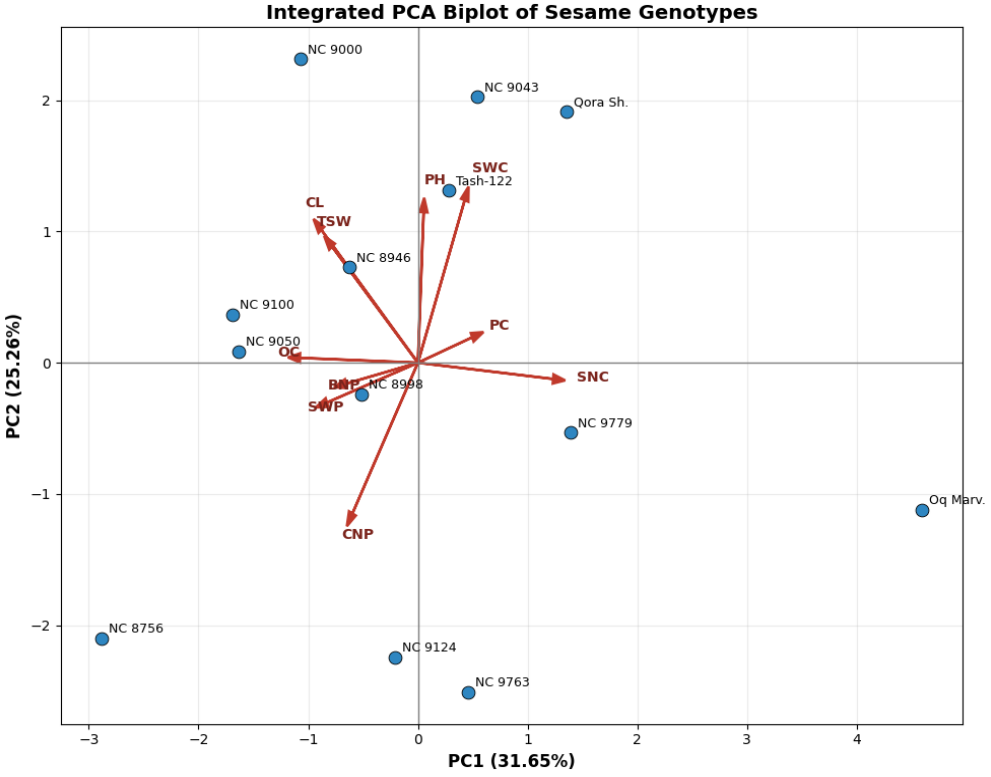


Fig. 5. Integrated principal component analysis (PCA) biplot of 13 sesame (*Sesamum indicum* L.) genotypes based on standardized morpho-agronomic, yield-related, and biochemical traits.

trait profiles. PC1 was mainly associated with variation in seed number per capsule (SNC), protein content (PC), oil content (OC), seed weight per plant (SWP), capsule number per plant (CNP), capsule length (CL), and thousand-seed weight (TSW), whereas PC2 was primarily influenced by plant height (PH), seed weight per capsule (SWC), capsule length, and thousand-seed weight. The distribution of genotypes confirmed substantial multivariate variation and supported the identification of contrasting materials for sesame breeding.

Discussion

The present study revealed considerable variation among sesame (*Sesamum indicum* L.) genotypes with respect to morphological and agronomic traits. The highest plant height was observed in the local variety Qora Shakhzoda (230.29 ± 1.98 cm), whereas the lowest value was recorded in accession NC 9763 originating from Syria (82.5 ± 1.58 cm). The highest number of productive branches was found in genotype NC 9050 introduced from Iran (8.80 ± 0.33), while the greatest capsule length (3.70 ± 0.03 cm) was recorded in accession NC 9000 from Tajikistan. (Muhammad et al. 2024) reported average values of 91.1 ± 3.39 cm for plant height, 6.7 ± 0.91 for the number of productive branches, and 56.5 ± 1.91 mm for capsule length in different sesame genotypes. Similarly, (Patel et al. 2023) reported a plant height of 92.66 cm and an average of 2.76 productive branches per plant. Except for the tall local variety Qora Shakhzoda, the results obtained in the present study were generally consistent with those reported previously, indicating substantial genetic variability among sesame genotypes.

The present study also evaluated major yield-related traits, including the number of capsules per plant (CNP), number of seeds per capsule (SNC), seed weight per capsule (SWC), seed weight per plant (SWP), and thousand-seed weight (TSW). The highest thousand-seed weight was recorded in the local variety Tashkentskiy-122 (3.58 ± 0.02 g) and accession NC 8946 from Uzbekistan (3.56 ± 0.04 g). Seed weight per plant reached the highest values in accessions NC 8756 (Uzbekistan) and NC 8998 (Tajikistan), with 74.20 ± 1.15 g and 72.40 ± 1.64 g, respectively. The maximum number of capsules per plant was observed in NC 8756 (417.50 ± 4.15), whereas the highest number of seeds per capsule was recorded in the variety Oq Marvarid (130.50 ± 0.79). In addition, the greatest seed weight per capsule was obtained in Qora Shakhzoda and in accessions NC 9000 (Tajikistan) and NC 9043 (Iran), ranging from 0.28 to 0.29 g. (Kalaiyarasi et al. 2019a) reported that thousand-seed weight varied from 2.4 to 3.8 g, the number of capsules per plant ranged from 133 to 255.7, and the number of seeds per capsule ranged from 48.9 to 82.0 in different sesame genotypes. Similarly, (Sudha Sundari et al. 2024) reported a thousand-seed weight of 3.74 g and an average of 147.33 capsules per plant. These findings are generally in agreement with the results obtained in the present study. The relatively higher values observed in some accessions may be attributed to genotypic differences and the influence of environmental conditions on the expression of yield-related traits.

Considerable variation was also observed in protein and oil contents among the studied sesame genotypes. The highest protein content was recorded in accession NC 8998 from Tajikistan (19.45%). In terms of oil content, the highest values were obtained in genotypes NC 9050 from Iran (50.44%) and NC 9100 from Uzbekistan (50.14%).

(Parsaeian et al. 2020) reported that oil content in different sesame genotypes ranged from 32.6% to 63.78%. Similarly, (Abdipour et al. 2018) observed oil contents varying between 45.3% and 60%, whereas (Uzun et al. 2008) reported values ranging from 41.3% to 62.7%. These findings indicate substantial variability in seed oil accumulation among sesame genotypes and are generally consistent with the results obtained in the present study.

Recent studies have also confirmed considerable variation in protein and oil contents among sesame genotypes. Reported substantial differences in the physicochemical composition of sesame seeds produced in Burkina Faso, highlighting the importance of genotype and environmental conditions in determining seed quality. Similarly, (Muhammad et al. 2024) emphasized the existence of significant genetic variability for yield and quality-related traits, which provides valuable opportunities for selecting superior genotypes for sesame breeding programs. These findings are in agreement with the results obtained in the present study.

Considerable variation was observed in the fatty acid composition of the studied sesame genotypes. Oleic acid, the major monounsaturated fatty acid in sesame oil, exhibited a wide range from 4.7% to 77.75%. The highest oleic acid contents (77.0-77.75%) were recorded in Tashkentskiy-122 and NC 9124 (China). In addition, substantial polymorphism was detected for other fatty acids, indicating the presence of considerable diversity among the studied genotypes. The identification of genotypes with high proportions of nutritionally important fatty acids highlights their potential value for sesame breeding programs aimed at improving oil quality. (Oboulbiga et al. 2023) reported oleic and linoleic acid contents ranging from 40.0% to 44.1%, palmitic acid contents from 7.9% to 12.0%, and stearic acid contents between 4.8% and 6.1% in different sesame genotypes. Similarly, (Thakur et al. 2018) reported that oleic acid content ranged from 39.88% to 48.81%, linoleic acid content varied from 31.84% to 41.73%, palmitic acid content ranged from 8.33% to 10.15%, and stearic acid content varied between 5.34% and 7.0%. These findings are in close agreement with the results obtained in the present study.

The considerable variation observed in oil content and oleic acid composition among the studied sesame genotypes may be attributed to genetic differences among accessions, as well as to the influence of environmental factors affecting lipid biosynthesis. Previous studies have demonstrated that fatty acid composition is largely controlled by genotype and may also be influenced by temperature, moisture availability, and growing conditions during seed development. Therefore, the wide variation detected in the present study indicates the existence of valuable genetic resources for improving oil quality and nutritional characteristics in sesame breeding programs.

A correlation analysis was performed to evaluate the relationships among important agronomic and biochemical traits in the studied sesame varieties and accessions. Both positive and negative correlations were identified among the investigated traits. A strong positive correlation was observed between the number of capsules per plant (CNP) and seed weight per plant (SWP; $r = 0.89$). Similar associations among yield-related traits were reported by (Ashri et al. 2006) and (Ali et al. 2020), emphasizing the importance of capsule number in determining seed productivity in sesame.

A strong positive correlation ($r = 0.79$) was also detected between thousand-seed weight (TSW) and capsule length (CL). (Emamgholizadeh et al. 2015) reported a similar relationship between these traits, indicating that larger capsules are generally associated with heavier seeds. In addition, a moderate positive correlation ($r = 0.48$) was found between plant height (PH) and seed weight per capsule (SWC), while a significant positive

correlation (r = 0.52) was observed between the number of branches per plant (BNP) and oil content (OC). These results suggest that such characteristics may serve as useful selection criteria for identifying superior and high-yielding genotypes. Comparable relationships among agronomic traits were also reported by (Abdipour et al. 2018).

Negative correlations were detected among several traits. In particular, a moderate negative correlation (r = -0.47) was found between the number of capsules per plant (CNP) and seed weight per capsule (SWC), suggesting the existence of a compensatory relationship among yield components. This finding indicates that the improvement of one yield component may be accompanied by a reduction in another, reflecting the complex nature of trait interactions in sesame.

The integrated PCA further demonstrated that the differentiation among sesame genotypes was determined by a combination of morpho-agronomic, yield-related, and biochemical traits rather than by seed composition alone. The first two principal components explained 56.91% of the total variation, indicating that a substantial proportion of the multivariate diversity could be summarized by these two axes. Traits related to seed yield, capsule characteristics, plant architecture, protein content, and oil content contributed differently to genotype separation. These findings support the use of multivariate analysis for identifying genotypes combining favorable agronomic performance with desirable seed-quality characteristics.Overall, the results obtained in the present study are in agreement with previous reports on the morphological, agronomic, and biochemical characteristics of sesame. The findings confirm that traits such as capsule length, number of capsules per plant, thousand-seed weight, and oil content are important selection criteria and may play a significant role in future sesame breeding programs.

Although considerable variation was detected among the studied sesame genotypes for agronomic, yield-related, and biochemical traits, the experiment was conducted under a single environment and irrigated conditions. Therefore, the individual effects of climatic variation, soil properties, and water stress on trait expression were not evaluated separately. Further investigations under multiple environments and stress conditions are required to assess the stability and adaptability of promising genotypes and to confirm their breeding potential under diverse environmental conditions.

Conclusion

This study revealed significant genetic variability among 13 sesame genotypes for morpho-agronomic, yield, protein, oil, and fatty acid traits. ANOVA confirmed significant genotypic differences, demonstrating the availability of valuable material for sesame breeding. NC 8998 showed the highest protein content, while NC 9050 and NC 9100 had the highest oil content. Tashkentskiy-122 and NC 9124 were distinguished by high oleic acid levels and may be useful for improving oil stability and nutritional quality. Overall, NC 8756, NC 8998, NC 9050, and NC 9100 were identified as promising genotypes for yield and oil-related improvement. The observed correlations suggest that yield may be improved indirectly through selected morphological traits. However, the

negative relationship between protein content and seed weight indicates that simultaneous improvement of productivity and seed quality will require a balanced breeding strategy.

Acknowledgments

This article was prepared based on scientific research carried out within the framework of state scientific programs funded by the State Budget of the Republic of Uzbekistan and supported by the Academy of Sciences of the Republic of Uzbekistan.

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