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# GENETIC VARIABILITY AND CORRELATION ANALYSES AMONG THE SUNFLOWER $F_3$ POPULATIONS FOR ECONOMIC TRAITS IN KARAKALPAKSTAN

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## SUMMARY

This study presents an evaluation of the variability for seed oil content and the relationship among the economic traits of sunflower (*Helianthus annuus* L.) $F_3$ populations under the environmental conditions of Karakalpakstan, Uzbekistan. Under simulated drought conditions, complex hybrids provided the basis for transgressive families due to high heterozygosity. It shows the location of families with high oil content was on the right side, making the selection in the sunflower $F_3$ simple and complex hybrid families. A moderate and high positive correlation existed between root mass and productivity traits, while a high positive correlation occurred between root mass and plant height. Moreover, a moderate positive correlation showed between root mass and head diameter, and varied correlations appeared between root mass and the total leaf surface area. The results revealed a weak to moderate negative correlation between the seed oil content and head diameter in the plants. The correlation analysis of seed oil content variability and the relationship of economically valuable traits in sunflower $F_3$ hybrid families indicated that larger heads correspond to lower oil content in most cases.

**Keywords:** Sunflower (*H. annuus* L.), simple and complex hybridization, variability, correlation analysis, root mass, productivity, plant height, leaf surface area, oil content

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**Key findings:** Through complex hybridization, the sunflower (*H. annuus* L.) $F_3$ families with high oil content attained selection under simulated drought conditions. The complex hybridization and high heterozygosity provided the basis for the emergence of transgressive segregants.

**INTRODUCTION**

On the global level, the conduct of comprehensive studies is ongoing on oilseed crops to identify the economically valuable traits, including seed oil content, due to the growing demand for vegetable oil. Given the high nutritional and dietary values, vegetable oil replaces animal fats in human consumption. Many large producers of sunflower (*Helianthus annuus* L.) abound on all continents of the Earth. Abdukarimov and Lukov (2019) have a vast collection of oilseeds at the All-Russian Research Institute of Plant Growing, and the plant breeders developed promising cultivars and hybrids of sunflower and other oilseed crops. Yormatova and Khushvaqtova (2008) developed the sunflower cultivars and hybrids with 55%–56% seed oil, with some varieties even having up to 60% oil content and 16% protein. According to Oripov and Khalilov (2006), the oilcake obtained by processing sunflower seeds proved very nutritious, containing 20%–35% protein, and especially was considered good feed for dairy cows. Razi and Assad (1999) obtained correlations of similar magnitude for the stem diameter (SD) but substantially lower for the head diameter (HD) (Razi and Assad, 1999). Syed *et al.* found no significant correlation between the OY (oil yield) and HD, while they found a moderate correlation between the HD and seed yield of 0.62 (Syed *et al.,* 2004).

With climate change, the water shortage negatively affected various crops, including oilseeds. The achievements through plant genetics and selection and in-depth study of the oilseeds flowering biology and the inheritance of economic traits showed improvement through the development of promising cultivars. According to Amanov *et al.* (2017), water is one of the primary factors in obtaining oil and high yields in sunflowers. Water scarcity disrupts the physiological processes and eventually influences the plant's growth and development. Bochkarev *et al.'s* (1992) findings revealed high-quality sunflower seeds increased seed yield by 20%–30%. However, to cultivate high-grade sunflower seeds, it is necessary to have complete information on their morpho-biological traits, flowering biology, and varietal characteristics.

In crop breeding, including sunflower, simple and complex hybridization are applicable to achieve wide variability in seed yield and oil traits to develop new genotypes. Regardless of how the hybridization proceeded, it leads to variations in heredity, resulting in the development of new genotypes with wide adaptation under varied environmental conditions. Through simple and complex hybridization of sunflowers under varied soil and climatic conditions of Karakalpakstan, the $F_3$ generation hybrids reached development, resulting in a change in one trait that leads to a considerable change in other traits (Genjeeva, 2018). The most effective way to increase the gross seed yield and oil of sunflower is the creation of new cultivars with high productivity and agroecological adaptation to varied soil and climatic conditions (Belevsev, 2003).

Sunflower hybrids developed through heterosis breeding have led to a sharp increase in this crop's yield and vegetable oil production (Kholmurodova and Abdiev, 2018; Buronov and Xamroev, 2022). Sunflowers are widely cultivated plants in the Commonwealth of Independent States, including the North Caucasus, Ukraine, Moldova, the Central Black Soil Region of Russia, and several regions of the Urals, Siberia, and Kazakhstan. In Uzbekistan, sunflower cultivation is greatly valuable, grown for silage preparation, seed production, and oil extraction (Buronov *et al*., 2023; Juraev *et al*., 2024).

Sunflower kernels are highly precious in medicine, where the selenium substance found in their composition has proven to prevent cancer (Lukov *et al*., 2019). Consuming a half glass of the sunflower seeds satisfies 95% of a person's daily requirement for vitamin E and several other important properties. Growing the early-maturing sunflower varieties on stubble lands freed from grain crops can obtain a seed yield of 2.5–3.0 t/ha and can succeed over a short period of 75–85 days. From this seed yield, successful extraction of 1.1–1.3 tons of oil and 1.2–1.5 tons can result.

The development of the agricultural sector in our republic and conducting in-depth practical research tended to be one of the main tasks of today. With the growing population, the demand for food products is increasing, especially for oil and fat products—various types of vegetable oils, with their need growing every day. Therefore, it is essential to develop the early-maturing and productive cultivars with high-oil content in sunflowers that are also resistant to various unfavorable environmental conditions, specifically drought. It is also vital to analyze the inheritance, variability, and relationship of economically valuable traits, crucial in developing early-maturing and high-yielding cultivars resistant to various biotic and abiotic factors.

Under the conditions of Karakalpakstan, developing the early-maturing, high-yielding, high-oil-bearing, and drought-resistant sunflowers is critical. Likewise, to meet the requirements of modern production and processing technologies, it is crucial to study the variability of the oil content in sunflower $F_3$ populations and the relationship of root mass and oil traits with other economically valuable traits.

## MATERIALS AND METHODS

The said research commenced under field and laboratory conditions at the Karakalpak Research Institute of Agriculture, Uzbekistan. The institute sits 4 km northeast of the city of Chimbay, in the territory of the District of Chimbay, Republic of Karakalpakstan, at 430–440 Northern latitudes. The mechanical composition of the soils of the experimental field was medium and light loams, with the groundwater located at a depth of 2.0–3.0 m. In summer, these were mostly cloudless days, with annual precipitation reaching 150–160 mm. During spring, the freezing temperature of the soil surface mainly occurs in March. In autumn, the freezing point of the upper soil layer arises at the end of October and at the beginning of November.

In field conditions, the sunflower seeds' sowing had a depth of 3–5 cm in an order of 60 × 30 × 1, in triples of 50 cells, and 3–4 seeds per cell. The variability range of some economically valuable traits in sunflower $F_3$ populations entailed studies in comparison with the parental forms. The oil content of sunflower seeds, as determined, employed a modern YAMR AMV-1006M analyzer. The recorded data on various traits based on the field and laboratory experiments underwent statistical processing and analysis following the methodology of Dospekhov (1985).

## RESULTS

Sunflower (*H. annuus* L.) cultivars' division comprised the following three subtypes based on seed size, oil content, and kernel yield. The cracked sunflower stem was thick, 4 m tall, with large leaves and heads up to 45 cm in diameter. The pistil was 11–23 mm long and 7.5–12 mm wide. The kernel occupies half of the pistil, and the 1000-seed weight was around 100–170 g. The height of the oilseed sunflower stem was 1.5–2.5 m, with branches and many heads. The head diameter was 14–20 cm. The pistachio was 7–13 mm long and 4–7 mm wide. The kernels completely occupied the pistachio, the shell was 40%–43%, and the 1000-seed weight was 35–80 g. In Eastern Siberia, the sunflower silage contains 25% protein, 8% fat, and 17% carbohydrates, matching corn in nutritional values (Voronin and Kruglov, 2007). Sunflower seeds contain up to 38% oil, 19% protein, 27% carbohydrates, and 2% phytin, as well as citric acid, with the inflorescences and leaves containing butyric and salicylic acids, while the marginal flowers have betalin, choline, flavonoids, and carotene (Sulliyeva and Ulug'berdiyev, 2018).

In the presented studies using Russian sunflower cultivars, a variational analysis of the oil traits ensued, obtained from simple and complex hybridization with high productivity

**Table 1.** Variational analysis of sunflower $F_3$ populations for seed oil content.

| No. | Simple and complex hybrids | K = 1 | | | | | | | | n | M±m | δ | V% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | | | | |
| 1 | $F_3$ (Tels x KK-1) | 2 | 6 | 11 | 7 | 5 | 4 | - | - | 35 | 48.5±0.2 | 1.4 | 2.8 |
| 2 | $F_3$ (C-AlstorxKK-1) | - | 1 | 3 | 10 | 11 | 8 | 3 | 1 | 37 | 49.9±0.2 | 1.2 | 2.5 |
| 3 | $F_3$ (S-HS-H-2011y x KK-1) | 1 | 4 | 8 | 12 | 7 | 3 | 1 | - | 36 | 48.9±0.2 | 1.3 | 2.6 |
| 4 | ₣3 (Jant lower x KK-1) | 4 | 3 | 10 | 9 | 4 | 3 | - | - | 33 | 48.4±0.2 | 1.4 | 2.9 |
| 5 | $F_3$ (Sor Gollips x KK-1) | - | - | 2 | 3 | 13 | 7 | 6 | 1 | 32 | 50.4±0.2 | 1.1 | 2.3 |
| 6 | $F_3$ (Ak-12/95 x KK-1) | 2 | 6 | 9 | 12 | 5 | 2 | - | - | 36 | 48.5±0.2 | 1.2 | 2.5 |
| 7 | $F_3$ *($F_1$ [Jant lower x KK-1]) x ($F_1$ [Ak-12/95 x KK-1]) | - | - | 1 | 2 | 11 | 9 | 7 | 4 | 34 | 50.9±0.2 | 1.2 | 2.4 |
| 8 | $FF_3$ ($F_1$ [S-HS-H-2011y x KK-1] x [C-Alstor x KK-1]) | - | 2 | 4 | 3 | 10 | 10 | 3 | 1 | 33 | 50.0±0.2 | 1.4 | 2.9 |
| 9 | $F_3$ ($F_1$ [Sor Gollips x KK-1]) x ($F_1$ [Tels x KK-1]) | - | - | 3 | 3 | 6 | 12 | 8 | 2 | 34 | 50.7±0.2 | 1.3 | 2.6 |

and oil content, adapted to the conditions of Karakalpakstan. The study established that under drought conditions, modeled by the oil content, variation series $F_3$ occurred in eight classes (K=1) in simple and complex hybrid families. However, for the said trait in simple hybrids, families were 32–37 plants. Meanwhile, in complex hybrids, up to 33–34 plants showed locations in the variation series differently, with the plants having relatively high indicators located in the sunflower complex hybrids (Table 1).

Among the sunflower's six simple hybrids, three hybrids emerged with the highest oil content under simulated drought conditions of 52 g and above, resulting in 2.7% to 19.4% of plants, comprising the most productive 1 to 7 families. It was evident that the $F_3$ simple hybrid families comprised distribution in 4–6 classes for this trait, with 34.2% to 56.7% of the plants in these families. Families with relatively low oil content appeared in 22.8% of the $F_3$ (Tels × KK-1) hybrid families and 22.2% of the $F_3$ (Ak-12/95 × KK-1) hybrid families, with eight families in each. In $F_3$ simple sunflower hybrids, the coefficient of variation for oil content occurred to range from 2.3% to 2.9%.

In three complex $F_3$ hybrid families of sunflower, the main plants placed in 5–6 classes ranged from 52.9% in $F_3$ ($F_1$ [Sor Gollips × KK-1] × $F_1$ [Tels × KK-1]) to 60.6% in $F_3$ ($F_1$ [S-NS-H-2011g. × KK-1] × $F_1$ [S-Alstor x KK-1]) hybrid generations, based on the oil content. However, the transgressive plants for the said trait were more abundant in complex than in simple hybrid families. In complex hybrids, the coefficient of variability ranged from 2.7% to 2.9%. The analysis based on oil content in simple and complex $F_2$ sunflower populations revealed plants with higher oil content were distinct in four simple cross combinations and two complex hybrids compared with other hybrids.

Thus, under simulated drought conditions, due to its high heterozygosity, the complex hybridization became the basis for the emergence of the transgressive plant families. Families with valuable economic traits, such as early maturity, leafiness, positive root mass, and higher oil content, indicated a location on the right side of the variation series and became selected. Through simple and complex hybridization, the $F_3$ generation sunflower hybrids, as studied under varied soil and climatic conditions of Karakalpakstan, provided their findings showing a change in one trait leads to a correlative change in other traits (Genjeeva, 2017).

The relationship among various traits was mostly of varying degrees, and from a genetic viewpoint, this can be due to the clustering of genes at one locus or through genes' pleiotropic effect. The traits' relationship is of two types—uniform and non-uniform. In a uniform systematic correlation, an increase or decrease in one variable may cause the same pattern in other traits. In the first case,

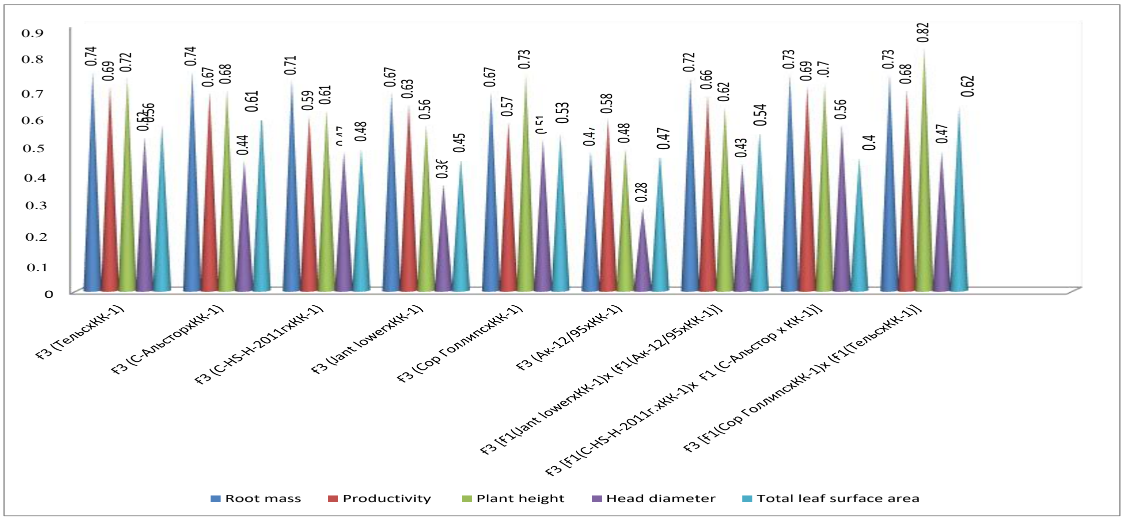


**Figure 1.** Correlation among the root mass, productivity, plant height, head diameter, and the total leaf surface area in sunflower plants.

positive correlation arises, while negative correlation surfaces in the second case. For developing initial material through breeding, the sunflower lines and cultivars with positive economical traits and their relationship need more analysis. Fayziyev and Salomov (2011) achieved the highest yields in sunflower cultivation with substantial income by utilizing the latest scientific and innovative technologies.

In the presented study, mathematical analysis took place for the correlation between root weight and various economic traits. These were plant productivity, plant height, head diameter, and the total leaf area in simple and complex $F_3$ hybrid families of sunflower examined under simulated drought conditions (Figure 1). In six $F_3$ simple hybrid families, moderate to strong positive correlation was notable between the root weight and productivity traits. The correlation coefficient ranged from 0.57 in $F_3$ (Sor Gollips × KK-1) to 0.69 in $F_3$ (Tels × KK-1). In three complex hybrid families, a significant positive correlation materialized, ranging from 0.66 to 0.69. These results provide information about the linkage of genes controlling these traits. Among these traits, the highest positive correlation coefficients resulted in the families of simple hybrids $F_3$ (Tels × KK-1), $F_3$ (S-Alstor × KK-1), and $F_3$ (Jant lower × KK-1), ranging from 0.63 to 0.69. In complex hybrid populations, the topmost positive correlations appeared in the $F_3$ ($F_1$ [S-NS-H-2011g. × KK-1] × $F_1$ [S-Alstor × KK-1]) family (0.69) and $F_3$ ($F_1$ [Sor Gollips × KK-1] × $F_1$ [Tels × KK-1]) family (0.68).

Root weight also showed a significant positive correlation with plant height, and correlation coefficients ranged from 0.48 to 0.73 in simple hybrids and from 0.62 to 0.82 in complex hybrids. In sunflower genotypes under water-deficit conditions, root weight significantly influenced the plant's growth and development. The well-developed root system of the sunflower absorbs more nutrients and water, eventually affecting plant growth and development. In $F_3$ simple and complex hybrid families, the correlation between root mass and the head diameter was moderately positive. In sunflower simple hybrids, it ranged from 0.36 to 0.52, while in complex hybrids, the said range was 0.43 to 0.56. The root mass signified a correlation to the total leaf surface

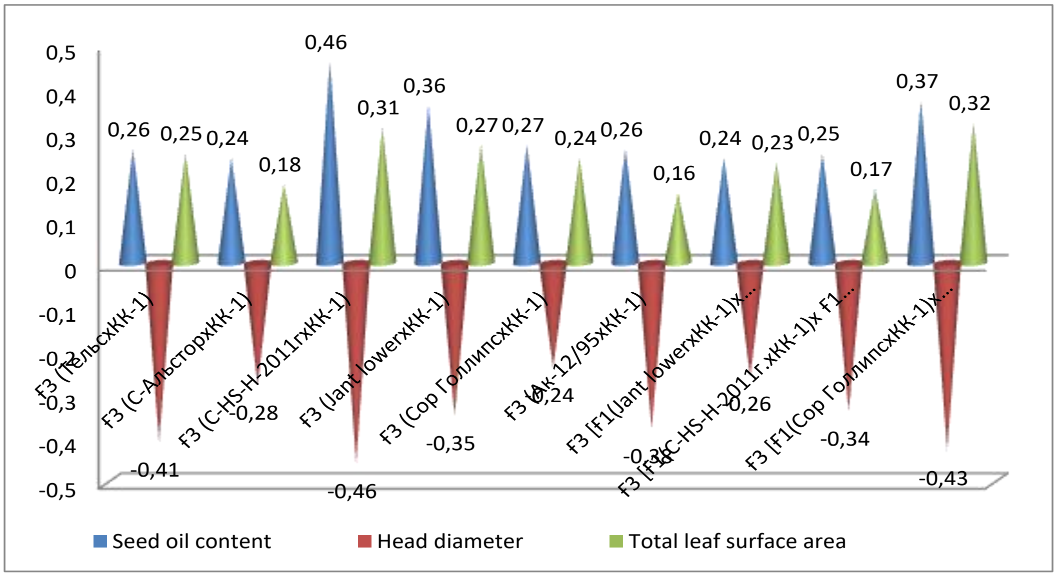


**Figure 2.** Correlation among the seed oil content, head diameter, and the total leaf area of sunflower plants.

area with varying degrees. In sunflower simple and complex hybrids, the correlation coefficient ranged from 0.4 to 0.5. Under simulated drought conditions, relevant correlation resulted in simple hybrids $F_3$ (S-Alstor × KK-1) and complex hybrids $F_3$ ($F_1$ [Sor Gollips × KK-1]) × ($F_1$ [Tels × KK-1]), with correlation coefficients exceeding 0.6. Consequently, the relationship in highly heterozygous hybrids shifts in a positive direction, with the higher values of two to three traits combined in a single genotype, which leads to a dramatic acceleration in the breeding process. Mamataliyev (2012) reported the highest values for sunflower stem height, leaf count, head size, and 1000-seed weight were evident under different field irrigation methods.

Establishing the relationship between the seed oil content and the head diameter and leaf surface area of sunflower genotypes has been successful (Figure 2). The diameter of the rhizomes displayed a weak and moderately negative correlation with the seed oil content. In simple hybrids, the said range was -0.24 (Sor Gollips × KK-1) to -0.46 (C-NS-H-2011g. × KK-1), while in complex hybrids, the said range was -0.17 to -0.34. It revealed that the larger the sunflower heads, the lower the oil content occurred in most cases. A weak positive correlation was for the seed oil content and leaf area in all the cross combinations. The relationship between these traits in simple hybrids ranged from 0.16 to 0.31, while in complex hybrids, the said range was from 0.17 to 0.32. Thus, the study established that the sunflower seed oil content with a strong leafy root system was somewhat higher.

In studies conducted over several years and analysis of the vegetation period, obtaining plant height, leaf number, root mass, plant productivity, and seed oil content in simple and complex hybrids resulted from crossing the local KK-1 and Russian sunflower cultivars. The $F_3$ simple hybrids (S-Alstor × KK-1) and $F_3$ (Sor Gollips × KK-1) and $F_3$ complex hybrids ($F_1$ [Jant lower × KK-1]) × ($F_1$ [Ak-12/95 × KK-1]) and $F_3$ ($F_1$ [Sor Gollips × KK-1]) × ($F_1$ [Tels × KK-1]) were in a positive state. These new families became selections in subsequent years to combine the most economically valuable traits and to develop new cultivars.

**DISCUSSION**

Sunflower (*H. annuus* L.) yield primarily depends on the productivity of individual heads and plant population per hectare (Egamov *et al.,* 2019). The productivity of a separate head relies on the number of seeds and the mass and weight of each seed. Here, the seed yield is of greater importance in sunflowers. This indicator depends upon the yield of the seed coat from the total mass. A 10% increase in the seed kernel leads to a 6%–7% increase in seed oil content. As a result of the selection process, the seed coat yield lessens from 40%–45% to 20%–25% in regionalized sunflower cultivars and hybrids.

Through intervarietal hybridization and developing sunflower source material, it is necessary to consider certain rules based on the experience in breeding practices (Borodin, 2002). Analyzing the sunflower breeding history, the increase in the seed yield occurs mainly due to an increase in the seed oil content in the seed kernels of the modern sunflower cultivars. Being a technical oilseed crop, the sunflower seed yield has a complex concept and includes two characteristics, i.e., seed oil content and the seed yield per unit area. Burdon (1977) proposed two types of genetic correlations: type-A correlation between two traits measured on the same individuals within the same environment or across the environments and type-B correlation between the same trait on the same individuals but measured in different environments.

Based on the results of research conducted by several scientists in probing new sunflower genotypes under the environmental conditions of Karakalpakstan, they came to the following conclusions. Under natural salinization conditions of Karakalpakstan, the seed yield of a new high-yielding seed kernel during station variety testing proves itself in the development of sunflower genotypes that meet world standards with relatively high indicators. In studied lines, the lines L-24, L-28, L-43, and L-63 with relatively high indicators for the economically valuable traits versus the standard variety could entail transferring to a large competitive variety-testing nursery next year (Aytjanov and Aytjanov, 2017).

The heterosis in sunflowers has greater economic importance, with the same reported by Nikitchin (2002). The homogeneity of the hybrid crops, the simultaneous ripening of the entire biological mass, allows for accelerating the harvest, which eventually positively affects the product quality. To date, the ideas about heterosis have become more specific and include the hypothesis of favorable dominant factors, with the concepts of extreme dominance and the genes' balance as key elements. The highest values for sunflower stem height, leaf count, head size, and 1000-seed weight emerged under different field irrigation methods (Mamataliyev, 2012).

Past studies reported the negative impact of soil salinity appeared more pronounced in sunflower plants planted late and as a repeated crop compared to those grown with early sowing (Lukov, 2010). In early spring, due to natural precipitation, the washing away of easily soluble salts in the arable layer of the soil flowed to the lower layer. In this case, uniform seedlings emerge from the sown seeds. However, if the sunflower field received a sufficient supply of seedlings, then they grow well even in saline soils and can produce 2.8–3.2 t/ha of seeds and 1200–1400 kg of vegetable oil. In sunflower cultivation, the highest yields and substantial income result from utilizing the latest scientific and innovative technologies (Fayziyev and Salomov, 2011). Three traits, namely, head diameter (HD), stem diameter (SD), and stay-green canopy (SG), served as secondary traits for selecting for oil yield. These traits were options on the basis that they are fast, cheap, and easy to measure speedily, and measurements can proceed before harvesting, which may effectively allow assessment of two generations per year. The other traits, seed yield, oil content, shell hardness and weight, except for fresh weight and plant height, were considerably direct components of oil yield (Gardner, 1995).

In this study, variational analysis of the seed oil content continued in the $F_3$ hybrid families of the sunflower. The results revealed complex hybridization under modeled drought conditions, and due to higher heterozygosity, these become the basis for the emergence of transgressive segregants in $F_3$ families of sunflowers. These families, as located on the right side of the variation series, became further selections for early maturity, the high number of leaves, and increased root mass and oil content. The correlation analysis between root mass and the plant productivity, plant height, head diameter, and total leaf area in simple and complex sunflower $F_3$ hybrids showed a moderate and strong positive correlation between root mass and productivity. Likewise, the said trait had a high positive correlation between root mass and plant height and a moderate positive correlation between root mass and head diameter. A weak and moderate negative correlation was evident between the seed oil content and head diameter, and a weak positive correlation existed between the seed oil content and leaf area in all studied cross combinations. With simple and complex hybridization, the $F_3$ sunflower hybrids showed that a change in one trait leads to a correlative change in other traits (Genjeeva, 2017).

## CONCLUSIONS

The $F_3$ hybrid families of sunflower (*H. annuus* L.) under simulated drought conditions, due to complex hybridization and high heterozygosity, provided the basis for the emergence of transgressive segregants. Additionally, families with higher oil content showed a location on the right side of the variation series, becoming selections for further evaluation. The correlation analysis between root weight and certain economically valuable traits in simple and complex $F_3$ hybrid families of sunflower revealed moderate, significant positive correlations between root weight and productivity traits.

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