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Potential for the Wide Use of Pollinating Bees in the Oil Flax Cultivation System of Kazakhstan

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ABSTRACT

The article examines the potential for the wide use of pollinating bees in the oil flax cultivation system in the Republic of Kazakhstan. The study aimed to determine the effect of organized pollination by cultivated bee breeds on the yield of oil flax under the conditions of Akmola and East Kazakhstan regions. The experiments were conducted in 2023-2025 on seed-production plots using isolated and non-isolated accounting plots located 200 and 500 m from apiaries. Carniolan bees were used as pollinators. It was found that in northern Kazakhstan, the seed yield of oil flax on plots accessible to bees exceeded the control variants by 17.8-28.4%, while in the east, the increase was 18.4-23.5%. Additional pollination contributed to an increase in the number of bolls per plant, the number of seeds per boll, and the weight of 1000 seeds, while seed oil content remained stable at 48.0-50.2%. The obtained data confirm the feasibility of including organized bee pollination in technological maps for oil flax cultivation.

Keywords: *Oil flax, Pollinating bees, Carniolan bee, Entomophilous crops, Yield, Kazakhstan*

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INTRODUCTION

Modern crop production faces the tasks of increasing yield, greening technologies, and preserving biodiversity. Under these conditions, biological pollination by bees becomes not only an agrotechnical practice but also an economically significant factor. However, Kazakhstan still lacks unified pollination technologies adapted to specific climatic conditions. This is especially true for scientifically substantiated standards for the placement of bee colonies, the timing of their introduction, the selection of breeds and lines adapted to different conditions, and the assessment of the economic efficiency of these measures (Gyulmagomedova *et al*., 2022).

The honey bee (Apis mellifera) plays a key role in maintaining the productivity of agroecosystems through the pollination of entomophilous crops. About 75% of all cultivated plants depend on insect pollinators, and more than half of them are pollinated by bees. In Kazakhstan, where agriculture is one of the priority sectors, the importance of beekeeping extends beyond the production of honey and other bee products; it becomes a strategically important element of sustainable agriculture.

International experience shows that higher yields and the introduction of resource-saving technologies are possible through the widespread use of methods for attracting insect pollinators, including managed bees, bumblebees, and others (Bee pollination affecting sunflower yield, 2016; Hao *et al*., 2025).

Every year, the area sown with entomophilous crops in the republic increases, since many of them are so-called business crops, such as oil flax, safflower, and sunflower; however, apiaries specifically intended for pollination are not being formed. In addition to these crops, the republic widely cultivates crops that are part of the food security basket, such as rapeseed, buckwheat, mustard, alfalfa, sweet clover, and sainfoin, as well as fruit, vegetable, and melon crops. The development of technologies for biological pollination of crops by bees is an urgent necessity for both crop producers and beekeepers.

In previous years, Kazakhstan conducted experiments on floral specialization and floral migration of different bee breeds, which showed that the increase in yield, for example, in oil flax pollinated by honey bees, reached 39% when an apiary was placed within an effective range of 200 m.

Field studies on the effect of bees on the yield of entomophilous crops are being conducted for the first time in different regions of Kazakhstan. Based on their results, recommendations will be developed for including the placement of apiaries during flowering in technological maps for the cultivation of entomophilous crops. This approach represents a new solution for increasing crop yield, creating a new type of service for crop producers, and introducing a risk insurance system for beekeepers (Limanskaya *et al*., 2021).

As international experience has shown, bee pollination increases the productivity of entomophilous plants, improves seed quality, and increases the size of seeds and fruits. A scientifically based approach to pollinating fields with honey bees is a key task for producers of crop products, including seed products (Krivtsov *et al*., 2000; Morgan *et al*., 2025).

In the absence of honey bees, obtaining an economically significant seed yield is rather difficult. Honey bees perform more than 80% of all pollination work in such crops. Therefore, the yield of entomophilous plants directly depends on the intensity of the pollination activity of these insects.

With proper placement of apiaries, productive pollination of large areas of perennial leguminous grasses and oil crops can be organized.

The arable land area in the Republic of Kazakhstan exceeds 23 million ha annually. Of this area, 16 million ha are allocated to grain crops, 3.5 million ha to oil crops, and 3 million ha to fodder, vegetable, melon crops, and potatoes (Di Fiore *et al*., 2024; Nagesh *et al*., 2025).

Of the total annual sown area, all oil crops, buckwheat among cereal crops, and practically all vegetable and melon crops are entomophilous.

In most regions with large sown areas exceeding 900 thousand ha, the priority entomophilous crops include oil crops such as sunflower in Akmola, East Kazakhstan, Kostanay, Pavlodar, and North Kazakhstan regions; curly flax in Akmola, Karaganda, Kostanay, Pavlodar, and North Kazakhstan regions; and safflower in Kostanay Region.

Flax production in these regions began to increase as part of the diversification of sown areas about five years ago. Later, sunflower areas also expanded. Soybean, rapeseed, safflower, mustard, and buckwheat occupy relatively small areas.

The regions located in the north-eastern and central parts of the republic account for 85% of all areas of cultivated honey plants (Kowalski *et al*., 2024).

Entomophilous crops are widely cultivated throughout Kazakhstan, with the largest areas concentrated in the northern, northeastern, and central regions. Their share exceeds 20% of the total sown area in Abay (41.3%), East Kazakhstan (39.8%), Pavlodar (29.6%), and Turkestan (21.6%) regions. The largest areas under priority entomophilous crops are recorded in Kostanay (711.3 thousand ha), North Kazakhstan (695.2 thousand ha), Pavlodar (478.1 thousand ha), Abay (309.4 thousand ha), Akmola (269.0 thousand ha), and East Kazakhstan (241.8 thousand ha). Sunflower predominates in Abay and East Kazakhstan regions, sunflower and buckwheat in Pavlodar Region, and vegetable and melon crops and safflower in Turkestan Region. In Akmola Region, where one of the experimental sites was located, oil flax is among the principal entomophilous crops, together with sunflower, rapeseed, safflower, mustard, and soybean. In East Kazakhstan Region, the main entomophilous crops include sunflower, rapeseed, vegetable and melon crops, buckwheat, and soybean.

Oil flax (Linum usitatissimum L.) is one of the most important crops in world farming. According to FAO data, this crop is grown in 50 countries. The main countries producing flaxseed oil are Canada, India, China, Ethiopia, and the United States (Methodology of State Variety Testing of Agricultural Crops, 1985). In Kazakhstan, interest in this crop has increased in recent years because of its high drought and cold resistance, the adaptation of highly productive varieties of domestic and introduced breeding, and the development of seed production. A steady increase in sown areas and gross seed harvests is observed. In 2025, more than 1.5 million ha were sown with oil flax in the republic, which is a record level. The yield of oil flax varies within 7-10 c/ha of oilseeds (Huber *et al*., 2025).

Oil flax is a multipurpose crop (oil, flax fiber, feed cakes, and meals) that has been used by humans since ancient times. It is undemanding in cultivation conditions, provides high yields of oilseeds, is characterized by relatively high yield stability, and does not require a special set of agricultural machinery for cultivation. Flax seeds contain 46-50% or more oil, which surpasses other oils in consumer properties. This explains its use as a technical raw material for several industries, including paint and varnish, soap-making, leather, and footwear industries (Rozhmina *et al*., 2018; Salem *et al*., 2025).

In addition to its importance for the food and processing industries, flax cultivation helps address the protein problem in livestock production. The cake remaining after oil pressing is a valuable feed for all types of farm animals. It contains, on average, 31-37% digestible protein and 9-15% fat. Therefore, flax cake is a very valuable, energy-rich feed. Its inclusion in concentrated grain feeds makes it possible to balance them in terms of protein, fat, and essential amino acids. Flax chaff is used as an additive to roughage and as bedding material (Pershakov *et al*., 2020). The nutrients of flax cake are easily digested by animals, increase milk yield in cows, and increase milk fat content. It is also important that, due to its high mucilage content, flax cake has a beneficial effect on the digestive system and on animal health in general. Therefore, the use of flax cakes and meals in diets significantly increases the productivity of farm animals. Thus, the whole complex of economically useful traits of oil flax determines the need for, and the prospects of, further research aimed at expanding its cultivation area. Oil flax is not a traditional crop for the regions of Kazakhstan, and when it is expanded and introduced into production, all features of its growth, development, and main cultivation technology elements under these soil and climatic conditions should be carefully studied (Novak & Jelic, 2025).

Flax is an annual plant, either single-stemmed or branching at the base. The stems are glabrous, covered with a waxy coating, cylindrical, and quite resistant to wind pressure. Blue flowers open at dawn and, by noon, with the onset of heat, close again or fall to the ground. Flowering lasts 5-10 days depending on crop density and air humidity. Blue, bluish, less often violet, pink, or white flowers are collected in an umbel-like raceme. They are rather large, 15-21 mm in diameter, regular in shape, and sway on long pedicels. There are many flowers on the stem: up to 6 thousand flowers can be found per 1 sq. m of curly flax sowing. These bisexual flowers are adapted for cross-pollination by insects (Galkin *et al*., 2008; Kwatra *et al*., 2024).

Flax can be used as a honey plant. In practice, however, this plant attracts little interest from bees. Nevertheless, apiaries are used to increase the productivity of flax fields. Researchers believe that cross-pollination plays a crucial role. Their experiments show that bee pollination of flax can increase yield by almost 50%; however, data on the effect of bee visitation to flax flowers on seed yield are contradictory, ranging from the absence of such a relationship (USA, GDR) to an increase in the number and weight of seeds per boll (USSR, Egypt) (Galkin *et al*., 2008; Vasilenko & Matyushchenko, 2021).

The conditions of formation and frequency of cross-pollination in flax have not been sufficiently studied. The possibility of anemophilous cross-pollination in this crop remains debatable. The probability and frequency of cross-pollination were studied at the Federal Scientific Center VNIIMK on the oil flax varieties VNIIMK 620, Danik, VNIIMK 630, and Surprise (Zolotarev *et al*., 2019; Zairkhanova *et al*., 2024). During the budding and flowering phases, the dynamics of anther opening, the routes of pollen deposition on pistil stigmas, and wind transfer of pollen were studied. It was found that the share of cross-pollination in flax ranged from 0.15 to 0.87%, in some cases increasing to 1.33-1.75%. Pollen transfer was recorded at distances of up to 9 m. However, it was not possible to separate the contributions of entomophilous and anemophilous cross-pollination to the genetic contamination of flax varieties. The main insect pollinators of flax are the honey bee and the alfalfa leafcutter bee. The onset and intensity of wind transfer of common flax pollen are determined by the rate at which it loses stickiness and sheds from the anther surface, the size of pollen agglomerates, and wind speed .

Many researchers believe that bees readily visit flowers from 7:00 to 12:00. The time spent by bees on one flower varies from 6-8 to 26 seconds. They are attracted by the scent of nectar, which is released in amounts sufficient to support a maintenance nectar flow. There are about 60 million flowers per 1 ha of flax crops. Every 100 flowers release 20-30 mg of nectar. The honey productivity of 1 ha of crops is about 15 kg (Aksoy & Akaydin, 2024).

With proper hive placement, productive pollination of flax fields can be organized through an intensive pollination process involving cultivated bee breeds in order to increase seed productivity.

Experiments by researchers are known to have produced positive results in increasing seed productivity of crops through the forced attraction of managed bees. Isolated plots excluding insect visits were used as control variants.

The first experiments on the pollination activity of bees were conducted by P. N. Veprikov in apple orchards and by S. A. Rozov on sunflower (Spaar *et al*., 1999; Lukomets *et al*., 2012). For fruit orchards, a pollination standard of 2-2.5 bee colonies per 1 ha of orchard was established, and the method of opposing pollination was proposed, with groups of bee colonies placed in orchards at intervals of no more than 250 m.

S. A. Rozov studied sunflower pollination in detail, taking into account the biology of flowering. He found that when heads were isolated from bees and when crops were located farther from the apiary, the proportion of empty seeds increased, while the yield increase from pollination averaged 50-60%.

This work aimed to determine the effect of bee pollination on oil flax yield.

MATERIALS AND METHODS

The methodology, scientific methods, and techniques used in the project include field and laboratory experiments; methods for phenological observations, biometric measurements, yield accounting, and experimental data analysis were applied. Statistical processing of numerical data was carried out using analysis of variance.

Experimental studies on the effect of organized intensive pollination by cultivated bee breeds were conducted on stationary field seed-production plots of elite seed-production farms in Akmola and East Kazakhstan regions of the Republic of Kazakhstan.

Scientific research and desk processing of the obtained data were carried out according to generally accepted methods and recommendations for field experimentation and agrotechnologies (Recommendations on the Methodology for Conducting Observations and Research in Field Experiments, 1973; Dospekhov, 1979; Methodology of State Variety Testing of Agricultural Crops, 1985; Methodology for Determining the Economic Efficiency of Using Agricultural Results of Research Work, New Technologies, Inventions, and Rationalization Proposals, 1989).

The object of the study was oil flax crops of the Severny variety in Akmola Region and the Azurit variety in East Kazakhstan Region. The experiments were conducted at the seed-production farms East Kazakhstan Agricultural Experimental Station LLP and Rodina Agrofirm LLP.

Experiments were established to assess the effect of bee pollination on the oil flax varieties Severny in Akmola Region and Azurit in East Kazakhstan Region. During the budding phase, isolated and non-isolated plots were installed and fixed in the crops at distances of 200 and 500 m from the apiaries. The agrotechnology was identical for all plots in accordance with VNIIMK recommendations.

The Severny oil flax variety was developed at the Siberian Experimental Station of VNIIMK by individual selection from a hybrid population obtained by crossing a VIR accession from Morocco (K-1994) with breeding line 157. The variety is early maturing. Its growing season is 70-87 days. Owing to its early maturity and high plasticity, it can be cultivated in steppe, forest-steppe, and other zones. Early maturity is combined with good productivity and high seed oil content. Potential seed yield ranges from 1.2 to 2.5 t/ha. Seed oil content is 47.0-50.0%, and the iodine value of the oil is 180-186 units. It is highly resistant to fusarium wilt (90-95%), shattering, and lodging. Stem height at maturity is 48-65 cm. Flowers and anthers are blue, and the corolla is dense. The boll is rounded, with a pointed tip. The number of seeds per boll is 6-9. The seeds are ovoid and uniformly brown. The weight of 1000 seeds is 7.0-8.5 g. The variety is suitable for mechanized cultivation.

The Azurit variety is mid-maturing, with a growing season of 91 days; it is high-oil and resistant to fusarium wilt. Plant height is 59 cm, and the height of attachment of the lower branch is 29 cm. Resistance to lodging and shattering is 5.0 points. The boll is medium-sized, and false septum fringiness is absent. The seed is brown. Average yield is 15.1 c/ha, and the weight of 1000 seeds is 6.8 g. Seed fat content is 50.5%; linoleic acid content is 15.7%, linolenic acid 50.8%, and oleic acid 21.5%.

Bee colonies were placed around the seed field in groups of 50-60 colonies per group, providing opposing pollination.

In total, four apiaries were installed in each field, with two sites on each field along the crop edge: sites were oriented to the south-east, south, and north-east. In the crop stand, isolated and non-isolated (fixed) accounting plots were established 200 m inward from the apiary and then at 500 m.

Carniolan bees were used as insect pollinators.

The Carniolan bee is a naturally occurring bee breed. It was first discovered in the county of Carniola, in the territory of present-day Slovenia. In 1880, the bees were officially named Apis mellifica carnica Polltn. Somewhat later, scientists concluded that the breed's distribution area was much larger. Since the late nineteenth century, these insects have been sold to different parts of the world.

The breed is characterized by good adaptive abilities. The main feature of this breed is its calm behavior, which makes it possible not to use smoke or a protective mask during honey collection. It is also characterized by high productivity and reduced susceptibility to diseases.

Carniolan bees tolerate winters well and quickly adapt to climate change. Unlike other breeds, Carniolan bees consume less feed during winter. Six kilograms of honey are sufficient for the colony for wintering and spring brood rearing.

This bee breed is the most widespread and preferred in breeding farms of the Republic of Kazakhstan.

The administrative regions of the Republic of Kazakhstan, where areas of cultivated farming are mainly concentrated, cover several types of natural and climatic zones. These zones differ in soil cover of different fertility levels, seasonal patterns, temperature and moisture dynamics, and the intensity, frequency, and direction of winds. These and many other indicators influence the established priorities for cultivating particular field crops in order to obtain stable yields. The cultivation of honey-bearing crops in active farming zones promotes the development of beekeeping when it is effectively used as a key tool for increasing seed productivity through intensified pollination processes. In turn, honey plants serve as a forage base for managed bees.

Active farming zones include regions located in the western, northern, and north-eastern parts of the Republic of Kazakhstan. Each of these regions crosses three to four natural and climatic zones, from forest-steppe to desert, depending on their geographical location and extent.

Our studies were conducted in Akmola and East Kazakhstan regions, where a substantial share of the sown area is allocated to entomophilous crops, including oil flax.

The climate of Akmola Region, located deep within a vast continent, is characterized by high variability in temperature, humidity, and other meteorological elements, both daily and annually. The average monthly air temperature of the warmest month, July, is 18.5-21.5 °C, while that of the coldest month, January, is -13 to -18 °C. On individual hot days, air temperature rises to 39-42 °C (absolute maximum), while during very severe winters in flat open areas it falls to -49 to -52 °C (absolute minimum). The duration of the warm period with temperatures above 0 °C averages 200 days. Unlike other regions of Northern Kazakhstan, the strongly dissected low-mountain relief has a considerable influence on the climate of Akmola Region. The low-mountain relief within the Akmola Region is characterized by higher precipitation and a more even distribution throughout the year. About 350 mm of precipitation falls annually in the central part of the region, and up to 400 mm in the east. The precipitation maximum occurs during the warm period (April-October). This distribution of precipitation is a characteristic feature of a continental climate. The average annual wind speed ranges from 3.4 to 5.4 m/s. The annual maximum wind speed in the region ranges from 20 to 34 m/s, with gusts of 30-48 m/s (maximum in Shchuchinsk and Stepnogorsk). According to annual calculations for the region, the prevailing wind direction is south-western, with a frequency of 40-55% (Jannath *et al*., 2024; Kazhydromet, n.d.).

The territory of the region is located in forest-steppe and steppe zones, where honey crops such as oil flax, rapeseed, sunflower, vegetable and melon crops, buckwheat, mustard, alfalfa, sweet clover, and sainfoin are successfully cultivated on plains and strongly dissected low-mountain areas, with a total annual sown area of up to 300 thousand ha.

In the Akmola Region, the territory of the farm where the study was conducted is represented by dark chestnut carbonate soils. The humus horizon thickness is within 38 cm. The humus content in the upper layer of virgin land is 2.5-3.5%, and the nitrogen content is 0.15-0.2%, respectively. A characteristic feature of these soils is the increased sandiness of the profile.

The climate of East Kazakhstan Region (now divided into Abay Region and East Kazakhstan Region) is highly diverse. Alongside flat steppe, semi-desert, and desert areas, foothills and high mountains occupy a considerable area, where ridges alternate with intermontane depressions and valleys. The climatic conditions of flat and mountain areas differ in both temperature regime and amount of precipitation. The sharp continentality of desert and semi-desert areas of the region is considerably moderated in mountain and foothill areas. Winter is cold and long. The coldest month is January, with an average monthly air temperature of -12 to -17 °C and, in some places, -23 to -27 °C. The temperature of the warmest month, July, is 15-24 °C. Minimum air temperatures in winter reach -20 to -32 °C, and the absolute minimum in some winters reaches -51 to -54 °C. The absolute maximum air temperature reaches 35-45 °C. In summer, the distribution of average temperatures in the mountains depends on altitude. The warm period with an average daily temperature above 0 °C lasts less than 200 days in the north-east of the region (mountain and foothill areas), and from 200 to 230 days in the south (steppe, semi-desert, and desert areas). Annual precipitation is unevenly distributed. In the north-east of the region, it is 400-650 mm (mountain and foothill areas), while the lowest amount of precipitation occurs in intermontane depressions, less than 200 mm per year. Precipitation during the warm period (IV-X) predominates over precipitation during the cold period (XII-III). This is a characteristic feature of the region's continentality. The precipitation maximum in most of the territory occurs in summer, most often in the second half. Average wind speeds are 2-5 m/s. However, in some districts of the region, strong winds (15 m/s and more) are not uncommon. On average over the year, south-eastern and southern winds prevail in most of the region, while eastern and north-eastern winds prevail in the southern part. The greatest wind activity is observed in the areas of the Zhangiztobe and Aktogay stations.

In the two regions, honey crops such as sunflower, rapeseed, vegetable and melon crops, buckwheat, and soybean are successfully cultivated on a total annual sown area of up to 550 thousand ha (Chandrasekhar *et al*., 2025; KAZHYDROMET, n.d.).

RESULTS AND DISCUSSION

During the study years in Akmola Region (2023-2025), the growing season was characterized by a slightly elevated temperature regime. Average daily temperatures exceeded the norm by 1.8 °C in May, 1.6 °C in June, and 4.2 °C in July, against the background of the absence of substantial precipitation in the initial period. The precipitation deficit during the growing season was 56%. The first substantial precipitation occurred in the first ten days of July, when plants were lagging in growth and development. At the beginning and end of July, sharp temperature transitions from low to high values (from 12.4 to 25.2 °C) and vice versa (from 26.6 to 12.4 °C) were recorded.

The active flowering period of oil flax in the northern part of the country occurs in the third ten-day period of July to the first ten-day period of August, when no strong wind activity is observed, and conditions are generally favorable for continuous insect activity. Heavy precipitation was not recorded (10.9 mm during the period); however, the flowering period was marked by high daytime temperatures above 29-33 °C for 10 days, which contributed to pollen sterilization and ultimately resulted in a low oilseed yield.

Phenological observations showed that the growing season of oil flax averaged 81 days from emergence to full maturity. Seedlings appeared on the 11th day after sowing, the period from emergence to full flowering was 44 days, and the active flowering period lasted 14 days, from July 24 to August 7.

During the main flowering period of oil flax in the northern part of the republic, from July 5 to July 22, average daily temperatures were 20.9 °C, ranging from 18.0 to 25.5 °C, and total precipitation amounted to 19.9 mm (7 days with precipitation). The range from minimum to maximum daily temperatures was 9.5-17.4 °C (min) to 23.1-32.7 °C (max). This indicator characterizes the flowering period as insufficiently warm and comfortable for bee activity. Air humidity on most days was relatively comfortable, ranging from 43% on clear days to 76% on rainy days **(Table 1)**.

Table 1. Characteristics of meteorological conditions during the flowering period of oil flax in Akmola Region using 2025 as an example

Date	Air temperature, °C			Air humidity, %	Wind direction	Wind speed, m/s	Maximum wind gusts, m/s	Total precipitation, mm
	Mean	min	max					
05.07	19.4	15.6	23.1	76	W-WNW	1.8	3	8.0
06.07	21.0	12.7	27.5	64	W-NW	1.6	3	-
07.07	21.6	16.8	25.8	63	W-WNW	1.8	3	5.0
08.07	19.8	12.1	24.6	54	NE-NNE	1.0	2	-
09.07	21.4	16.8	24.9	44	NNE-NE	1.0	2	-
10.07	20.4	14.4	25.8	58	NNE-NW	1.0	2	4.0
11.07	21.0	12.9	27.9	61	S-SSW	1.1	3	2.0
12.07	19.9	14.7	23.3	58	NW-WNW	1.6	3	-
13.07	19.2	15.6	23.1	60	W-WNW	1.6	3	-
14.07	18.0	10.5	23.2	64	W-WNW	1.6	4	0.6
15.07	18.5	11.2	25.0	68	WNW-NW	0.6	2	-
16.07	22.8	13.5	29.3	48	S-W	0.8	1	-
17.07	24.5	17.4	30.5	45	NW-SW	3.0	5	-
18.07	25.5	17.2	32.7	51	SSW-SW	2.1	4	-
19.07	19.1	12.5	23.8	65	WNW-NW	4.3	7	0.1
20.07	18.8	9.5	26.4	55	WNW-NNW	1.8	3	-
21.07	21.2	11.1	29.0	50	W-WNW	2.7	5	-
22.07	24.3	15.1	30.1	43	E-WNW	2.3	3	0.2

The wind background throughout the flowering period of oil flax is assessed as sufficiently comfortable and confirms compliance with long-term average indicators of prevailing northern and north-western directions; their intensity did not affect the activity of insect pollinators.

During the study years (2023-2025), the growing season in the eastern part of the country was also characterized by a slightly elevated temperature regime. Average daily temperatures exceeded the norm by 3.2 °C in May, 4.6 °C in June, and 3.3 °C in July, against the background of substantial precipitation. A precipitation deficit was observed only in June 2023, when only 5.7 mm fell during the month compared with the norm of 40 mm.

During the main flowering period of oil flax in the east, traditionally from June 25 to July 12, average daily temperatures are 20.6 °C, ranging from 18 to 24 °C, while total precipitation is about 95 mm. The range from minimum to maximum daily temperatures is 12-17 °C (min) to 19-32 °C (max). This indicator characterizes the flowering period as sufficiently warm and comfortable for bee activity. Air humidity on most days is relatively comfortable, ranging from 59% on clear days to 83% on rainy days **(Table 2)**.

Table 2. Characteristics of meteorological conditions during the flowering period of oil flax in East Kazakhstan Region using 2025 as an example

Date	Air temperature, °C			Air humidity, %	Wind direction	Wind speed, m/s	Maximum wind gusts, m/s	Total precipitation, mm
	Mean	min	max					
25.06	20.2	16.0	26.4	73	E	3.9	8	35
26.06	20.8	15.6	27.2	75	NNE-E	1.6	3	trace
27.06	22.4	17.4	28.4	61	E-SSW	4.1	6	4.3
28.06	19.1	15.2	23.1	70	N-E	2.6	4	3.0
29.06	21.7	15.7	27.2	59	ENE-E	3.4	5	0.9
30.06	21.7	15.7	27.2	59	ENE-E	3.4	5	0.9
01.07	19.6	15.0	23.7	68	E-SW	2.6	4	0.4
02.07	21.3	14.8	27.8	68	E-SSW	2.4	4	-
03.07	22.8	15.0	28.6	66	W	2.1	5	-
04.07	24.0	16.3	31.4	64	NE-E	1.6	2	-
05.07	23.9	15.6	31.9	66	ENE-E	4.8	8	1.0
06.07	18.8	16.1	23.0	79	ESE-W	3.4	6	22.0
07.07	19.2	15.6	22.6	83	E	2.8	4	20.0
08.08	20.0	15.2	23.7	20	SW-WSW	2.1	8	trace
09.07	19.2	13.1	24.7	70	W-NW	2.1	4	-
10.07	19.5	12.2	24.8	76	SW-W	2.0	3	-
11.07	18.0	16.4	19.9	88	SSW	1.1	2	5.4
12.07	19.6	15.3	23.6	80	SE-SW	2.1	6	3.0

The wind background throughout the flowering period of oil flax in the east is assessed as less stable but sufficiently comfortable and confirms compliance with long-term average indicators of prevailing south-western directions; its intensity did not affect the activity of insect pollinators.

In the north, the biological yield of oil flax seeds on plots isolated from pollination (control), depending on the distance from the apiary (200 and 500 m), averaged 7.3-7.4 c/ha for the south-eastern variant. On fixed plots with intensive bee pollination, the yield was higher, amounting to 8.6-9.5 c/ha, which was 17.8-28.4% higher than in the variants without pollination **(Table 3)**.

Table 3. Biological yield of oil flax seeds over the study years in the north

Cardinal direction (Factor A)	Plot status (Factor B)	Biological yield, c/ha			Mean, c/ha	Yield increase, %
		2023	2024	2025		
South-East	Fixed plot (200 m)	10.2	8.6	9.7	9.5	28.4
	Isolated, without pollination (200 m), control	8.3	5.6	8.2	7.4	-
	Fixed plot (500 m)	9.1	7.7	9.0	8.6	17.8
	Isolated, without pollination (500 m), control	8.2	5.5	8.3	7.3	-
LSD05: for factor A - 0.99 c/ha; for factor B - 1.00 c/ha; interaction AB - 1.01 c/ha; for partial means - 1.12 c/ha.						

In the experiments in the east, the biological yield of oil flax seeds on plots isolated from pollination (control), depending on the distance from the apiary (200 and 500 m), averaged 12.7-12.9 c/ha for the north-eastern variant. On fixed plots with intensive bee pollination, the yield was higher, amounting to 15.6-16.9 c/ha, which was 18.4-23.5% higher than in the variants without pollination **(Table 4)**.

Table 4. Biological yield of oil flax seeds over the study years in the east

Cardinal direction	Plot status	Biological yield, c/ha			Mean, c/ha	Yield increase, %
		2023	2024	2025		
North-East	Fixed plot (200 m)	12.1	18.4	20.1	16.9	23.5
	Isolated, without pollination (200 m), control	9.3	14.4	15	12.9	-
	Fixed plot (500 m)	11.3	17.5	18	15.6	18.4
	Isolated, without pollination (500 m), control	9.1	14.3	14.8	12.7	-
LSD05: 1.45 c/ha						

The significant increase in yield on non-isolated plots is based on the formation of a greater number of bolls on plants after active bee visitation and effective pollination. The weight of 1000 seeds was also higher on plots with active pollination **(Tables 5 and 6)**.

Table 5. Structural analysis of sheaf material averaged over the study years in the north

Cardinal direction (Factor A)	Plot status (Factor B)	Plant density, plants/m²	Number of bolls per plant, pcs.	Number of seeds per boll, pcs.	Weight of 1000 seeds, g
South-East	Fixed plot with pollination (200 m)	265	9.2	7.5	4.7
	Isolated, without pollination (200 m), control	265	7.5	6.6	4.3
	Fixed plot with pollination (500 m)	265	9.1	7.3	4.4
	Isolated, without pollination (500 m), control	265	7.5	6.5	4.3

Table 6. Structural analysis of sheaf material averaged over the study years in the east

Cardinal direction	Plot status	Plant density, plants/m²	Number of bolls per plant, pcs.	Number of seeds per boll, pcs.	Weight of 1000 seeds, g
North-East	Fixed plot with pollination (200 m)	269	20	7.5	5.3
	Isolated, without pollination (200 m), control	269	16	6.6	4.8
	Fixed plot with pollination (500 m)	269	17	7.3	5.1
	Isolated, without pollination (500 m), control	269	16	6.5	4.8

Seed oil content averaged from 48.0 to 50.2%; this indicator was stable across the experimental variants.

The obtained results show that organized pollination of oil flax by Carniolan bees provided a stable yield advantage compared with isolated control plots. The most pronounced effect was observed when accounting plots were placed 200 m from the apiary, which is consistent with the technological logic of opposing pollination and the need to bring bee colonies closer to the flowering crop stand.

The yield increase on non-isolated plots was associated not only with the general access of insects to flowers but also with improved yield structure elements: an increase in the number of bolls per plant, the number of seeds per boll, and the weight of 1000 seeds. At the same time, the stability of seed oil content across the experimental variants indicates that additional pollination primarily affected seed productivity rather than oil content (Liedekerke *et al*., 2025).

Comparison of the northern and eastern zones shows that the efficiency of bee pollination was maintained under different natural and climatic conditions, although the meteorological background during flowering differed. This confirms the practical significance of placing apiaries during the flowering period of oil flax and the need for further adaptation of bee colony placement standards to specific regions of Kazakhstan.

CONCLUSION

The conducted studies confirmed that organized intensive pollination of oil flax by bees can be regarded as an effective agrotechnical practice for increasing crop yield. Under the conditions of Akmola Region, the yield increase in pollinated variants was 17.8-28.4%, while under the conditions of East Kazakhstan Region, it was 18.4-23.5% compared with isolated variants without bee access.

Additional pollination contributed to the formation of a greater number of bolls per plant, an increase in the number of seeds per boll, and an increase in the weight of 1000 seeds. Seed oil content remained stable and averaged 48.0-50.2%. Based on the obtained data, it is recommended to include apiary placement during flowering in technological maps for oil flax cultivation, especially in regions with a high share of entomophilous crops in the structure of sown areas.

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