RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (5) 1870-1882, 2025
http://doi.org/10.54910/sabrao2025.57.5.9
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

# BREEDING RESEARCH WORK STATUS AND DEVELOPMENT ON FLAX CROP IN KAZAKHSTAN

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## SUMMARY

Flax (*Linum usitatissimum* L.) is a valuable oilseed and technical crop. The flaxseed oil ranks first among the various technical oils. Kazakhstan has the leading position and was the largest producer of oilseed flax from 2019 to 2022 worldwide. In the recommended crop cultivars of Kazakhstan, 15 flax cultivars' registration succeeded, including six cultivars obtained through domestic selection. The developed flax cultivars are mostly products from research organizations, such as the Karabalyk Agricultural Experimental Station, Astana, and the Agricultural Experimental Station of Zarechnoye, Northern Kazakhstan. In previous years, flax cultivars, such as Kostanaysky-11 and Altyn, have been part of crop breeding achievements of Kazakhstan. In the competitive variety testing nursery during 2020–2024 at the Karabalyk Agricultural Experimental Station, the genotype K-57-13-2 'Asay' emerged as the leader with an average seed yield of 1.7 t/ha, oil content of 42.6%, and oil yield of 0.721 t/ha. At the Agricultural Experimental Station, Zarechnoye, in the competitive variety testing nursery during 2021–2024, the flax genotype C5402 'Satti' stood out with an average seed yield of 1.92 t/ha, oil content of 36.4%, and oil yield of 0.700 t/ha.

**Keywords:** Flax (*L. usitatissimum* L.), breeding, variety, seed yield, oil, oil yield, Kazakhstan

Communicating Editor: Dr. Tabynbaeva Laila

Manuscript received: February 13, 2025; Accepted: May 28, 2025.


**Citation:** Didorenko SV, Iskakov RK, Tynyspaeva BI, Zinchenko AV, Sidorik IV, Kushanova RZH, Kassenov RZH (2025). Breeding research work status and development on flax crop in Kazakhstan. *SABRAO J. Breed. Genet.* 57(5): 1870-1882. http://doi.org/10.54910/sabrao2025.57.5.9.

**Key findings:** As a result of breeding research work on the flax (*L. usitatissimum* L.) at the Karabalyk Agricultural Experimental Station, Astana, and Agricultural Experimental Station, Zarechnoye, the flax cultivars 'Asay' and 'Satti' were the products developed and submitted for evaluation to the State Commission on Crops, Kazakhstan.

## INTRODUCTION

Flax (*Linum usitatissimum* L.) is a valuable oilseed and technical crop. Flax is widely grown in the world, primarily in the countries of Russia, Kazakhstan, Canada, China, the USA, and India, whose share is more than 85% worldwide (Amanov *et al.,* 2022). The modern cultivar seeds of flax contain up to 50% and even more desiccated oil and 33% protein. The high content of polyunsaturated fatty acids contributes to the formation of a strong and durable film when linseed oil dries out. Paints and varnishes made from linseed oil are more durable and reliable. Flaxseed oil is distinct with the most content of polyunsaturated fatty acids, such as linolenic and linoleic acids that are essential in the human diet. Thus, flaxseed oil has dietary, therapeutic, and preventive purposes (Manimurugan *et al.,* 2023).

Moreover, oilseed flax can be a source of raw fiber material. The said direction is becoming more promising in the flax-growing countries (Rozhmina *et al.,* 2019). Additionally, flax seeds have prebiotic properties, which improve the health of the gut microbiota. In the global food chain, the flax crop is gaining importance due to growing consumer interest in products with exceptional nutritional values (Kauser *et al.,* 2024).

Overall, flax occupies a cultivation area of about 3.5 million hectares worldwide, spreading over 58 countries. From these, oilseed flax crops cover more than 3 million hectares, which serve for seed and oil production. Currently, the raw flax production has reached 876.0 tons in the world, with Russia taking the lead at 75% of the total production (Current Affairs, 2024). Most of the flax crop seed yield in these countries becomes import products for European Union countries and China. The flax crop area, as well as its demand and profitability, is steadily increasing in the leading countries and worldwide. The flax fiber business has projections that could come from several factors, particularly the increased consumption from industrial use of flax fiber, leading to an escalated global production in the future (Ivanova *et al.,* 2022; Cognitive Market Research, 2024).

In the flax market during 2019–2022, Kazakhstan held a leading position and was the largest producer of oilseed flax. The country had a harvest of 683.3 tons in the crop season of 2018, surpassing previous leaders, such as Russia (603.2 tons) and Canada (555.0 tons). In 2020, the oilseed flax crop has reached 1.580 million tons. However, in 2021, the production decreased to 775,600 tons due to extreme drought conditions. The smallest production of flax appeared in 2023, which can refer to unfavorable weather conditions, including heavy rains in spring and fall, reducing the sown area and production. In 2020, the flax area reached 1.526 million hectares. In Kazakhstan during 2024, the oilseed crops area slightly rose, and the flax area has also increased to 971,600 hectares (AIC-Inform, 2024) (Figure 1). The flax cultivation in Kazakhstan is mainly prevalent in the Kostanay and Akmola regions of North Kazakhstan.

The development of flax cultivars progresses in various research organizations and seed production companies worldwide, and the leadings ones are V.S. Pustovoit All-Russian Research Institute of Oilseeds (ARRIO), All-Russian Research Institute of Flax (ARRIF) (ARRIO, 2024; ARRIF, 2024); University of Saskatchewan, Morden Research and Development Centre, Sertis Holding S.A., Canada (University of Saskatchewan, 2024; Morden Research and Development Centre, 2024; Flagma, 2024); Institute of Industrial Crop, Agricultural Crops Research Institute, Chinese Academy of Agricultural Sciences, China (Hua *et al.,* 2024); Karabalyk Agricultural Experimental Station, Agricultural

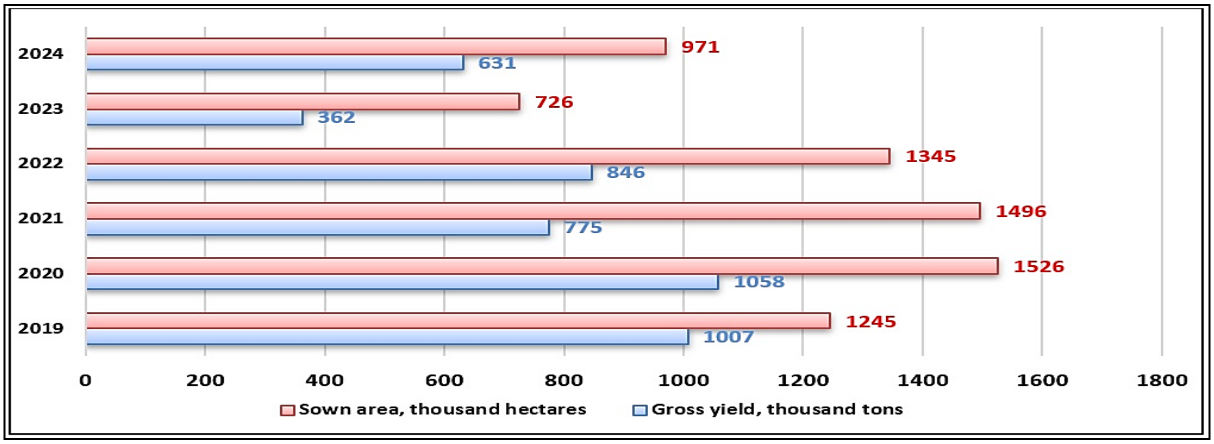


**Figure 1.** Sown areas and gross yield of flax in Kazakhstan during 2019–2024.

Experimental Station, Zarechnoye, Kazakhstan (Iskakov *et al.*, 2023); North Dakota State University, Iowa State University, USA (Hoque *et al.,* 2020; Iowa State University, 2024); Indian Institute of Oilseeds Research (ICAR), India (ICAR, 2024); and German Seed Alliance, Deutsche Saatveredelung AG, Germany (German Seed Alliance, 2024; Deutsche Saatveredelung AG, 2024).

In Kazakhstan, the breeding research work on oilseed flax centers on increasing productivity, drought resistance, high seed oil content, large-seededness, and resistance to lodging, diseases, and pests, and the development of high-yielding cultivars with short growing seasons (Amangaliev *et al.,* 2023). In Kostanay Region, Kazakhstan, two research organizations, Karabalyk Agricultural Experimental Station and Agricultural Experimental Station, Zarechnoye, currently engage in developing flax's high-yielding cultivars with early maturity.

In Kazakhstan during 2024, 15 flax cultivars (including six obtained through local selection) have succeeded in being recommended for cultivation. These cultivars include Altyn, Kazar, Kostanaysky-11, Karabalyksky-7, Kustanai Yantar, and Azur (Agricultural Experimental Station, Zarechnoye, Karabalyk Agricultural Experimental Station, East Kazakhstan Agricultural Experimental Station), Kazakhstan (State Register, 2024); VNIIMK 620 and Severny (V.S. Pustovoit All-Russian Research Institute of Oilseeds, Siberian Experimental Station of the V.S. Pustovoit All-Russian Research Institute), Russia; Aisberg, Vodograi, and Orfei (Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine), Ukraine; Libra and Justess (Limagrain Europe, Gie Linea Semences de Lin), France; and Bingo and Lirina (Nord Deutsche Pflanzentsucht, Deutsche Saatveredelung AG), Germany (Table 1). The latest research, carried out during 2021–2024 at the Karabalyk Agricultural Experimental Station and Agricultural Experimental Station, Zarechnoye, Kazakhstan, aimed to evaluate advanced flax lines obtained through hybridization.

## MATERIALS AND METHODS

### Research area climatic conditions

The experimental field layout occurred at the Agricultural Experimental Station, Zarechnoye, Kazakhstan, located in the dry-steppe zone (53°14′06″ N latitude and 63°44′02″ E longitude). In this zone, the climate is sharply continental, with hot and dry summers and cold and low-snow winters. The annual air temperatures average 75 °C, while in some seasons, it reaches 88 °C. In winter, the minimum air temperature often drops to 35 °C–40 °C, and in summer, the absolute

**Table 1.** Domestic and foreign flax cultivars recommended for production in Kazakhstan.

| Cultivars and hybrids | Year of variety's approval | Origin | Country | Recommended zone of cultivation |
|---|---|---|---|---|
| Karabalyksky 7 | 1979 | Karabalyk Agricultural Experimental Station | Kazakhstan | Akmola zone, North Kazakhstan zone |
| Kustanai Yantar | 1994 | Agricultural Experimental Station «Zarechnoye» | Kazakhstan | Akmola zone, Karaganda zone, Kostanay zone, North Kazakhstan zone |
| Kazar | 2005 | Agricultural Experimental Station «Zarechnoye» | Kazakhstan | Kostanay zone |
| Kostanaysky 11 | 2016 | Agricultural Experimental Station «Zarechnoye» | Kazakhstan | Kostanay zone, North Kazakhstan zone |
| Altyn | 2021 | Agricultural Experimental Station «Zarechnoye» | Kazakhstan | Akmola zone, Kostanay zone |
| Azur | 2024 | East Kazakhstan Agricultural Experimental Station | Kazakhstan | East Kazakhstan zone |
| Severny | 2006 | State Scientific Institution «Siberian Experimental Station of the V.S. Pustovoit All-Russian Research Institute» | Russia | North Kazakhstan zone |
| VNIIMK 620 | 2021 | Federal State Budgetary Scientific Institution «Federal Scientific Center «V.S. Pustovoit All-Russian Research Institute of Oilseeds» | Russia | East Kazakhstan zone, North Kazakhstan zone |
| Aisberg | 2019 | State institution «Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine» | Ukraine | Pavlodar zone |
| Vodograi | 2020 | State institution «Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine» | Ukraine | Akmola zone, Karaganda zone |
| Orfei | 2020 | State institution «Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine» | Ukraine | Akmola zone |
| Libra | 2015 | Limagrain Europe | France | Akmola zone, East Kazakhstan zone, North Kazakhstan zone |
| Justess | 2023 | Gie Linea Semences de Lin | France | Almaty zone, East Kazakhstan zone, Kostanay zone, Abay zone, Zhetysu zone |
| Lirina | 2011 | Research Institute for Cereals and Industrial Crops | Romania | Akmola zone |
| Bingo | 2020 | Nord Deutsche Pflanzentsucht | Germany | Akmola zone, North Kazakhstan zone |

temperature was +41 °C–43 °C. The frost-free period varies from 108 to 130 days. The characteristic feature of continental climate, as recorded, had the predominance of precipitation in the warm period (May–October), with 60%–80% of the annual norm falling out. However, the maximum precipitation occurs in the second half of summer, most frequently in July. The humidity index ranges from 0.9 (North) to 0.5 (South) in the said region. The experimental soil was southern black soil and medium loamy. The humus content in the arable horizon (0–30 cm) does not exceed 3%, with low nitrogen (19.2 mg/kg), medium available phosphorus (28 mg/kg), and high potassium (331 mg/kg of soil).

The second experimental location was Karabalyk Agricultural Experimental Station, Kazakhstan, located at the northwestern tip of Kostanay Region (53°51′06″ N latitude and 62°06′14″ E longitude) and the moderately arid forest-steppe zone. Geographically, the zone is transitional from the West Siberian lowland to the southern steppes, which predetermines its constant exposure to the penetration of both northern cold and southern warm air masses. This could refer to the highly unstable weather conditions and droughts with strong winds. Over the last 60 years, the average annual precipitation was 319.5 mm, and the temperature was 2.2 °C. The most humid and warm months were in June and especially July. The moisture and heat availability were evident with considerable differences year-wise. In general, precipitation was more frequent during the warm period than the cold period. The temperature of the research area had a sharply fluctuating characteristic by the month and even within a day. The average annual duration of the frost-free period was 105–110 days. The soils belong to the medium humus black soils and contain 5.2%–6.0% of humus. The soil is heavy loam with very high nitrogen (5 mg/100 g of soil) and a high potassium content (20 mg/100 g of soil).

In the study regions, the meteorological indicators had a general trend of high temperature and precipitation deficits in 2021, which was an extremely dry year. Against the background of a less high temperature, the year 2022 also showed low rainfall during the flax-crop growing season, and the most moisture-supplied year was 2024, giving 270–295 mm of precipitation from May to August. The atmospheric precipitation was higher for the three years of research in the area of Zarechnoye Village. Uneven precipitation from May to August was evident by years. The most important month when forming reproductive organs was July, with July 2024 having the most water-supplied month. The amount of precipitation in this month affected both the yield of flax and the process of artificial hybridization. With low precipitation in July, the percentage of setting decreased.

**Breeding material**

The research material comprised flax breeding lines developed through local selection at the Karabalyk Agricultural Experimental Station and Agricultural Experimental Station, Zarechnoye, Kazakhstan (Table 2). Planting of experiments and observations proceeded by following the methodology of Dospekhov (2012). The precursor was herbicide fallow. Moisture closure took place as the soil reached physical maturity with a rotary harrow without disturbing the mulch layer. Herbicide weeding used 'Uragan Forte,' carried out 8–9 days before sowing, and the rate of consumption was 1.5–2.0 L ha$^{-1}$. The flaxseed hand-sowing ensued on the 20th and 30th days of May. The seeding rate followed was that of 6.5–7 million germinated seeds per hectare at the depth of 2–3 cm. The sowing method was row sowing with disk seeders, with a row spacing of 15 cm, and the accounting plot area was as follows: hybrid nursery—1 m$^2$; breeding nurseries—0.2–0.4 m$^2$; control nursery—6 m$^2$ with 2-fold repetition; competitive variety testing—10 m$^2$; 4-fold repetition; and the seeding was randomized.

The best domestic cultivars, Altyn and Kustanai Yantar, were sample standards. The sowing of the hybridization nursery comprised two terms. Flax hybridization progressed according to the methodology of Rogash and Dunayeva (1969). In the intraspecific hybridization of oilseed flax, scientists carried out two types of crosses: a) pair crosses and the simple crossing (A × B), widely used at the first stages of developing original breeding material. The use of pairwise crosses mainly improved the individual traits and properties in locally adapted cultivars. b) Three-way crosses ([A × B] × C) usage will enhance the genetic diversity of the source material and bring together various traits in the newly constructed genotype. The pairwise cross usually involves donors of traits with relatively simple inheritance. The third component of crosses should receive greater attention, as it contributes up to 50% of the heritability to the hybrids. For crossing, researchers preferred to select the high-yielding and locally adapted flax cultivars.

**Table 2.** Scheme of breeding process at the Karabalyk Agricultural Experimental Station and Agricultural Experimental Station, Zarechnoye during 2021–2024.

| Nurseries | Number of years studied, pcs | | | | |
|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | Total |
| Karabalyk Agricultural Experimental Station | | | | | |
| F1 | 38 | 40 | 39 | 20 | 207 |
| F2 | 32 | 31 | 32 | 25 | 120 |
| F3 | 33 | 29 | 37 | 30 | 129 |
| 1st year breeding nursery | 100 | 100 | 100 | 100 | 400 |
| 2nd year breeding nursery | 60 | 60 | 60 | 50 | 230 |
| Control nursery | 42 | 42 | 42 | 40 | 42 |
| Competitive variety testing | 11 | 11 | 11 | 13 | 13 |
| Ecological variety testing | 18 | 18 | 18 | 18 | 18 |
| Total | 334 | 331 | 339 | 296 | 1159 |
| Agricultural Experimental Station «Zarechnoye» | | | | | |
| F1 | 24 | 20 | 12 | 12 | 68 |
| F2 | 0 | 24 | 20 | 12 | 56 |
| F3 | - | - | 38 | 12 | 50 |
| F4 | - | - | - | 65 | 65 |
| Breeding nursery | 351 | 165 | 165 | 88 | 769 |
| Preliminary variety testing | 115 | 116 | 116 | 100 | 116 |
| Control nursery | 10 | 12 | 12 | 10 | 12 |
| Competitive variety testing | 10 | 12 | 12 | 10 | 12 |
| Total | 498 | 355 | 367 | 309 | 1148 |

Harvesting operations transpired with a sealed combine, 'Wintersteiger-Classic,' in the phase of 'browning of bolls' with the seed moisture content at 14%–16% and cutting height of 10–15 cm. Harvesting continued with immediate drying of the heaps to 9% of their moisture content. Carrying out all the observations based on the evaluation of oilseed flax genotypes occurred through morphological and economically valuable traits, as well as mathematical processing of research results as per the guidelines for studying the flax (*L. usitatissimum* L.) species (Kutuzova and Pitko, 1989). The description and distribution of flax cultivars into various groups based on morpho-biological parameters applied the methodology and the international classifier of *L. usitatissimum* L. species (Rykova, 1989). Analysis of the crude fat content in soybean seeds employed spectroscopy on a FOSS Infratech 1241 device, calibrated according to the standard Soxhlet method (State Standard 10857-96). Statistical processing of data analysis continued in the open-source software environment R version 4.4.2 and in Windows Excel.

## RESULTS AND DISCUSSION

The study breeding material of flax incurred development through intervarietal hybridization (Uschapovsky *et al.,* 2015). Based on the extensive gene pool of flax, working collections have been formed, and the cultivars that develop the collection are the sources and donors of economically useful traits. The best local and exotic cultivars used in crosses became parental genotypes. Over the years, hybridization of the best parental forms (having resistance to various stress factors) resulted in developing the hybrid material (Kutuzova *et al.,* 2010). An important source of genes of economically valuable traits for combinational breeding is the working national and international (under the auspices of FAO) flax collections, totaling more than 25,000 storage units (Pavelek, 2001).

For the study years 2021–2024, hybridization occurred on 248 cross combinations, with the seeds successfully crossed on 215 cross combinations. The percentage of crossbreeding ranged from 12.8% to 82.3%, which may be related to the

**Table 3.** The hybridization and production results of hybrid progeny of oilseed flax during 2021–2024.

| Years | Research organizations | Number of hybrid combinations (#) | Number of pollinated flowers (#) | Number of crossed hybrid fruits (#) | Crossbreeding (%) |
|---|---|---|---|---|---|
| 2021 | Karabalyk Agricultural Experimental Station | 50 | 750 | 96 | 12.8 |
| | Agricultural Experimental Station «Zarechnoye» | 24 | 600 | 494 | 82.3 |
| 2022 | Karabalyk Agricultural Experimental Station | 50 | 750 | 112 | 14.9 |
| | Agricultural Experimental Station «Zarechnoye» | 20 | 600 | 428 | 71.3 |
| 2023 | Karabalyk Agricultural Experimental Station | 50 | 892 | 125 | 14.0 |
| | Agricultural Experimental Station «Zarechnoye» | 12 | 758 | 98 | 12.9 |
| 2024 | Karabalyk Agricultural Experimental Station | 30 | 300 | 198 | 66.0 |
| | Agricultural Experimental Station «Zarechnoye» | 12 | 600 | 456 | 76.0 |

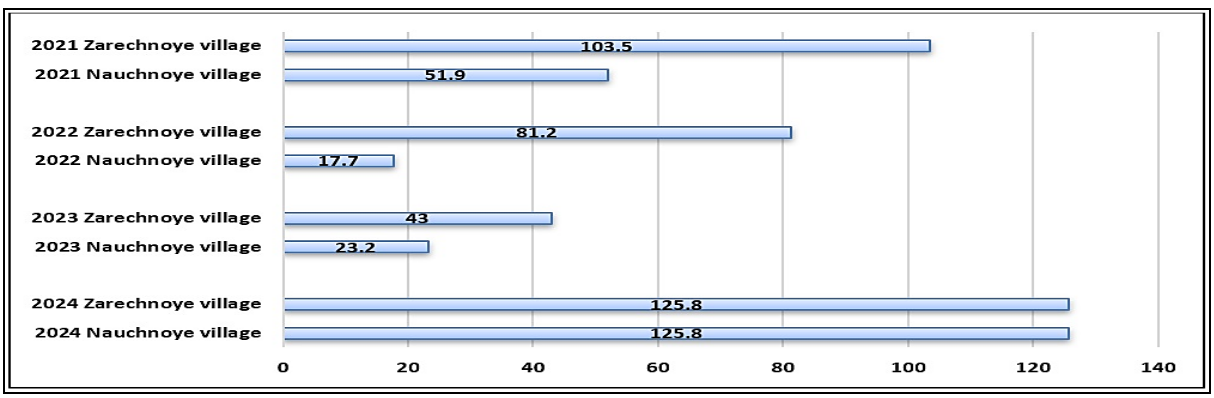


**Figure 2.** Precipitation (mm) during the formation of flax generative organs (July) at the research areas during 2021–2024

environmental conditions under which the hybridization took place (Table 3). Thus, the low percentage of crossbreeding at the Karabalyk Agricultural Experimental Station during 2021–2023, as well as at the Agricultural Experimental Station, Zarechnoye, in 2023, showed an association with drought conditions and precipitation (15–50 mm) during the flowering period of flax. This negatively affected the formation of reproductive organs. The best hybridization results of 66.0% and 76.0% resulted in the most moisture-rich crop season of 2024 (Figure 2).

In hybrid nurseries of the first to fourth generation, selection for productivity traits did not take place. Starting the breeding nurseries continued to select the genotypes with productive plants whose progeny will serve as new cultivars in the future. In senior breeding nurseries—the control, preliminary, and competitive nurseries—the promising flax genotypes with superior seed yield as compared with the standards underwent selection. Thus, in the breeding nurseries, the rejection rate was 83.0% to 83.7%, while in senior nurseries, the rejection rate was 39.8% to 59.9% (Table 4). As a result of the

**Table 4.** Number of flax breeding lines outstanding in seed yield.

| The research organizations | Nurseries | 2021 | 2022 | 2023 | 2024 | Total (#) | Percentage of selection from studied forms (%) |
|---|---|---|---|---|---|---|---|
| Karabalyk Agricultural Experimental Station | 1st year breeding nursery | 10 | 14 | 12 | 29 | 65 | 16.3 |
| | 2nd year breeding nursery | 7 | 11 | 12 | 9 | 39 | 17.0 |
| | Control nursery | 2 | 7 | 13 | 7 | 7 | 17.5 |
| | Competitive variety testing | 3 | 4 | 4 | 4 | 4 | 39.8 |
| Agricultural Experimental Station, Zarechnoye | Breeding nursery | 79 | 138 | 42 | 15 | 274 | 35.6 |
| | Control nursery | 70 | 72 | 26 | 20 | 188 | 42.1 |
| | Preliminary variety testing | 1 | 8 | 4 | 6 | 5 | 43.2 |
| | Competitive variety testing | 6 | 5 | 6 | 5 | 6 | 59.9 |

presented research, the high-yielding flax lines obtained identification at different stages of the breeding process. In the studies, negative selection in hybrid combinations was up to 90%. Such factors as height, branching, large-seededness, resistance to lodging, and disease resistance were considerations in this study (Uschapovsky, 2013). The research has established that the method of selecting oil flax plants according to a new trait—the flowering period compared with the accepted analogue—was successful. It made it possible to increase the yield of renewed (original) seeds by 35.6%, increase their uniformity in seed weight by 8% and seed strength by 9.1%, and reduce labor costs by 31% (Ponazhev, 2022).

At the Karabalyk Agricultural Experimental Station, in the nursery of competitive varietal testing of flax based on the yield, four best genotypes (K-15-10-2, K-55-12-2, K-57-13-2, and K-51-12-2) surfaced in comparison with the standard cultivar 'Kustanai Yantar' (1.48 t/ha). However, the average seed yield of the selected promising genotypes ranged from 1.6 to 1.7 t/ha, with a gain of 0.12 to 0.22 t/ha, respectively. The highest productivity emerged in the flax genotype K-57-13-2, with a growing season of 88 days and a seed yield of 1.66 t/ha during the years of research. In the said nursery, the oil yield per hectare was in the range of 0.594 to 0.721 t/ha (Table 5). In studies by Begalina *et al.* (2021) in the Akmola Region, the highest productivity in 2019 resulted in varieties Kustanai Yantar (Kazakhstan) and UF02 (China); their yields were 1.45 and 1.50 t/ha, with oil contents of 43.6% and 45.2%, respectively. Under the influence of more favorable weather conditions in 2020, high yields were in the released varieties, such as Kustanai Yantar and Severny (2.05 and 2.17 t/ha, respectively).

At the Agricultural Experimental Station, Zarechnoye, in the flax nursery of competitive varietal testing based on seed yields, six best genotypes (C-5402, 757, 397, K 1529, C1104(2), and 120) arose in comparison with the standard cultivar 'Altyn' (1.4 t/ha). The average seed yield of the selected promising flax genotypes ranged from 1.52 to 1.67 t/ha, with a gain of 0.11 to 0.27 t/ha, respectively. However, the highest productivity was evident in the flax genotype C-5402, with a growing season of 79 days and a seed yield of 1.67 t/ha. The flax oil yield ranged from 0.528 to 0.638 t/ha in the competitive variety testing nursery.

For the study years 2021–2024, in the flax nursery of competitive varietal testing at the Karabalyk Agricultural Experimental Station, the leading genotype was K-57-13-2 'Asay,' with an average seed yield of 1.7 t/ha. It was higher (by 0.22 t/ha) than the standard genotype 'Kustanai Yantar.' The growing season was 88 days, the seed oil content was 42.6%, and the oil yield was 0.721 t/ha. The

**Table 5.** The flax genotypes selected from the competitive variety testing nursery in the Northern Kazakhstan.

| Breeding lines | Seed yield (t/ha) | | | | | Deviation from the standard (t/ha) | Oil content (%) | | | | | Oil yield (t/ha) | | | | | Deviation from the standard (t/ha) | Growing season (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | Average | | 2021 | 2022 | 2023 | 2024 | Average | 2021 | 2022 | 2023 | 2024 | Average | | |
| Karabalyk Agricultural Experimental Station | | | | | | | | | | | | | | | | | | |
| Kustanai Yantar (st) | 1.0 | 1.58 | 1.63 | 1.69 | 1.48 | - | 42.7 | 42.3 | 42.5 | 42.7 | 42.6 | 0.427 | 0.668 | 0.692 | 0.721 | 0.627 | - | 87.0 |
| K-57-13-2 | 1.13 | 1.84 | 1.85 | 1.97 | 1.7 | +0.22 | 39.3 | 43.3 | 43.5 | 43.8 | 42.5 | 0.444 | 0.796 | 0.804 | 0.862 | 0.721 | 0.093 | 87.8 |
| K-55-12-2 | 1.14 | 1.75 | 1.81 | 1.94 | 1.66 | +0.18 | 40.5 | 40.6 | 40.7 | 44.1 | 41.5 | 0.461 | 0.710 | 0.736 | 0.855 | 0.688 | 0.060 | 88.0 |
| K-15-10-2 | 1.18 | 1.78 | 1.80 | 1.83 | 1.65 | +0.17 | 42.8 | 40.4 | 40.1 | 42.9 | 41.6 | 0.505 | 0.719 | 0.721 | 0.785 | 0.684 | 0.056 | 86.5 |
| K-51-12-2 | 0.99 | 1.73 | 1.78 | 1.89 | 1.6 | +0.12 | 42.9 | 42.9 | 42.2 | 42.5 | 42.6 | 0.424 | 0.742 | 0.751 | 0.803 | 0.680 | 0.053 | 89.5 |
| Agricultural Experimental Station, Zarechnoye | | | | | | | | | | | | | | | | | | |
| Altyn (st) | 1.54 | 1.05 | 1.5 | 1.51 | 1.4 | - | 42.2 | 42.8 | 29.1 | 38.3 | 38.1 | 0.649 | 0.449 | 0.436 | 0.578 | 0.528 | - | 79 |
| C5402 | 1.73 | 1.67 | 1.62 | 1.67 | 1.67 | +0.27 | 36.9 | 37.0 | 33.5 | 38.0 | 36.4 | 0.638 | 0.617 | 0.542 | 0.634 | 0.608 | 0.079 | 79 |
| 757 | 1.87 | 1.47 | 1.6 | 1.64 | 1.64 | +0.24 | 39.9 | 42.0 | 32.2 | 36.9 | 37.8 | 0.746 | 0.617 | 0.515 | 0.605 | 0.620 | 0.092 | 79 |
| 120 | 2.06 | 1.55 | 1.33 | 1.56 | 1.63 | +0.22 | 39.2 | 41.0 | 37.5 | 39.2 | 39.2 | 0.807 | 0.635 | 0.498 | 0.611 | 0.638 | 0.109 | 78 |
| 397 | 1.85 | 1.2 | 1.55 | 1.61 | 1.55 | +0.12 | 41.1 | 42.0 | 37.3 | 39.5 | 40.0 | 0.760 | 0.504 | 0.578 | 0.635 | 0.619 | 0.091 | 79 |
| C1104(2) | 1.78 | 1.61 | 1.36 | 1.5 | 1.56 | +0.11 | 41.0 | 42.0 | 34.3 | 30.3 | 36.9 | 0.729 | 0.676 | 0.466 | 0.454 | 0.581 | 0.053 | 79 |
| K1529 | 1.85 | 1.0 | 1.68 | 1.55 | 1.52 | +0.12 | 41.4 | 41.0 | 34.3 | 40.1 | 39.2 | 0.765 | 0.410 | 0.576 | 0.621 | 0.593 | 0.065 | 79 |

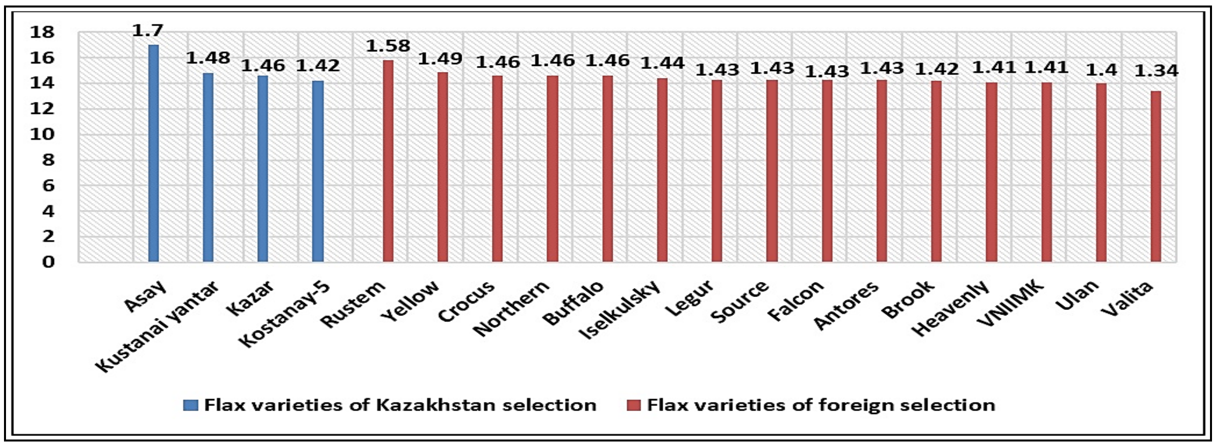


**Figure 3.** Flax cultivars' yield (t/ha) obtained through domestic and foreign selection.

said cultivar, developed through hybridization of the flax cultivars Danik × (Opus × K-75-09), followed the individual selection process. The cultivar type was ‘mezzeumok,’ with a plant height of 50–65 cm, the attachment height of the lower branches was 20 cm, and 1000-seed weight ranged from 6.8 to 7.0 g. The said cultivar matures friendly with high ecological plasticity and has the highest seed yield and seed-oil potential, with resistance to fusariosis. The mentioned cultivar was notably resistant to drought conditions and also suitable for food and medical purposes. The said genotype appeared with the highest seed yield (2.02 t/ha) in 2020 on fallow land.

At the Agricultural Experimental Station, Zarechnoye, during the study years of 2021–2024, in the flax nursery of competitive variety testing, the genotype C-5402 'Satti' was noteworthy with an average seed yield of 1.67 t/ha. It was higher (by 0.27 t/ha) than the standard variety Altyn. Its growing season was 79 days, the seed-oil content was 36.4%, and the oil yield was 0.608 t/ha. The said flax genotype’s plant height was 50–59 cm, and 1000-seed weight was 7.0 g. It is high yielding, drought resistant, and resistant to diseases. The said cultivar also showed resistance to lodging and suitability for mechanized harvesting. The flowers were of medium size, and the petals were light blue at full development.

Past biochemical analyses of flax seeds have led to the identification of their bioactive substances, lignans, which may find application in improving human health (Al-Madhagy *et al.,* 2023). In addition, Canadian scientists’ breeding research work also aimed at developing the improved flax cultivars adapted to prairie conditions, with higher seed yield potential, early maturity, and better lodging resistance (Duguid *et al.,* 2014). Moreover, in the USA, researchers studied the effect of crop rotation on plant growth, seed yield, seed-oil concentration, and nitrogen use efficiency in flax crops (Upendra *et al.,* 2020). Overall, worldwide, the flax breeding work mostly focused on the production of cultivars resistant to abiotic and biotic environmental factors with a high level of productivity and quality of flax raw materials (Andronik *et al.,* 2016).

Previous studies have progressed worldwide to investigate the quality of flax seeds obtained from different geographical areas, which confirm that environmental conditions considerably impact plant growth and development, seed yield, and seed-oil yield (Mishra and Awasthi, 2021). Past studies also comprised the characterization of flax genetic diversity available in different gene pools around the world, which are pertinent for long-term sustainability of flax production and diversification, as well as for the overall success in flax breeding programs (Vikender *et al.,* 2023).

At the field station of the Karabalyk Agricultural Experimental Station, the comparative study of exotic and local flax genotypes was successful under the conditions of the Kostanay Region. Long-term studies have shown nonsignificant differences in seed yield and seed-oil yield per hectare. Thus, the seed yield level of the domestic flax cultivars was within the range of 1.42 to 1.7 t/ha, and exotic cultivars ranged from 1.34 to 1.58 t/ha. The most common flax cultivar, 'Severny,' obtained through Russian selection and studied for four years, showed on average a seed yield of 1.46 t/ha, which was lower than the best domestic flax cultivars (Figure 3). The seed-oil yield of all the exotic flax cultivars was at par with the local cultivars, ranging from 0.564 to 0.655 t/ha, except the domestic flax variety ‘Asay,’ whose seed-oil yield was 0.721 t/ha over four years.

The Russian Agricultural Center has ranked the 10 most popular oilseed flax varieties by seeding volume in the Russian Federation for 2023. Leading were varieties of V.S. Pustovoit All-Russian Research Institute of Oilseeds, such as Severny, VNIIMK 620, and August. In the conditions of the Krasnodar Region, they have indicators: variety Severny—oil content of 46.4%–48.6% and a yield of 2.4–2.6 t/ha; variety VNIIMK 620—oil content of 48.0%–49.6% and a yield of 2.2–2.5 t/ha; and variety August—oil content of 49.8%–53.3% and a yield of 2.5–2.7 t/ha (Direct Farm, 2024). Flax varieties popular in the Republic of Belarus attained creation at the Flax Institute, such as the Ilim variety with a yield of 2.21 t/ha and oil content in seeds of

47.6%; the Opus variety with a yield of 2.29 t/ha and oil content in seeds of 44.6%; and the Salut variety with a yield of 2.07 t/ha (Golub *et al.,* 2015).

## CONCLUSIONS

As a result of the flax breeding research work carried out during 2021–2024 at the Karabalyk Agricultural Experimental Station and Agricultural Experimental Station, Zarechnoye, Kazakhstan, 2307 flax breeding lines underwent studies. The high-yielding advanced lines of flax succeeded in being identified. The flax cultivar 'Asay' had an average seed yield of 1.7 t/ha, which was developed at the Karabalyk Agricultural Experimental Station. The flax cultivar 'Satti' displayed an average seed yield of 1.67 t/ha, developed at the Agricultural Experimental Station, Zarechnoye. Comparative research on the local and exotic flax cultivars revealed nonsignificant differences in seed yield and seed-oil yield under the conditions of the Kostanay Region, Kazakhstan.

## ACKNOWLEDGMENTS

The work ran within the program-target financing of the Ministry of Agriculture of the Republic of Kazakhstan under the budget program 267, BR22885857, 'Development and introduction of highly productive oilseed and cereal varieties and hybrids to ensure food security of Kazakhstan.'

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