RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
58 (3) 1050-1060, 2026
http://doi.org/10.54910/sabrao2026.58.3.10
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

BREEDING ASSESSMENT OF SAFFLOWER AND FLAX UNDER RAINFED CONDITIONS IN UZBEKISTAN

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SUMMARY

A considerable demand for domestically produced vegetable oil prevails, which can be met by expanding cultivation areas and increasing the productivity of oilseed crops in Uzbekistan. The country's demand for vegetable oil is about 450,000–500,000, with only 40% covered locally and the rest imported from Russia, Ukraine, and Kazakhstan. The drive for breeding work on safflower (*Carthamus tinctorius* L.) and flax (*Linum usitatissimum* L.) crops results from rapidly growing global demand for vegetable oil. Safflower is one of the most promising oil crops, with a high-yield potential and adaptability to extreme environmental conditions under the rainfed farming system. Flax is also a valuable oilseed and technical crop, and its seeds contain up to 50% of high-quality oil. The subsequent research comprised breeding efforts and morphophysiological assessments of safflower and flax under rainfed conditions in Uzbekistan. The key research includes genotype evaluation based on ecological and geographical origins and varietal forms by agro-biological traits, parental genotype selection for hybridization considering ecological and geographical distances, and adaptation to regional cultivation requirements. As a result of the research, the selection of new high-yielding, oil-rich, and stress-resistant genotypes of the safflower and flax was successful.

Keywords: Safflower (*C. tinctorius* L.), flax (*L. usitatissimum* L.), breeding efforts, rainfed conditions, biomass, seed yield, 1000-seed weight, seed oil content, water content

Key findings: Safflower cultivars Moydor, 2018/10, and Jizzakh-1 showed the highest yield and resilience under drought conditions. Specifically, Jizzakh-1 had a seed oil content of 30.4% and a 1000-seed weight of 42.3 g. Among flax genotypes, 2021/3 provided the maximum oil content at 39.3%, while the variety Lalmikor had a 1000-seed weight of 5.9 g and biomass accumulation of 168.60 g. These varieties reached high recommendations for breeding programs to improve crop production in rainfed areas.

Communicating Editor: Dr. Sajjad Hussain Qureshi

Manuscript received: April 12, 2025; Accepted: April 09, 2026.

Citation: Oripov SH KH, Mavlanov JS, Makhammadieva AO (2026). Breeding assessment of safflower and flax under rainfed conditions in Uzbekistan. *SABRAO J. Breed. Genet. 58 (3) 1050-1060. http://doi.org/10.54910/sabrao2026.58.3.10*.

INTRODUCTION

In Uzbekistan's dryland regions, a growing demand for vegetable oil and a crucial need to improve self-sufficiency through improving the domestic oilseed crops' production prevail. Safflower (*C. tinctorius* L.) and flax (*L. usitatissimum* L.) are the most suitable oilseed crops for rainfed conditions due to their drought tolerance, short vegetation cycle, and economic importance. Safflower genotypes show adaptive plasticity via water-use efficiency, canopy-temperature depression, and differential drought-tolerant traits (Chennamsetti *et al.,* 2023). The Scientific Research Institute of Rainfed Agriculture, Uzbekistan, has been conducting research since 1913 to improve crop resilience to water-limited environments. This study focuses on breeding efforts and evaluation of local and introduced cultivars, with emphasis on their morphophysiological traits, productivity, and seed oil content under drought stress conditions. Global research is also promoting drought-resilient genotypes for climate-smart agriculture (Assefa *et al.,* 2023).

In the 'Uzbekistan 2030' Development Strategy, special attention focuses on providing the population with food products and ensuring the country's food security. Likewise, the strategy ensures the careful use of energy resources, both non-renewable and alternative, through the development and implementation of scientifically grounded recommendations and proposals for the rational use of natural resources. The climatic conditions of Uzbekistan are characteristic of a long period of high air temperature. In this context, the development of a reliable forage base depends on the introduction of new crop cultivars with high productivity and resistance to adverse climatic conditions. Ustymenko *et al.* (2022) emphasized the importance of using linseed and safflower in arid zones due to their combined nutritional and economic value. The leading oilseed crops grown under rainfed conditions are safflower, flax, and sesame in Uzbekistan. These crops play a vital role in being a primary source for meeting the needs of the local edible and technical oil industries and the national economy. Moreover, in the forage sector, by-products of oilseed crops, such as oilcake and meal, are widely used materials for high-quality animal feeds. Oripov *et al.* (2024) conducted a comprehensive study in Uzbekistan's rainfed (low-input) conditions, focusing on safflower and oil flax. The research highlighted economically valuable phenotypic and morpho-biological traits, including seed set rate, yield stability, and oil content—identifying promising varieties with strong potential for breeding and selection. The authors recommended these genotypes as valuable donors for improving crop adaptation in rainfed agriculture.

With global climate change, the drought area and the duration of droughts are increasing with time. This leads to a reduction in total oilseed harvests, and the said region is experiencing a shortage of vegetable oil (Pokrovskiy and Solyanko, 1966). Safflower (*C. tinctorius* L.), also known as wild saffron or dyer's thistle, is a heat-loving, highly drought-tolerant, and short-day oilseed crop, well adapted to the dry continental climate. This herbaceous plant is usually annual, though occasionally biennial, and belongs to the family Asteraceae (Norov, 1987). Safflower has attracted attention as a forage crop, especially in arid zones, due to its adaptability and high nutritional value. Spineless cultivars are suitable for hay, silage, and green forage production, both in pure stands and in mixtures with other crops (Dajue and Mundel, 1996).

Sowing of oilseed crops finishes by the end of March, when sufficient soil moisture occurs under rainfed conditions in Uzbekistan. Early sowing is beneficial, as the flowering phase of safflower coincides with a period when soil moisture reserves are still adequate. Therefore, crops grown earlier exhibit a higher seed yield and an increased seed oil content. Past studies confirm the importance of early sowing in achieving higher safflower productivity, which directly depends on climatic and soil conditions existing in the areas (Lavronov, 1948)**.** According to Melikhov and Popov (2017), the rapid accumulation of safflower's raw biomass begins at the budding stage. About 30–35 days before the middle of the fruiting phase, the plant reaches its maximum aboveground biomass, and later, the gradual decline begins**.** These phenological responses are consistent with results reported by Daryanto *et al.* (2017), who found optimized timing significantly improves reproductive efficiency under drought. As recent research underscores, safflower exhibits multiple adaptive mechanisms—deep root architecture, osmotic adjustment, and antioxidant defenses—which support resilience under drought stress and provide avenues for improving oil composition through genotype selection (Hussain et al., 2016).

Similarly, according to FAO data, flax is a valuable multipurpose crop, occupying about 3.5 million hectares of sown area worldwide. In this, more than three million hectares comprised flax cultivation for seed and oil production (Lukomets and Bochkarev, 2008). Cultivated flax (*L. usitatissimum*) belongs to the family Linaceae. Based on morphological and agronomic traits, five types of cultivated flax are distinct: fiber flax, intermediate types, curly flax, large-seeded, and prostrate cultivars.

Oilcake and meal are valuable concentrated feeds in terms of protein content used by livestock and are not inferior to rapeseed cake. According to Minkevich (1957), flax seeds contain 25%–45% oil and up to 30% protein. Their seeds also contain up to 5% nitrogen, 4% ash, and 4.5% fiber. One kilogram of flaxseed cake contains 1.14 feed units and 285 g of digestible protein. Flax oil contains 16%–20% oleic acid, 14%–17% linoleic acid, 50%–60% linolenic acid, 5%–7% palmitic acid, and 3%–4% stearic acid (Minkevich, 1957). Recently, a growing global interest exists in the consumption of flax oil due to its medicinal properties, which refers to its high content of linolenic acid. In flax cultivation, one of the unresolved issues is achieving high seed yield with higher oil content and improved quality. Flax oil improves metabolism, reduces cholesterol levels in the body, regulates blood pressure, and lowers the risk of tumor formation. It also reduces the risk of cardiovascular diseases and is applicable in the treatment of diabetes (Sorochinskaya and Galkin, 2016). The flax crop is popular for its excellent biological and agronomic qualities, including high drought resistance, short vegetation period, ease of cultivation, higher seed yield, and profitability **(**Minkevich, 1960**).**

Over the years, the Scientific Research Institute of Rainfed Agriculture, Uzbekistan, has developed several safflower cultivars, such as Milyutinsky-114, Gallaaral, Jizzakh-1, Moydor, and Tikandor, and oil flax cultivars, i.e., Bakhmal-2, Bakhorikor, Lalmikor, and Baraka. This research aimed to conduct a comprehensive evaluation of safflower and oil flax cultivars in terms of morphophysiological traits under rainfed conditions in Uzbekistan.

MATERIALS AND METHODS

The breeding material comprised 84 cultivars of safflower and 77 cultivars of oil flax, evaluated under competitive varietal trials conducted during 2021–2024 under rainfed conditions at the Scientific Research Institute of Rainfed Agriculture, Uzbekistan. These two crop cultivars assessment proceeded in accordance with the methodologies approved by the State Commission for Testing Agricultural Crops (1989), 'Methodology for testing cultivars of agricultural crops,' Tashkent, Uzbekistan. The study included safflower (*Carthamus tinctorius* L.) and oil flax (*Linum usitatissimum* L.) cultivars and breeding lines, comprising both local and introduced genetic materials. The heat tolerance of the genotypes received assessment by determining the coagulation temperature of leaf cytoplasmic proteins. This parameter reflects the critical temperature at which cellular proteins begin to denature, causing irreversible damage to the plasma membrane. The conducted measurements followed the method described by Genkel (1982).

The experiment layout was in a randomized complete block design (RCBD) with three replications to minimize field variability. Each block contained all genotypes randomly assigned to plots. For safflower, row spacing was 15 cm with 4–5 cm between plants within the row, and the seeding rate ranged from 300,000 to 400,000 seeds per hectare. For oil flax, row spacing was also 15 cm, but plant spacing within rows was 2–3 cm, with a seeding rate of 3.0 to 3.5 million seeds per hectare. Each plot consisted of four rows, 5 m in length. Sowing commenced in the first 10-day period of March each year, based on local recommendations for optimal soil moisture conditions in rainfed systems, following standard agronomic practices.

Statistical analysis

Data recorded on key agro-morphological and physiological traits included total aboveground biomass (g), the number of flower heads or capsules per plant, seed yield (t/ha), 1000-seed weight (g), and seed oil content (%). Leaf samples entailed analysis at the flowering stage to determine the relative water content (%) and the coagulation temperature of water-soluble proteins (°C).

Statistical analyses used OriginPro 2025b (v10.2.5.212). Differences among means underwent testing using the least significant difference (LSD) test at $p \leq 0.05$. Performing data analysis and visualization used Microsoft Excel 2019 and Statistica version 13.3.

RESULTS AND DISCUSSION

Based on the results of the study during 2021–2024, selecting safflower cultivars with the highest indicators of drought and heat resistance succeeded in the competitive varietal trials. The key parameters used in assessment and selection were the temperature of coagulation of water-soluble proteins and the total water content in leaves. The best-performing safflower cultivars were Gallaaral, Jizzakh-1, Shakhzhulduz, and line 2018/10 (Table 1). Reports of similar findings occurred in past studies, which emphasized the effect of drought stress conditions on leaf water content and protein stability in arid regions (Chaves *et al*., 2003). These traits have become reliable indicators of drought adaptation in oilseed crops.

The results showed the average total water content in safflower leaves varied between 67.20% (2018/8) and 77.00% (2021/1) with the standard cultivar Milyutinsky-114 (75.15%). The protein coagulation temperature ranged from 63.0 °C (Gallaaral) to 64.5 °C (Shakhzhulduz), with the standard cultivar Milyutinsky-114 at 62.3 °C. These observations align with the findings of Blum (2011), which demonstrated that the total biomass accumulation under water-limited environments was a primary driver of yield performance in drought-tolerant genotypes. The accumulation of total biomass in safflower cultivars under competitive varietal trials entailed studies over the period 2020–2024 (Table 2). According to the results, the accumulation of total safflower biomass varied by cultivar as follows: In 2020, it ranged from 173.96 g (Ak-may) to 250.24 g (Moldir), while the standard cultivar Milyutinsky-114 had 161.14 g. For 2021, it ranged from 146.22 g (Jizzakh-1) to 440.12 g (Irkas), with the standard cultivar Milyutinsky-114 having 121.80 g. In 2022, it ranged from 319.14 g (Irkas) to 606.96 g (Nurlan), with the standard cultivar Milyutinsky-114 observed at 442.74 g. During 2023, the range was from 345.12 g (Ak-may) to 680.1 g (Moldir), and the standard cultivar Milyutinsky-114 showed 416.72 g. In 2024, it ranged from 79.4 g (Shakhzulduz) to 227.94 g (Ak-may), while the standard cultivar Milyutinsky-114 emerged with 111.56 g.

The results of the accumulation and distribution of total biomass in safflower cultivars in the competitive trials appear in Table 3. Total biomass ranged from 79.48 g (Shakhzhulduz) to 227.94 g (Ak-Moy), with the standard cultivar Milyutinsky-114 observed at 111.56 g. The proportion of capitula (flower heads) ranged from 9.81% (Shakhzhulduz) to 34.27% (2018/10), and the standard cultivar Milyutinsky-114 was at 30.15%. Flexas *et al.* (2006) discussed the comparable distribution of reproductive biomass and highlighted that partitioning efficiency under drought conditions supports the reproductive development and seed setting. Similar observations came from Daryanto *et al.* (2017), who stated that optimizing allocation to reproductive organs ensures efficient resource use and improves yield under dryland conditions. In oil flax cultivars under competitive varietal trials, the accumulation of total biomass gained

Table 1. Safflower cultivars with variations in total leaf water content and protein coagulation temperature under rainfed conditions (Gallaaral, 2022–2024).

No.	Cultivars	Total leaf water content (%)		Coagulation temperature of water-soluble proteins (°C)	
		Range	X	Range	x
1	Milyutinskiy-114	62.35-84.74	75.15	60.5-64.5	62.3
2	Gallaaral	64.59-83.28	76.73	62.0-64.0	63.0
3	Jizzax-1	64.46-83.03	74.93	62.5-64.5	63.5
4	Moydor	67.62-82.03	74,80	62,5-65.0	63.4
5	Nurlan	66.66-82.66	75.19	62.0-65.0	63.9
6	Ak-moy	69.17-82.57	76.59	62.5-65.0	64.0
7	Shakhjulduz	65.76-82.75	75.22	63.0-65.5	64.5
8	Irkas	66.41-83.98	75.62	61.0-67.5	64.4
9	Moldir	65.23-83.33	75.68	60.5-65.5	63.3
10	2018/10	58.34-82.26	72.91	63.0-65.0	64.1
11	2018/8	67.20	67.20	61.0-65.5	63.2
12	2021/1	77.00	77.00	61.5-65.5	63.5

Table 2. Safflower cultivars with variations in total biomass accumulation under rainfed conditions (Gallaaral, 2020–2024).

No.	Cultivars	Total biomass in 10 plants (g)					
		2020	2021	2022	2023	2024	Average (g)
1	Milyutinskiy-114	161.14	121.80	442.74	416.72	111.56	167.44
2	Gallaaral	140.00	208.28	405.66	347.72	126.20	245.57
3	Jizzax-1	203.56	146.22	565.12	418.56	118.04	290.30
4	Moydor	239.54	219.16	415.26	409.16	200.24	280.23
5	Nurlan	230.18	213.56	606.96	445.16	119.16	323.07
6	Ak-moy	173.96	269.28	463.66	345.12	227.94	261.20
7	Shakhjulduz	216.66	241.16	449.98	567.92	79.48	311.04
8	Irkas	198.58	440.12	319.14	647.88	160.32	392.92
9	Moldir	250.24	335.24	446.18	680.12	156.52	355.53
10	2018/10	181.92	284.04	526.45	490.28	194.52	287.69

Table 3. Safflower cultivars with variations in the distribution of total biomass in plant organs under rainfed conditions (Gallaaral, 2024).

No.	Cultivars	Raw weight (g)								
		Root		Stem		Leaf		Capitulum		Total biomass (g)
		G	%	g	%	G	%	g	%	
1	Milyutinskiy-114	9.36	8.39	46.12	41.34	17.00	15.23	33.64	30.15	111.56
2	Gallaaral	10.20	8.08	50.20	39.37	23.16	18.35	37.80	29.95	126.20
3	Jizzax-1	10.24	8.67	52.56	44.52	28.84	24.43	19.24	16.29	118.04
4	Moydor	17.88	8.92	71.72	35.81	45.72	22.83	47.04	23.49	200.24
5	Nurlan	11.12	9.33	48.96	41.08	20.64	17.32	30.40	25.51	119.16
6	Ak-moy	20.08	8.80	89.84	39.41	50.92	22.33	43.00	18.86	227.94
7	Shakhjulduz	8.04	10.11	37.76	47.50	21.88	27.52	7.80	9.81	79.48
8	Irkas	16.76	10.45	65.80	41.04	35.64	22.23	31.16	19.43	160.32
9	Moldir	12.96	8.28	63.52	40.58	33.60	21.46	49.68	31.74	156.52
10	2018/10	18.98	9.75	64.80	33.31	33.80	17.37	66.68	34.27	194.52

Table 4. Oil flax cultivars with variations in total biomass accumulation under rainfed conditions (Gallaaral, 2022–2024).

No.	Cultivars	Total biomass in 10 plants (g)			
		2022	2023	2024	Average (g)
1	Bakhorikor	148.48	74.24	36.14	92.99
2	Lalmikor	168.60	109.22	35.92	104.58
3	2021/3	109.56	130.40	48.04	96.00
4	2018/4	71.92	121.72	65.34	86.32
5	2018/5	166.16	90.56	77.30	111.34
6	2018/6	106.92	115.28	84.88	102.36
7	2018/7	144.16	96.46	71.20	103.94
8	2024/1	151.68	127.16	67.76	115.53
9	2024/2	145.14	118.40	93.16	118.9
10	2024/3	124.30	98.62	47.80	90.24

significant influences from annual precipitation, i.e., 2022 (395.3 mm), 2023 (363.7 mm), and 2024 (322.1 mm) (Table 4). Uga *et al.* (2013) also reported that improved root traits and biomass development were crucial in maintaining plant productivity under rainfed conditions. According to Sertse *et al.* (2019), genotypic variation in root architecture (e.g., root depth, surface area) and shoot biomass significantly affects biomass productivity in flax, particularly under conditions of limited soil moisture.

In 2022, biomass ranged from 71.92 g (2018/4) to 168.60 g (Lalmikor), with the standard Milyutinsky-114 having 148.48 g. In 2023, the range was from 90.56 g (2018/5) to 130.40 g (2021/3), and the standard cultivar had 74.24 g. For 2024, it ranged from 35.92 g (Lalmikor) to 93.16 g (2024/2), while the standard Milyutinsky-114 had 36.14 g. In 2024, the accumulation of total aboveground biomass among the oil flax genotypes under rainfed conditions demonstrated significant variability, ranging from 71.92 g (2018/4) to 168.60 g (Lalmikor). The proportion of capsules within the total biomass structure, a key determinant of potential seed yield, also showed notable variations across genotypes in reproductive allocation, ranging from 36.37% (2018/5) to 47.79% (2021/3). The standard cultivar Bakhorikor exhibited a capsule biomass share of 43.31%, positioning it among the higher-performing lines for reproductive efficiency under water deficit conditions.

This three-year study during 2022–2024 resulted in identifying several safflower cultivars—Moydor, Shakhzhulduz, Nurlan, and 2018/10—with the highest seed yield and oil content. Seed yield ranged from 4.9 t/ha (Gallaaral, 2024) to 9.6 t/ha (2018/10, 2022), with the standard cultivar Milyutinsky-114 yielding 7.0–7.5 t/ha. Oil content ranged from 22.1% (Irkas, 2023) to 32.8% (Nurlan, 2022), compared with the standard cultivar (25.8%). The 1000-seed weight values varied between 34.4 and 42.3 g, with the highest mass observed in the genotype Jizzakh-1 (42.3 g), exceeding the standard cultivar Milyutinsky-114 by 3.5 g. Comas *et al.* (2013) showed that genotypic variation in root architecture, such as finer root diameters, higher specific root length, and deeper rooting, significantly contributes to biomass productivity under drought stress. The yield dynamics across three years revealed considerable genotype-by-environment interactions.

Cultivars Moydor, Jizzakh-1, and 2018/10 consistently outperformed the standard cultivar, demonstrating greater genetic potential under rainfed stress conditions. However, the stable cultivars Gallaaral and Shakhzhulduz showed lower productivity, likely due to limited adaptation under drought conditions. The highest oil content resulted in the cultivars Nurlan (32.8%) and Irkas (30.6%), indicating considerable potential for industrial oil extraction. These results are consistent with findings that seed oil content in linseed shows strong genotype × environment interaction, with cultivar remaining the principal factor influencing oil percentage (Adugna and

Labuschagne, 2002). Furthermore, the genetic makeup of genotypes and seasonal rainfall both influenced seed weight, a key component of yield structure. Cultivars Ak-Moy and Shakhzhulduz showed at-par seed mass with the standard, suggesting their use as parental lines in breeding programs targeting stability and size.

According to this research, the cultivar yield varied by year, ranging from 0.68 to 0.92 t/ha, with an average of 0.78 t/ha. Under unfavorable weather conditions, it ranged from 0.49 to 0.68 t/ha, while the standard cultivar occurred with 0.7 t/ha. The cultivars Gallaaral, Ak-moy, Irkas, and Moldir were on par with the standard cultivar. The most productive cultivars that exceeded the standard cultivar in seed yield were Moydor, Jizzakh-1, and 2018/10. These results corroborate findings that genotype × environment interactions play a pivotal role in determining seed yield stability in safflower under rainfed conditions, as demonstrated by safflower trials over multiple environments (Moghaddam *et al.,* 2009). Based on the analysis, one can conclude that sowing in the second 10-day period of March showed the most stable yield structure. Over the years, the 1000-seed weight ranged from 34.4 g to 42.3 g, with an average value of 36.1 g. The highest 1000-seed weight was evident in the cultivar Jizzakh-1 (42.3 g), which was 3.5 g higher than the standard. The cultivars Ak-moy and Shakhzholdoz were at the level of the standard, while the other genotypes appeared inferior to the standard cultivar Myutinsky-114 (Figure 1). These results align with findings that genotype × environment interactions significantly affect 1000-seed weight and seed yield stability in flax across multiple environments (Abo-El-Komsan *et al.,* 2023).

In this three-year study, during 2022–2024, in safflower seeds, the oil content depended on the genetic makeup of the genotypes and the environmental conditions during the growing seasons. Over a three-year average, the oil content varied from 22.9% to 30.4% across the safflower cultivar seeds. Under rainfed conditions, the highest oil content emerged in the cultivar Jizzakh-1 (30.4%), followed by Nurlan (29.7%), Irkas (29.9%), and other lines with 28.6% and 29.1% (Figure 2). These results support earlier findings of genotype × environment interactions remarkably affecting oil content in flax, particularly under stress and varying seasonal conditions (Zhang *et al.,* 2016). During the study years, the seed yield of oil flax depended on weather conditions and varietal characteristics. According to results obtained over three years, the number of capsules per plant across all flax cultivars ranged from 26 to 44. In the first year of the study, the most productive flax cultivars were Lalmikor, 2021/3, 2018/4, and 2018/5. These cultivars manifested with seed yields ranging from 0.78 to 0.86 t/ha. These findings are consistent with results showing that genotype × environment interactions substantially alter 1000-seed weight and seed yield stability in flax under diverse environmental conditions (Abo-El-Komsan *et al.,* 2023).

In the three-year study, the 1000-seed weight depended largely on weather conditions during the growing period and flax varietal characteristics. These findings align broadly with evidence from Masella *et al.* (2024), who demonstrated that environmental conditions—location and seasonality—significantly determine flax grain yield under rainfed conditions, whereas genotype had nonsignificant effects on seed yield. The highest 1000-seed weight resulted in the second year of the study and ranged up to 5.9 g in the cultivar Lalmikor, which was 0.6–1.5 g and 0.7–1.8 g higher than cultivars Bahorikor, 2024/1, and 2024/3. This may refer to the longer growing period of the crop. According to three years of study, during 2022–2024, the seed oil content was dependent on the genetic characteristics of flax genotypes and the weather conditions during the growing seasons. On average, over three years, the seed oil content across flax cultivars ranged from 31.9% to 39.3%. The highest seed oil content under rainfed conditions (39.3%) was notable in large-seeded flax cultivars 2021/3, 2018/5, and 2018/7.

According to the results, the seed yield in flax cultivars in 2022 ranged from 0.62 t/ha (2018/4) to 0.86 t/ha (2018/5), with the standard Bahorikor at 0.68 t/ha. In 2023, the

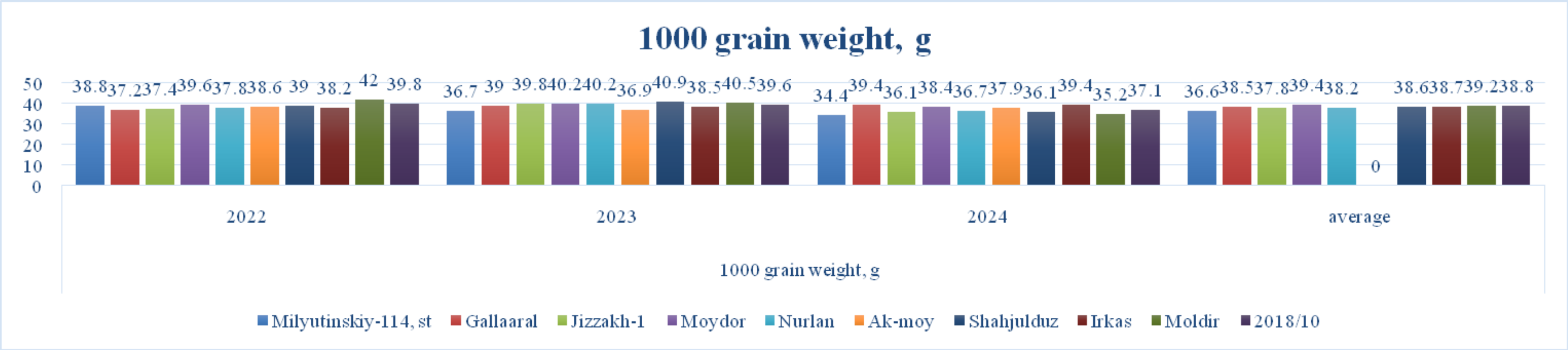

Figure 1. Safflower cultivars with variations in 1000-seed weight under rainfed conditions during 2022–2024.

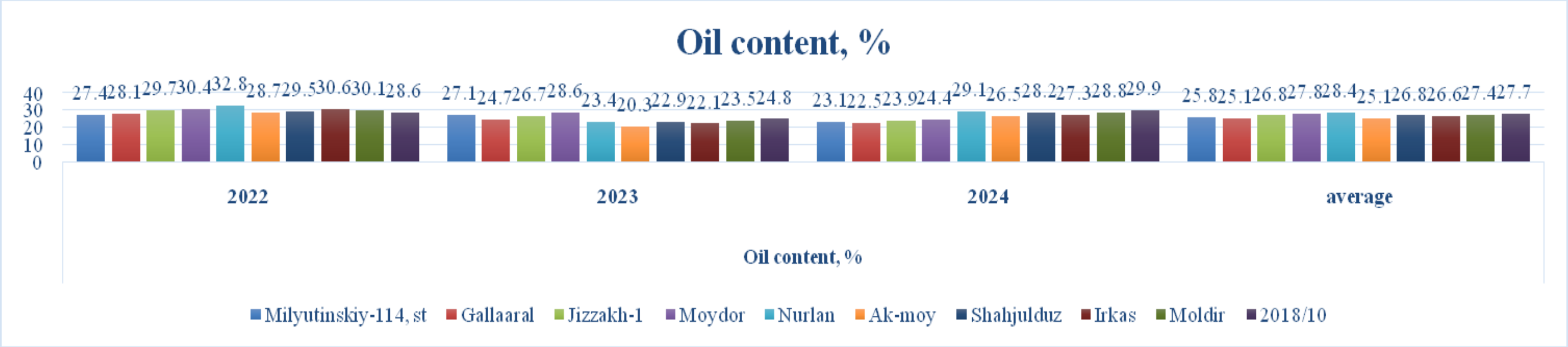

Figure 2. Safflower cultivars with variations in seed oil content under rainfed conditions during 2022–2024.

seed yield ranged from 0.64 t/ha (2018/6, 2024/3) to 0.8 t/ha (Lalmikor, 2021/3), with the standard cultivar having 0.71 t/ha. For 2024, seed yield ranged from 0.52 t/ha (2018/4) to 0.73 t/ha (2021/3), and the standard Bahorikor had 0.51 t/ha. The seed oil content of the flax cultivars in 2022 ranged from 36.5% (2024/1) to 39.3% (2021/3), with the standard Bahmal-2 at 35.4%. In 2023, seed oil ranged from 34.4% (2024/1) to 38.5% (2021/3), while the standard cultivar gave 35.5%. Finally, in 2024, the seed oil content varied from 31.8% (2028/4) to 36.4% (RNS-2018/6), with the standard Bahorikor at 33.6%. These findings are consistent with evidence that oil biosynthesis in linseed entails significant impacts from cultivar and environmental variables such as seasonal climatic conditions and location effects (Savoire *et al.,* 2015). The results further showed seed yield in safflower cultivars during 2022 ranged from 0.69 t/ha (Gallyaaral) to 0.84 t/ha (2018/10), with the standard cultivar Milyutinsky-114 having 0.7 t/ha. In 2023, the seed yield ranged from 0.58 t/ha (Gallaaral) to 0.88 t/ha (2018/10), and the standard cultivar had 0.75 t/ha. For 2024, seed yield ranged from 0.49 t/ha (Gallaaral) to 0.71 t/ha (Moydor), while the standard cultivar was evident with 0.59 t/ha.

In safflower cultivars during 2022, the seed oil content ranged from 28.1% (Gallaaral) to 32.8% (Nurlan), with the standard cultivar Milyutinsky-114 at 27.4%. During 2023, the seed oil content ranged from 22.1% (Irkas) to 28.6% (Moydor), while the standard cultivar had 27.1%. In 2024, seed oil ranged from 22.5% (Gallaaral) to 29.9% (2018/10), with the standard cultivar having 23.1%. The variability in seed oil content of the different safflower genotypes under drought conditions has received validation in several past studies, including Shinozaki and Yamaguchi-Shinozaki (2007), where genetic regulation of drought-responsive genes influenced the oil biosynthesis and its accumulation. These findings were consistent with research demonstrating that genotypes exhibiting stronger sink strength and drought resilience produced higher seed yields in safflower under rainfed systems, referring to significant genotype-by-environment interactions (Koç, 2021). Based on the results of competitive cultivar testing for oil flax in 2022–2024, the promising cultivars Bahorikor, Lalmikor, 2021/3, 2024/2, and 2018/5 were the best options for their highest seed yield and oil content.

Correlation and regression analysis

The correlation analysis detected a strong positive association between the coagulation temperature of water-soluble proteins (CTWSP) and the total biomass of ten plants (TBTP) (Pearson's r = 0.707) (Figure 3). Safflower cultivars exhibiting superior heat tolerance, characterized by elevated protein coagulation temperatures, demonstrated a significantly higher capacity for biomass accumulation under arid conditions. The regression model for this relationship yielded an adjusted coefficient of determination (adjusted R^2) of 0.438, suggesting that 43.8% of the variability in total biomass can succeed prediction from the protein stability parameters.

Similarly, a robust positive correlation was evident between TBTP and 1,000-kernel weight (TKW) (Pearson's r = 0.674, adjusted R^2 = 0.386), indicating that vigorous vegetative development provides a critical physiological foundation for superior grain filling. In contrast, a significant negative correlation appeared between total leaf water content (TLWC) and final oil content (OC) (Pearson's r = -0.662, adjusted R^2 = 0.368). This inverse relationship implies that excessive moisture retention in the foliage during critical stages may impede the efficiency of oil biosynthesis in seeds. Furthermore, moderate positive correlations between oil content and both TKW (Pearson's r = 0.494) and TBTP (Pearson's r = 0.489) confirm that enhanced crop productivity and heavier seeds are key determinants of final oil yield in the studied breeding materials.

CONCLUSIONS

Multi-year field evaluations under rainfed conditions led to the identification of promising safflower (Moydor, Jizzakh-1, and 2018/10) and oil flax (Lalmikor and 2021/3) genotypes with superior seed yield and seed oil content. Notably, Jizzakh-1 achieved a seed oil content of 30.4%, while flax genotype 2021/3 reached 39.3%. These cultivars exhibited considerable physiological responses to drought, including high biomass accumulation (up to 168.60 g in Lalmikor), stable 1000-seed weight, and favorable reproductive allocation. The results also confirmed the effectiveness of early sowing and genotype selection in mitigating climate-induced stress. Consequently, Lalmikor and 2021/3 are specific recommendations as donor materials for breeding programs and large-scale cultivation in water-limited areas of Uzbekistan.

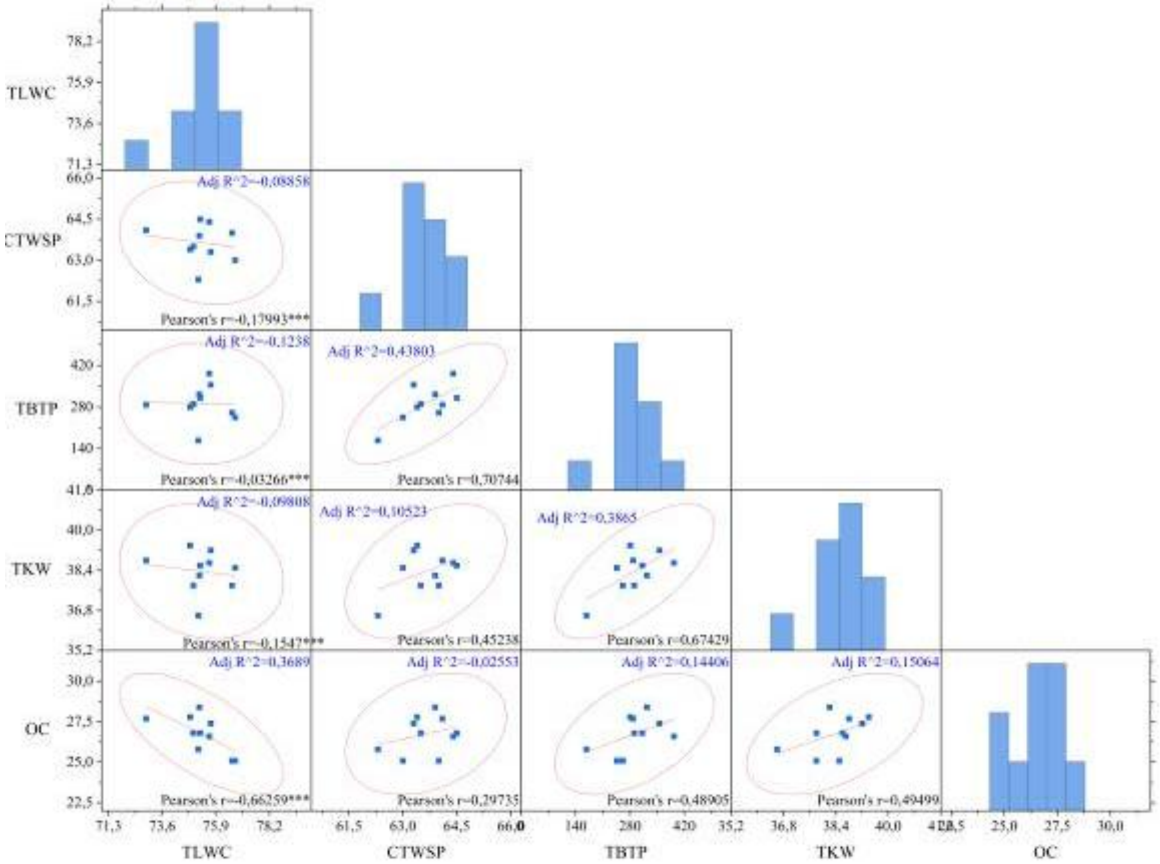

Figure 3. Correlation analysis of water content, biomass, coagulation temperature, and oil content traits in safflower. CTWSP - Coagulation temperature of water-soluble proteins, TBTP - Total biomass in 10 plants.

ACKNOWLEDGMENTS

The authors express their sincere gratitude to the Scientific Research Institute of Rainfed Agriculture, Uzbekistan, for providing resources and field trial facilities. This work received partial support from national and institutional research grants on oilseed crop improvement.

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