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OPTIMIZATION OF THE HONEY CONVEYOR IN THE ARID STEPPE CONDITIONS OF NORTHERN KAZAKHSTAN

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ABSTRACT

This study evaluated perennial and annual honey crops for optimizing a continuous honey conveyor under arid steppe conditions in Northern Kazakhstan. Field experiments were conducted in 2022–2024 on dark chestnut soils in the Akmola region. The tested crops were blue hybrid alfalfa cv. Lazurnaya, Sandy Sainfoin CV. Shortandinsky Rubin, yellow sweet clover cv. Sarbas, buckwheat cv. Shortandinskaya-4, rapeseed cv. Maybulak, mustard cv. Slavyanka, sunflower cv. Sochinsky, and phacelia cv. Ulyanovskaya. Six Carpathian honey bee colonies were placed near the plots, and control subplots were isolated from bee pollination. Flowering duration, nectar productivity, bee visitation, flower set, crop yield, and honey quality were assessed. Meteorological conditions varied among years and influenced crop development and nectar availability. Buckwheat showed the highest nectar productivity (163.2 kg/ha) and the longest flowering period (42 days). Yellow sweet clover and sandy sainfoin were stable perennial components, producing 103.8 and 90.8 kg/ha of nectar, respectively. Bee visitation differed significantly by time of day and crop species, with peak activity at 13:00 and the highest mean visitation rates in yellow sweet clover, sunflower, and rapeseed. Bee pollination increased mean flower set from 26.0 ± 16.2% in isolated plots to 74.6 ± 14.1% in bee-accessible plots. Honey quality depended on botanical origin: buckwheat honey had the highest diastase number, while sandy sainfoin honey had low acidity and high invert sugar. Buckwheat, yellow sweet clover, and sandy sainfoin are recommended as priority crops for a sustainable honey conveyor in Northern Kazakhstan.

Keywords: Honey conveyor, Nectar productivity, Honey bee pollination, Flower set, Bee visitation, Arid steppe, Northern Kazakhstan.

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1. INTRODUCTION

The honey bee (Apis mellifera) is a keystone eusocial insect critical in maintaining natural ecosystems and providing significant benefits to humanity (Papa et al., 2022). The species produces honey, royal jelly, propolis, and bee bread, and performs important pollination services for wild and agricultural plants (Anjum et al., 2019; Requier et al., 2019; Ahmad et al., 2021).

At the agricultural scale, pollination by honey bees and wild bee species is essential for the productivity of many entomophilous crops. In Kazakhstan and neighboring countries, about 190 plant species, excluding medicinal and ornamental species, require bee pollination to achieve optimal yield formation (Chenikalova & Cherkashin, 2019). Beekeeping therefore has both agricultural and ecological value, because honey bees support crop yield formation and help maintain vegetation diversity (Vassilev et al., 2019; Kashkovsky, 2021; Szczurek et al., 2023).

However, honey bee populations are subject to various pressures, including habitat loss, predators, parasites, diseases, pesticide use, and climate change (Willcox et al., 2023). Bee feeding dynamics are important in maintaining populations and colony health (Khan & Ghramh, 2021). In addition, adequate food availability is essential for normal colony growth and development. The challenges faced by honey bees are particularly acute in arid and semi-arid regions, such as the steppe zone of Northern Kazakhstan. Northern Kazakhstan's arid steppe climate is distinguished by harsh, cold winters and scorching, dry summers. The region receives little precipitation, averaging 150-300 mm per year, making moisture scarce, particularly in the summer. These elements, along with strong winds, create weakly constructed soils that are prone to wind and water erosion, increasing the risk of wildfires and desertification (Merembayev et al., 2022). The potential productivity of natural pasture is modest, and there are issues with ongoing degradation. The degradation is attributable to the complex environment, local ecology, and inadequate agronomic management in recent decades, including overgrazing (Stybayev et al., 2021;

Akhylbekova et al., 2022). Due to the agricultural pressure and difficulties faced in Northern Kazakhstan, such as climate-related challenges, sporadic land degradation, poor land management, and seed availability, these conditions make the optimization of agricultural practices, like establishing a reliable honey conveyor, not just an economic issue but an ecological imperative (Ryssaliyeva et al., 2025).

In steppe agrocenoses, where agricultural production is maintained under reduced plant diversity, the stability of pollination services becomes especially important. The active use of chemical plant protection products and the transformation of natural habitats may reduce the abundance of wild pollinators, increasing the practical importance of managed honey bee colonies in crop pollination (Sergienko et al., 2018; Komlatsky et al., 2020).

Honey bees can simultaneously visit various food sources and can travel up to 10 kilometers to collect primary food resources such as nectar and pollen. These resources are stored in their colonies as honey and bee bread (Wright et al., 2018). Nectar, in particular, is the main source of carbohydrates needed to meet the energy needs of bees (Khan et al., 2021). Pollen, in turn, provides honey bees with macro- and micronutrients, including proteins, minerals, vitamins, and lipids, which are critical for brood growth, maturation, longevity of adults, and overall colony development (Arien et al., 2018). The fatty acid content and nutritional components of pollen vary with plant species diversity and are directly related to honey bee health (Kacemi et al., 2023). Importantly, the nutritional value of pollen can be more accurately estimated based on its amino acid composition rather than its total protein content, as its nutritional value is reduced by a deficiency of essential amino acids (Al-Kahtani et al., 2020). Determining the forage intake of honey bees is a complex process due to significant variations in nutrient requirements that depend on the bee's caste and life stage, as well as inter- and intra-seasonal changes in food availability.

Additionally, supplemental feeding practices in beekeeping show significant variability (Rodney & Purdy, 2020). During winter or drought conditions, when food resources become limited, queen reproductive performance declines, leading to reduced worker numbers and an increased risk of migration or colony abandonment. In the Middle East, high temperatures and dry conditions during summer increase mortality in honey bees due to reduced flowering and reduced pollen availability caused by heat stress, an important food source for foraging bees (Awad et al., 2017). Thus, to ensure the health of the bee colony, necessary for honey production and pollination functions, a food base is required during the warm period, especially in the arid steppe of Northern Kazakhstan.

Bee pollination is particularly important for crops such as sunflowers, buckwheat, and alfalfa, whose yield formation depends substantially on cross-pollination. Therefore, pollination management and the selection of honey crops with overlapping flowering periods are key elements of sustainable beekeeping and crop production in arid steppe landscapes.

In this regard, the development and use of honey conveyors are pressing issues in modern beekeeping, as they optimize access to nutritional resources and ensure the sustainable development of bee populations. A honey conveyor is a simple system of honey value crops that provides a continuous supply of pollen and efficiently keeps bees in the field. The best techniques in beekeeping and pollination management result in higher agricultural yields. Placing beehives near agricultural fields with flowering cultivated plant species, where honey yield is heavily reliant on the optimal design strategy, is critical for maximizing bee efficiency in pollination and bee product production. There are mathematical methods that can help optimize the number of bee colonies and apiary sites by selecting the optimum option from a list of alternatives. Creating a "honey conveyor" of flowering cultivated plants during the active honey-gathering season is an intriguing method for providing food for bee colonies (Atanasov & Vezirov, 2021). When designing a honey conveyor, it's crucial to consider the honey base and plant classification based on phenological criteria, such as flowering stage length and season (Cîrlig, 2022). Effective planning of honey conveyors can include selecting perennial and annual honey crops that provide a continuous flow of nectar and pollen and contribute to ecosystem improvement and increased agricultural productivity in the region. According to recent studies, the plants selected for this study include annuals such as buckwheat, phacelia, and sunflower, as well as perennial legumes such as yellow sweet clover, sandy sainfoin, and alfalfa (Medicago sativa). Buckwheat is renowned for its quick nectar secretion and long flowering, while sweet clover is well-known for its high nectar sugar content (Žiganova et al., 2022; Akter et al., 2023). However, the majority of their recorded performance comes from more temperate or humid areas. There is still much to learn about their relative effectiveness, resistance to the unique abiotic stresses of the Kazakh steppe, and potential for synergy in a coordinated conveyor system. For Kazakhstan's agricultural industry, closing this knowledge gap is crucial. Given the potential to increase both domestic honey production and the pollination services that support other important agricultural commodities, beekeeping is an essential part of the rural economy (Selamoglu et al., 2025). Strong pollinator populations directly affect the yield of entomophilous crops like sunflower, buckwheat, and other fruits and vegetables. This study contributes to food security and rural livelihoods by securing a robust forage base through optimized honey conveyors, supporting not only apiculture but also the resilience and productivity of the region's overall agricultural system.

The aim of the study is to optimize the honey conveyor in the arid steppe of Northern Kazakhstan, increasing beekeeping productivity and the sustainability of the region's ecosystem.

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2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted from 2022 to 2024 at the A.I. Barayev Scientific and Production Center for Agricultural Production, located in the Talapker rural district, Tselinograd district, Akmola region, Northern Kazakhstan (Fig. 1). The experimental site was established on dark chestnut soils typical of the arid steppe zone.

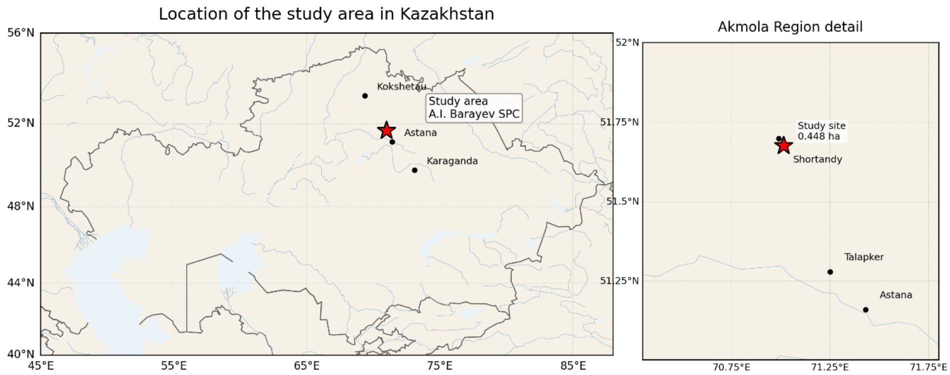

Fig. 1: Study area map.

2.2. Data Collection

The study's objects were perennial and annual honey crops selected for their potential use in a continuous honey conveyor. The perennial crops included blue hybrid alfalfa, cv. Lazurnaya; sandy sainfoin, cv. Shortandinsky Rubin; and yellow sweet clover, cv. Sarbas. The annual crops included common buckwheat, cv. Shortandinskaya-4; rapeseed, cv. Maybulak; Sarepta mustard, cv. Slavyanka; sunflower, cv. Sochinsky; and phacelia, cv. Ulyanovskaya. Honey bees of the Carpathian breed were used as managed pollinators.

The total experimental area was 0.448 ha, calculated as 8 crops × 4 replications × 140 m² = 4,480 m². Each experimental plot had an area of 140 m², and the experiment was arranged in four replications. Within each plot, a 1 m² control subplot was isolated from honey bee pollination to evaluate the dependence of flower set and yield formation on bee pollination. The experimental scheme is presented in Table 1. The general field experiment scheme is presented in Fig. 2. In May, six Carpathian honey bee colonies were placed directly near the experimental plots to provide pollination during the flowering period of the studied crops (Fig. 3).

Table 1: Field experiment scheme

No.	Crop	Variety	Sowing rate (million germinated seeds)	Sowing date	Sowing method
1	Sainfoin	Shortandinsky ruby	4	02.05	Wide-row 60 cm
2	Alfalfa	Lazurnaya	3	02.05	Wide-row 60 cm
3	Yellow sweet clover	Sarbas	3	02.05	Wide-row 60 cm
4	Rapeseed	Maybulak	3	15.05	Row 15 cm
5	Mustard	Slavyanka	3	15.05	Row 15 cm
6	Phacelia	Ulyanovskaya	3	15.05	Wide-row 60 cm
7	Sunflower	Sochinsky	0.06	14.05	Wide-row 70 cm
8	Buckwheat	Shortandinskaya-4	2.5	30.05	Row 15 cm

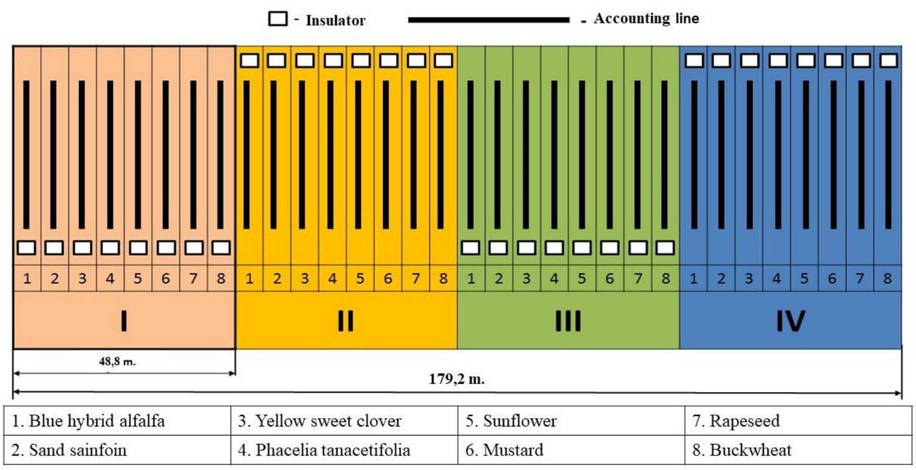

Fig. 2: Field experiment scheme.

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Fig. 3: Location of bee colonies for pollination of experimental plots.

The colonies were kept in Dadan hives, each containing 10 frames in a single hive body. The close placement of the hives ensured regular access for foraging honey bees to the experimental crops. Observations were also made on wild pollinators; however, the main pollination factor in the experiment was managed honey bee pollination, since full local pollination can be achieved by transporting apiaries to honey-bearing lands.

Two pollination conditions were compared: open pollination by honey bees and isolation from honey bee pollination. The control variant consisted of plots without access to honey bees. In this variant, 1 m² subplots were covered with gauze or polymer-mesh isolators to prevent the pollination of flowers by honey bees and other insect pollinators. The placement of gauze insulators in the experimental areas is shown in Fig. 4.

Fig. 4: Location of gauze insulators in experimental areas.

The isolators were installed according to the method for determining the dependence of seed yield of entomophilous crops on bee pollination described in Pankov's patent No. 2420950, "Method for determining the dependence of the seed yield of entomophilous crops on pollination by bees" (Pankov, 2011). General principles of field experiment design were applied in accordance with Dospekhov (1985).

The use of polymer mesh with a pore size of 355–390 µm provided a reliable barrier against the penetration of pollinating insects and foreign pollen onto flowering plants while allowing the isolated plants to remain under field conditions. The comparison between isolated and bee-accessible plots enabled the determination of the effects of honey bee pollination and the degree of self-fertility in the crops studied.

The crops were grown in accordance with the generally accepted and recommended cultivation technologies for the Akmola region, except for the pollination factor under study. The experiments were repeated over time during three growing seasons, from 2022 to 2024.

During the research, the following records and observations were made:

1. The sowing suitability of seeds was determined according to GOST 12038-84 (USSR State Committee on Standards, 1984).
2. Phenological observations of plant growth and development phases were carried out according to the generally accepted methodology of state variety testing of agricultural crops. The beginning and end of flowering, flowering duration, and interphase periods were recorded for each crop (Golovachev & Kirilovskaya, 1989; Ministry of Agriculture of the Republic of Kazakhstan, 2011).
3. Nectar productivity was determined using the flushing method for honey plants described by Kirillenko and Golovin (1985). Measurements were carried out under field conditions using an RL-1 refractometer. Nectar productivity was expressed in kg/ha.
4. Plant density was recorded according to the methodology of state variety testing of agricultural crops (Golovachev & Kirilovskaya, 1989; Ministry of Agriculture of the Republic of Kazakhstan, 2011).
5. Plant height was measured by development phases according to the state variety testing methodology (Golovachev & Kirilovskaya, 1989; Ministry of Agriculture of the Republic of Kazakhstan, 2011).

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6. The number of honey bee visits during crop flowering was recorded according to the methods of Kirillenko and Golovin (1985) and Pankov (2011). These observations were used to evaluate the pollination activity of honey bees on different honey crops.
7. The number of pollinating insects visiting crop flowers was recorded in 20 × 1 m² counting strips arranged in four replications using the pollinator counting strip method of Fasulati K.K. Fig. 5 shows the field layout of the counting strips, which were marked with twine, tied to stakes, and located on both sides of the plot center. Pollinator counts were carried out during flowering at two-hour intervals from 6:00 to 18:00. For each count, the observer walked along the counting strip and recorded the number of honey bees visiting the flowers. The data presented in the analysis were summarized for the main observation times: 9:00, 11:00, 13:00, 15:00, and 17:00.

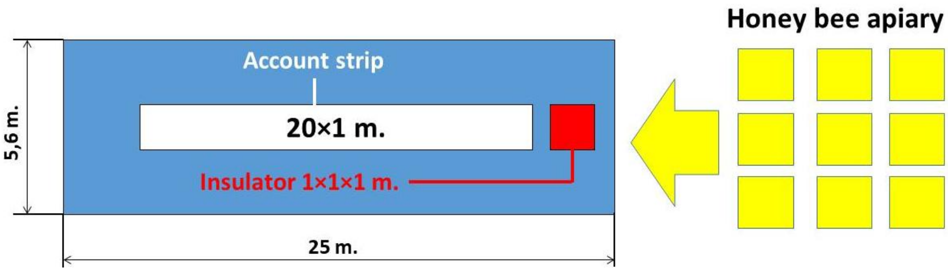

Fig. 5: Layout of honey bee apiary, counting strips and isolators in seed plots.

8. The structural elements of yield and crop yield were determined using the state variety testing methodology (Golovachev & Kirilovskaya, 1989; Ministry of Agriculture of the Republic of Kazakhstan, 2011).
9. Meteorological conditions during the growing seasons were characterized using air temperature, precipitation, and relative air humidity. Hydrothermal coefficient and bioclimatic potential values were also used to interpret the influence of environmental conditions on flowering dynamics, nectar productivity, bee visitation, and yield formation.
10. Honey samples obtained from single-species crops were analyzed for basic quality indicators, including moisture content, acidity, diastase number, and invert sugar content. These indicators were used to compare the quality of honey obtained from different botanical origins within the honey conveyor.

2.3. Data Analysis

Statistical analysis was performed on experimental data collected during the 2022–2024 growing seasons. Flower set data were analyzed as paired observations because, for each crop and year, two pollination conditions were compared: isolated control plots without honey bee access and plots accessible to honey bees. The pollination effect was calculated as both an absolute and a relative increase in flower set. The absolute increase was expressed in percentage points:

$$\text{Absolute increase} = P - C,$$

where P is a flower set in plots accessible to honey bees, and C is a flower set in isolated control plots.
The relative increase in flower set due to bee pollination was calculated as:

$$\text{Pollination effect (\%)} = [(P - C) / C] \times 100.$$

For the overall assessment of the pollination effect, three-year crop means were compared using a paired Student's t-test. The normality of paired differences was evaluated using the Shapiro–Wilk test. Because of the small number of crops, the Wilcoxon signed-rank test was additionally used as a non-parametric confirmation of the pollination effect.

To determine whether the magnitude of the pollination response differed among crops and years, the absolute increase in flower set was analyzed using two-way analysis of variance with crop and year as fixed factors. Because one value was available for each crop × year combination, the crop × year interaction was not included in this model.

Honey bee visitation data were analyzed using the mean number of bees recorded per 20 m² counting strip at five observation times: 9:00, 11:00, 13:00, 15:00, and 17:00. Since the available visitation data were presented as three-year mean values, the effects of crop species and observation time were evaluated using two-way ANOVA without replication. Friedman tests were also applied as non-parametric confirmatory tests: crop species were used as blocks when testing the time-of-day effect, and observation times were used as blocks when testing the crop effect.

Relationships among nectar productivity, flowering duration, crop yield, and mean honey bee visitation were assessed using Pearson correlation coefficients and Spearman rank correlations. Because these variables were available as crop-level mean values, the correlation analysis was considered exploratory. Honey quality indicators, including moisture content, acidity, diastase number, and invert sugar content, were summarized descriptively by crop species. Results were reported as means, standard deviations, percentage-point differences, relative increases, test statistics, and p-values. Statistical significance was accepted at $P<0.05$.

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3. RESULTS AND DISCUSSION

3.1. Meteorological Conditions during the Study Period

A study of honey productivity data from honey resources revealed complex relationships influenced by many factors. These include microclimatic conditions such as illumination, temperature, humidity, wind, and drought, as well as geographical parameters such as latitude and altitude. No less important is the anthropogenic impact, including soil type, agricultural practices, fertilizer use, and irrigation. According to studies by other authors (Wang et al., 2025), the optimal temperature range for active nectar secretion is 22-31°C. During the flowering period of honey crops (from June to August), average daily temperatures ranged from 20.0 to 24.4°C (Fig. 6). Comparison of actual temperatures with the optimal temperatures for the growth and development of perennial grasses (25-32°C) and photosynthesis (25-28°C) (Plos et al., 2023) allows us to conclude that the temperature conditions contributed to intensive nectar secretion and an increase in honey productivity.

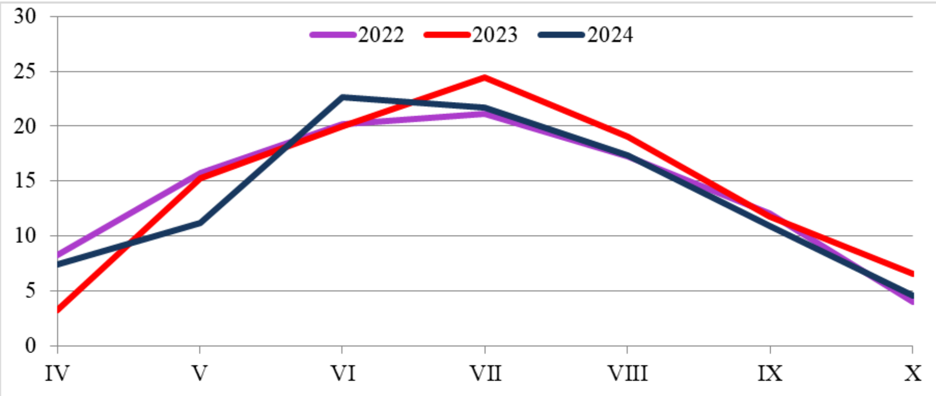

Fig. 6: Average daily air temperature during the growing season of perennial legumes, 0 C (2022-2024).

Analysis of the distribution of atmospheric precipitation during the growing season revealed significant unevenness, which affected the growth and development of honey crops (Fig. 7).

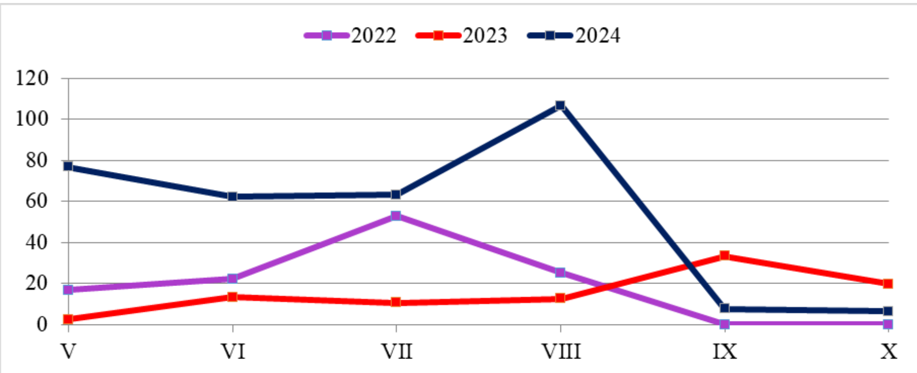

Fig. 7: Intake of atmospheric precipitation during the growing season of perennial legume crops, mm (2022-2024).

The year 2024 was characterized by the highest precipitation (334 mm), with the key factors being heavy precipitation in May (76.9 mm) and August (106.6 mm). This ensured an optimal moisture supply during the critical growth and flowering phases, thereby positively affecting honey productivity.

The year 2023 was the least favorable (156 mm of precipitation). Despite heavy precipitation in April (64.1 mm, 3 times higher than the long-term average), a sharp decrease in precipitation in May and June during the critical phases negatively affected plant development.

The year 2022 demonstrated specific dynamics. Low moisture at the beginning of the growing season (April-May) limited initial growth. However, sufficient precipitation in July (52.9 mm, at long-term average levels) during the budding-flowering phase compensated for the initial moisture deficit. Therefore, the year with the maximum total precipitation is not necessarily the most favorable. The dynamics of precipitation distribution throughout the growing season and the correspondence between this precipitation and the needs of plants during critical phases of development are important.

Analysis of available literature shows that for most plants, optimal conditions for nectar secretion are achieved at a relative air humidity of 60 to 80% and soil moisture at 50-60% of the total moisture capacity. However, some species, such as meadow knapweed and sweet clover, can produce nectar even under low-humidity conditions, indicating adaptive mechanisms and the possible independence of nectar production from standard humidity indicators.

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During the study, conducted from June to August, the relative air humidity in the growing area of legumes ranged from 52% to 79%, which is close to the optimal values described in scientific sources. However, interannual variability was observed: the most favorable humidity conditions were recorded in 2024, while in 2023, the conditions were less favorable (Fig. 8). This suggests that in 2024, the nectar production potential of honey crops could be realized to a greater extent compared to 2023, which requires identifying the relationships between humidity indicators and the actual nectar productivity of the studied plants.

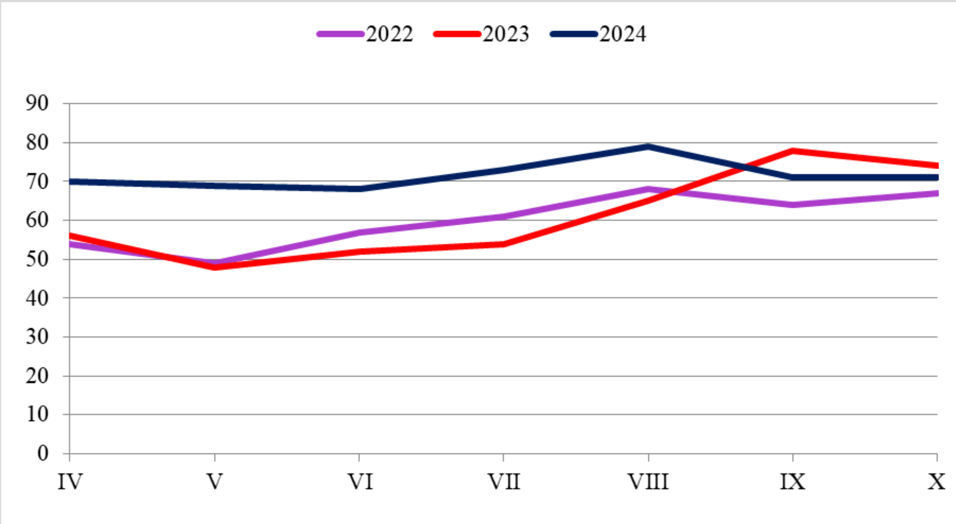

Fig. 8: Relative air humidity (%) during the growing season of perennial legumes (2022-2024).

The analysis of meteorological conditions during the study years revealed the following characteristics: 2022 is marked by dry conditions with a hydrothermal coefficient (HTC) of -0.173, while 2023 is characterized by dry conditions (HTC -0.126). Unlike previous years, 2024 shows moderate conditions with an HTC of -0.303.

The study of bioclimatic potential (BCP) according to the Shashko method for the period 2022–2024 showed significant fluctuations in values: in 2022, the BCP was -0.74, which corresponds to the category of very low potential (≤0.8), in 2023 it improved to -0.53, and in 2024 it reached a value of 2.2, indicating an average bioclimatic potential (1.6-2.2).

3.2. Honey bee Visitation and Pollination Activity

The data analysis revealed significant differences in the attractiveness of honey crops for bees during the day. Bees' greatest activity and, as a consequence, optimal conditions for pollination are recorded in the interval 11:00-15:00 (Table 2), which is consistent with generally accepted ideas about the peak of bee flight activity.

Table 2: Number of pollinating bees per 20 m² of honey crops in a conveyor during the day, hour (average for 2022-2024)

Crops	Times				
	9:00	11:00	13:00	15:00	17:00
Blue hybrid alfalfa	8	76	96	47	23
Sand sainfoin	11	66	115	54	25
Yellow sweet clover	10	85	124	95	22
Phacelia tanacetifolia	4	13	27	14	6
Sunflower	7	74	118	92	36
Mustard	6	68	112	58	24
Rapeseed	29	125	86	57	22
Buckwheat	28	41	101	84	17

At the same time, significant differences are observed between the crops. Sainfoin and yellow sweet clover demonstrate superior bee visitation rates compared to blue hybrid alfalfa during the specified period. It is noted that blue hybrid alfalfa has the fewest bees at 9:00, which may indicate specific features of its flowering or nectar secretion, leading to a later start of bee activity on it. During the observation period, yellow sweet clover stands out as the most attractive crop for bees, suggesting it may have higher honey production than the other crops studied.

Statistical analysis confirmed that honey bee visitation differed significantly by both time of day and crop species (Table 3). The mean number of honey bees per 20 m² was lowest at 9:00 (12.9 ± 9.9) and reached its maximum at 13:00 (97.4 ± 31.1), indicating that the most favorable period for pollination was between 11:00 and 15:00. The time-of-day effect was significant according to the Friedman test, $\chi^2(4) = 28.10$, $p = 1.19 \times 10^{-5}$, and two-way ANOVA without replication, $F(4,28) = 27.51$, $p = 2.42 \times 10^{-9}$. Crop species also had a significant effect on bee visitation, $\chi^2(7) = 15.62$, $p = 0.029$ by the Friedman test and $F(7.28) = 4.23$, $p = 0.0027$ by ANOVA. The highest mean visitation rates were recorded for yellow sweet clover, sunflower, and rapeseed, whereas phacelia showed the lowest attractiveness to honey bees under the conditions of the experiment (Table 3).

Table 3: Descriptive summary of honey bee visitation based on the 2022–2024 mean data

A) Observation time and B) Crops	Mean number of bees per 20 m² across observation times	Rank
A) Time-of-day pattern of honey bee visitation		
9:00	12.9 ± 9.90	5
11:00	68.5 ± 32.5	2
13:00	97.4 ± 31.1	1
15:00	62.6 ± 27.0	3
17:00	21.9 ± 8.40	4
B) Crop-level pattern of honey bee visitation		
Yellow sweet clover	67.2 ± 49.1	1
Sunflower	65.4 ± 44.2	2
Rapeseed	63.8 ± 42.6	3
Sandy sainfoin	54.2 ± 40.5	4
Buckwheat	54.2 ± 36.5	4
Mustard	53.6 ± 41.2	6
Blue hybrid alfalfa	50.0 ± 36.4	7
Phacelia tanacetifolia	12.8 ± 9.00	8

Values are mean ± SD. In part A, mean and SD values were calculated for each observation time across the eight crops studied. In part B, means and SD values were calculated across the five observation times for each crop. Therefore, the SD values describe variation among crops or observation times, not variation among field replications.

The study's results highlight the significant influence of honey bees on flower sets in various crops. In the control plots where bees were absent, the flower set rate was significantly lower than in plots pollinated by bees. The most pronounced difference is observed in buckwheat, where the flower set rate was 20% in the control plots versus 69% in the pollinated plots, and in rapeseed, 40% versus 85%. These data indicate a high dependence of these crops on insect pollination. In addition, yellow sweet clover and sand sainfoin demonstrate a significant increase in flower set in the presence of bees, consistent with previously obtained results (Amarilla et al., 2025). Interestingly, even in crops such as sunflower and phacelia, which can be partially pollinated by the wind or independently, a 30–40% increase in flower set is observed when bees are involved. This is consistent with the findings of Crochard et al. (2026), who indicate that additional pollination by bees can increase sunflower yields by 20–30%. The detailed three-year flower set data for all crops under control and bee-pollinated conditions are presented in Table 4.

Table 4: The number of flowers set in honey crops in the conveyor from pollination by honey bees, % m²

Crops	Years							
	2022		2023		2024		Average for 3 years	
	plots without bees (control)	plots with bees	plots without bees (control)	plots with bees	plots without bees (control)	plots with bees	plots without bees (control)	plots with bees
Blue hybrid alfalfa	7	55	6	52	9	65	7	57
Sand sainfoin	17	65	15	60	22	75	18	67
Yellow sweet clover	6	55	5	50	9	65	7	57
Phacelia tanacetifolia	15	72	22	78	30	85	22	78
Sunflower	42	88	48	92	55	95	48	92
Mustard	35	85	42	90	50	95	42	90
Rapeseed	40	85	35	80	50	95	42	87
Buckwheat	20	68	18	65	25	75	21	69

The results also confirm the findings of Margaoan et al. (2025), according to which, without bees' participation, the flower-setting level of most honey plants remains low. In particular, this figure does not exceed 25–30% for buckwheat without bees, which is consistent with our data (20%). Similar trends are observed in rapeseed, underscoring the need to locate apiaries near crops to optimize yields.

Statistical assessment confirmed a strong positive effect of honey bee pollination on flower set. Across the eight studied crops, the three-year mean flower set increased from 26.0 ± 16.2% in isolated control plots to 74.6 ± 14.1% in plots accessible to honey bees. The mean absolute increase was 48.6 percentage points, with a 95% confidence interval of 45.5–51.8 percentage points. This difference was highly significant according to the paired Student's t-test, $t(7) = 36.33$, $p = 3.11 \times 10^{-9}$, and was confirmed by the Wilcoxon signed-rank test, $W = 0$, $p = 0.0078$.

The absolute pollination response differed significantly among crops, $F(7,14) = 3.96$, $p = 0.014$, whereas the year effect was not significant, $F(2,14) = 1.69$, $p = 0.219$. The highest absolute response was recorded for Phacelia tanacetifolia (+56.0 percentage points), followed by blue hybrid alfalfa and yellow sweet clover (+50.0 percentage points each). In relative terms, the strongest response was observed in yellow sweet clover (+750.0%) and blue hybrid alfalfa (+681.8%), reflecting their low flower set under isolated conditions (Table 5). The statistical tests used to assess the pollination effect and honey bee visitation patterns are summarized in Table 6.

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Table 5: Effect of honey bee pollination on flower set of honey crops in the conveyor, 2022–2024

Crop	Flower set without bees, %	Flower set with bees, %	Absolute increase, percentage points	Relative increase, %
Blue hybrid alfalfa	7.3 ± 1.5	57.3 ± 6.8	50.0	681.8
Sandy sainfoin	18.0 ± 3.6	66.7 ± 7.6	48.7	270.4
Yellow sweet clover	6.7 ± 2.1	56.7 ± 7.6	50.0	750.0
Phacelia tanacetifolia	22.3 ± 7.5	78.3 ± 6.5	56.0	250.7
Sunflower	48.3 ± 6.5	91.7 ± 3.5	43.3	89.7
Mustard	42.3 ± 7.5	90.0 ± 5.0	47.7	112.6
Rapeseed	41.7 ± 7.6	86.7 ± 7.6	45.0	108.0
Buckwheat	21.0 ± 3.6	69.3 ± 5.1	48.3	230.2

Note: Values are mean ± SD for 2022–2024. Relative increase was calculated using three-year mean values.

Table 6: Statistical assessment of pollination effect and honey bee visitation patterns

Dataset / response variable	Statistical test	Test statistic	p-value	Interpretation
Flower set, control vs. bee-pollinated plots	Shapiro–Wilk test for paired differences	W = 0.933	0.541	Normality assumption was not rejected
	Paired Student's t-test	t(7) = 36.33	3.11×10^{-9}	Bee pollination significantly increased flower set
	Wilcoxon signed-rank test	W = 0	0.0078	Non-parametric confirmation of the pollination effect
Absolute pollination effect	Two-way ANOVA, crop effect	F(7.14) = 3.96	0.014	Pollination response differed among crops
	Two-way ANOVA, year effect	F(2.14) = 1.69	0.219	Year effect was not significant
Honey bee visitation	Friedman test, time-of-day effect	$\chi^2(4)$ = 28.10	1.19×10^{-5}	Bee activity differed significantly by time of day
	Two-way ANOVA, time-of-day effect	F(4.28)= 27.51	2.42×10^{-9}	Peak bee activity occurred around midday
	Friedman test, crop effect	$\chi^2(7)$ = 15.62	0.029	Bee visitation differed among crops
	Two-way ANOVA, crop effect	F(7.28) = 4.23	0.0027	Crop species significantly affected bee visitation

Two-way ANOVA for honey bee visitation was performed without replication because the available visitation data were presented as three-year mean values.

The high pollination response observed in the isolated-versus-open plots supports the practical role of managed honey bee colonies in the arid steppe agrocenosis. Although wild pollinators were present in the experimental area, the placement of Carpathian bee colonies near the plots likely increased the stability of pollination services during flowering. This is important because the productivity of bee colonies depends not only on floral resources but also on colony strength, queen quality, genetic potential, disease resistance, overwintering ability, and adaptation to local conditions (Eremia et al., 2018).

Nectar productivity is a quantitative characteristic of the volume of nectar produced by plants, mainly by floral organs (Carisio et al., 2022; Langlois et al., 2026). It can be expressed in various units of measurement, such as milliliters per flower or grams per hectare. This indicator is of significant importance in both ecology and agriculture, as it directly affects the food base for pollinators, including bees, butterflies, and other insects, as well as honey production. The study of nectar productivity is an important aspect of improving the efficiency of agricultural production, protecting biodiversity, and maintaining ecosystem sustainability. The quality of honey produced is affected by temperature, humidity, light, and soil quality. Different plant species demonstrate different levels of nectar productivity, which can be critical for optimizing agronomic practices.

An analysis of the results of the study, conducted as part of the surveys and observations of plants in single-species crops of agrophytocenoses of perennial and annual honey crops, shows that in the honey conveyor over three years (2022-2024), buckwheat crops provided the highest seed yield per unit area among all the studied crops. The buckwheat yield was 8.0 centners per hectare, and the nectar productivity reached 163.2 kg/hectare, which was also accompanied by the most extended flowering period of up to 42 days (Table 7). These results highlight the importance of buckwheat as a valuable element in agroecosystems, contributing to both increased agricultural productivity and ecosystem sustainability.

The study revealed high nectar productivity of sainfoin and yellow sweet clover crops, amounting to 90.8 and 103.8 kg/ha, respectively. These crops play a key role in the honey conveyor, providing a stable source of nectar for 55 days of flowering (from May 30 to July 25). These results align with those of Serekpayev and Saurov (2025), who observed similar effects in their study of the double effect of a honey conveyor on both honey production and seed productivity. Serekpayev and Saurov (2025) also observed similar results for sainfoin and yellow sweet clover crops, stating that this high productivity trait makes buckwheat, yellow sweet clover and sainfoin excellent candidates for honey conveyor systems in arid regions.

In the steppe zone of the Akmola region, sunflower and mustard achieved high yields, averaging 12.4 and 11.7 c/ha over three years, respectively. However, their nectar productivity was lower than that of other crops studied.

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Nevertheless, mass cultivation of these plants can provide a significant amount of nectar from the first ten days of July to the second ten days of August, with a total flowering period of 35 days. Buckwheat, with a nectar productivity of 163.2 kg / ha, stands out as one of the most valuable crops, playing an important role in the honey conveyor. These results are consistent with regional surveys that identify buckwheat, sweet clover and sainfoin as key honey plants in Central Asia and Kazakhstan. Kurmanov (2023) in his study on honey and nectar-free pergan-bearing plants of Central Asia and Kazakhstan reported that in northern Kazakhstan sunflower and white mustard are important nectar sources, while Onobrychis (sainfoin) is prevalent farther south.

Table 7: Productivity and nectar productivity of single-species crops of honey plants in the conveyor

Crop	Sowing method, row spacing	Sowing rate, million germinated seeds/ha	Sowing time	Yield, c/ha	Beginning and end of flowering	Flowering duration, days	Nectar productivity, kg/ha
Blue hybrid alfalfa	wide-row, 60 cm	3.0	02.V	1.6	07.VI 04.VII	27	42.6
Sand sainfoin	wide-row, 60 cm	4.0	02.V	3.8	30.V 15.VI	16	90.8
Yellow sweet clover	wide-row, 60 cm	3.0	02.V	1.4	18.VI 25.VII	37	103.8
Phacelia tanacetifolia	wide-row, 60 cm	3.0	15.V	0.43	02.VII 29.VII	27	21.2
Sunflower	wide-row, 60 cm	0.06	14.V	12.4	25.VII 07.VIII	13	54.8
Mustard	row, 15 cm	3.0	15.V	11.7	03.VII 01.VIII	29	42.4
Rapeseed	row, 15 cm	3.0	15.V	10.5	07.VII 02.VIII	27	37
Buckwheat	row, 15 cm	2.5	30.V	8.0	27.VI 08.VIII	42	163.2

Buckwheat, clover, and sainfoin all produce a lot of nectar, which probably explains why bees find them appealing. Because it provides abundant nectar and pollen, sainfoin attracts dense bee communities (Butters et al., 2022). According to Sakhraoui et al. (2024), sainfoin flowers attract ten times as many bees as alfalfa or white clover because they produce rich nectar and pollen. They noted that sainfoin is commonly foraged by native and managed pollinators, including *Apis, Bombus, and Osmia*, in a variety of climates.

Similarly, yellow sweet clover, Melilotus officinalis, blooms for several weeks, offering a sustained supply of nectar. Sweet clover's long bloom and high nectar content in this study were in line with predictions made by earlier research, and its honey yield was calculated to be substantial. Honeybees significantly boost oilseed crop yield, according to empirical research. Mazzilli et al. (2023) found that additional *Apis mellifera* visitation increased rapeseed yield by about 14% (2089 vs. 1836 kg/ha), and Hossain et al. (2021) found that bee pollination increased mustard seed set by 15%. The high nectar values for buckwheat, clover, and sainfoin suggest that these crops would attract many bees and improve pollination, even though we did not measure pollination services specifically. However, even though they produced many flowers, sunflowers and mustard had shorter bloom times and lower nectar concentrations, making them less dependable sources during dry years. Sunflower nectar's value to bees may be limited due to its variable nectar quality, pollen's low protein content, and nectar sugar content (Husband et al., 2025). Its late-season bloom, however, helps to cover midsummer voids.

Notably, pollination produces co-benefits: in Kazakhstan, rape and sunflower integration in crop rotations has been promoted in part due to bee cross-pollination, which increases seed size and oil content (reported increases of 20–30% in sunflower and canola yields). This pattern (high harvest index but modest nectar) is consistent with the rapeseed plots in this study. In contrast, new research indicates that bee pollination increased buckwheat seed yields in northern Kazakhstan, a sign of true meliferous plants like buckwheat. According to Defalque et al. (2025), buckwheat's floral resources are extremely vulnerable to heat, drought, and stress, all of which significantly lower nectar and pollen levels and, consequently, pollinator visits.

Yellow sweet clover and sandy sainfoin also showed results, making them important for maintaining the bee population during the flowering period. At the same time, phacelia tanacetifolia showed low yield and nectar productivity (0.43 c/ha and 21.2 kg/ha), which makes it less preferable for the honey conveyor in the conditions of the arid steppe zone. Rapeseed crops, despite high yield (10.5 c/ha) and flowering duration (27 days), also demonstrated low nectar productivity (37 kg/ha) compared to other crops.

Yellow sweet clover is leading in flowering duration, providing nectar for 37 days. Buckwheat and mustard also have significant flowering periods (42 and 29 days, respectively), which makes them important for maintaining a stable nectar flow. The quality of honey obtained from single-species crops of honey plants depends on the botanical origin, growing conditions, and meteorological factors. Table 8 presents the quality indicators of honey,

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such as moisture, acidity, diastase number, and inverted sugar content, obtained from different crop periods in the conveyor. Staggered flowering is an essential characteristic of a honey belt. According to our data, sainfoin and sweet clover flower for one to two months each, while mustard and buckwheat have somewhat longer flowering periods. Phacelia, known for its long bloom in temperate regions, did not fare well in this area, most likely due to its late planting and drought stress. On the other hand, the prolonged bloom of sainfoin is consistent with earlier findings (Żarczyński et al., 2025). This study's crop combination roughly corresponds to a nectar calendar spanning late May to mid-August. Such sequencing is essential in practice because even in the absence of late-flowering species, bees will starve despite an abundance of early-season nectar. This aligns with the opinions of UNDP beekeepers that bees can be kept busy throughout the year by mass-flowering legumes and cereal belts, also known as the "green grass conveyor".

Table 8: Quality indicators of honey from single-species crops of honey plants in the conveyor

Crop	Sowing method, row spacing	Seeding rate, million shoots. seeds/ha	Sowing period	Honey quality indicators			
				humidity, %	acidity (degrees)	дdiastase number (Gothe units)	invert sugar
Blue hybrid alfalfa	wide-row, 60 cm	3.0	02.V	17.3	2	17.3	75
Sand sainfoin	wide-row, 60 cm	4.0	02.V	16.8	1	15.7	78
Yellow sweet clover	wide-row, 60 cm	3.0	02.V	16.2	1	13.8	73
Phacelia tanacetifolia	wide-row, 60 cm	3.0	15.V	17.2	2	16.4	72
Sunflower	wide-row, 60 cm	0.06	14.V	15.8	2	13.8	75
Mustard	row, 15 cm	3.0	15.V	16.6	2	18.6	73
Rapeseed	row, 15 cm	3.0	15.V	16.3	3	20.8	75
Buckwheat	row, 15 cm	2.5	30.V	18.6	3	28.4	77

In contrast, monocultural fields in other areas frequently exhibit gaps. Thus, phacelia, sainfoin, and mixes have been promoted by Western European schemes. According to recent studies, bees may not find phacelia appealing if other blooms compete with it, even if it is planted for pollinators (Żarczyński et al., 2025). The high nectar content of clover and buckwheat in our environment indicates that bees would be drawn to those plants before phacelia.

The optimum moisture content of honey should be below 20%. The lowest moisture content was recorded in sunflower honey, at 15.8%. This value may indicate the high quality of this product. At the same time, the highest moisture content is observed in buckwheat honey (18.6%), which is acceptable, but may indicate an increased likelihood of crystallization.

Honey acidity is an important parameter that determines its quality. Low acidity is considered optimal, as it helps improve the product's organoleptic characteristics. The lowest acidity was recorded in honey from sand sainfoin (1°), which makes it preferable for consumption. In contrast, the highest acidity value (3°) is observed in rapeseed and buckwheat honey, which may negatively affect their taste.

The diastase number, which reflects enzyme activity, also significantly affects honey quality. The highest diastase number was recorded in buckwheat honey (28.4), indicating its high quality. In contrast, sweet clover honey demonstrated the lowest diastase number (13.8), which may indicate its lower quality.

The invert sugar content is an important criterion for assessing the sweetness of honey. The highest invert sugar content was found in sainfoin honey (78), making it sweeter than the other samples. The lowest invert sugar value is observed in sweet clover honey (73). In particular, buckwheat honey often has high levels of phenolics and antioxidants, and the honey produced from our conveyor crops meets standard quality criteria and exhibits chemical characteristics that reflect its floral origin (Pătruică et al., 2022; Ongalbek et al., 2024). Sunflower honey had significantly more flavonoids than rapeseed honey, according to a study of Romanian honeys by Pătruică et al. (2022), demonstrating how bioactive compounds are driven by botanical sources. The findings demonstrated comparable patterns and support the notion that blending different nectar sources will produce honey with a range of health and sensory qualities. Additionally, they support research trends indicating that the chemical profiles of buckwheat and sainfoin make them particularly promising for "high-quality" honey.

The crops under examination show varying degrees of resistance to the cold springs and hot, dry summers of northern Kazakhstan's arid continental climate. According to Sakhraoui et al. (2024), sainfoin's protective physiology naturally adapts it to semi-arid environments. Similarly, Żarczyński et al. (2025) recommend phacelia for low-input mixtures due to its remarkable resistance to frost and drought. However, buckwheat is more sensitive to heat or drought, which significantly lowers its flower count, nectar production, and bee visits. This is important because Kazakhstan's summers are notoriously dry (Defalque et al., 2025). While oilseeds like rapeseed require more moisture, leguminous clovers increase soil nitrogen content and are more drought-tolerant. Overall, the species tested exhibit a variety of adaptations.

The relatively poor performance of alfalfa and phacelia in Northern Kazakhstan is likely due to the region's unpredictable precipitation. These findings support more general analyses showing that plant-pollinator synchrony is changing due to climate change. Thus, any management plan must account for phenology under variable weather.

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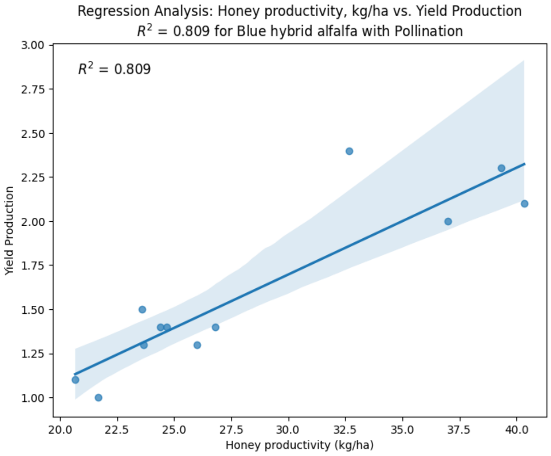
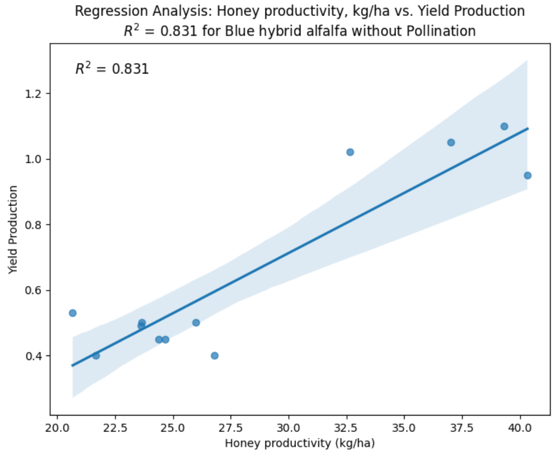
The ecological implications show that it is entirely possible to strengthen the pollinator base in an otherwise harsh landscape by choosing drought-tolerant nectar plants (clover, sainfoin) and staggered bloom times.

3.3. Exploratory Correlation Analysis of Nectar Productivity, Crop Yield, Flowering Duration and Bee Visitation

Because nectar productivity, crop yield, flowering duration, and honey bee visitation were available as crop-level mean values, the correlation analysis was interpreted as exploratory. Pearson and Spearman correlation coefficients were calculated to evaluate the direction and strength of relationships among these indicators. The graphical relationships among honey productivity indicators under pollinated and non-pollinated conditions are presented in Fig. 9.



Blue hybrid alfalfa with pollution



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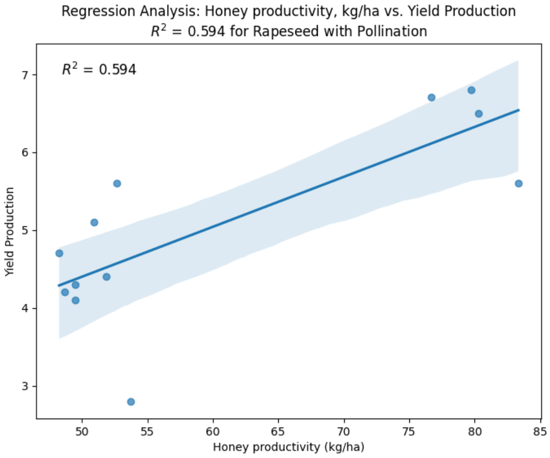
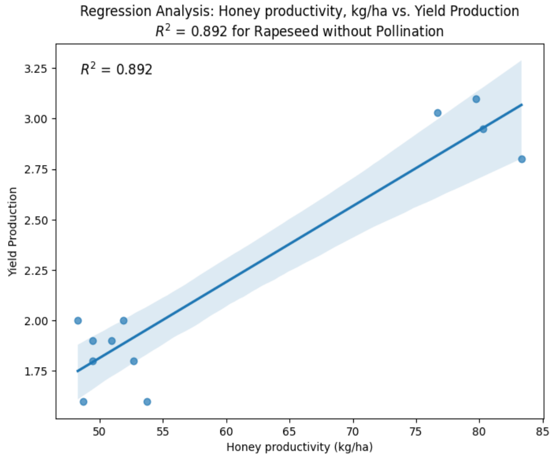
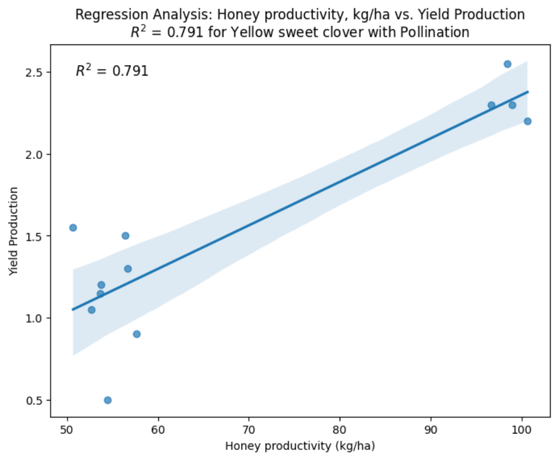


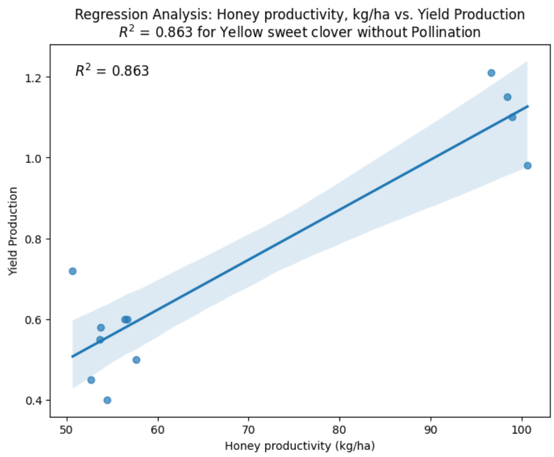
Sand sainfoin with pollination



Sand sainfoin without pollination



Yellow sweet clover with pollination



Yellow sweet clover without pollination

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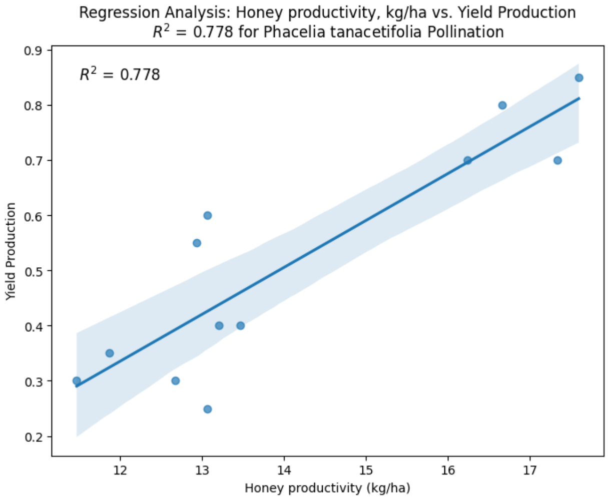
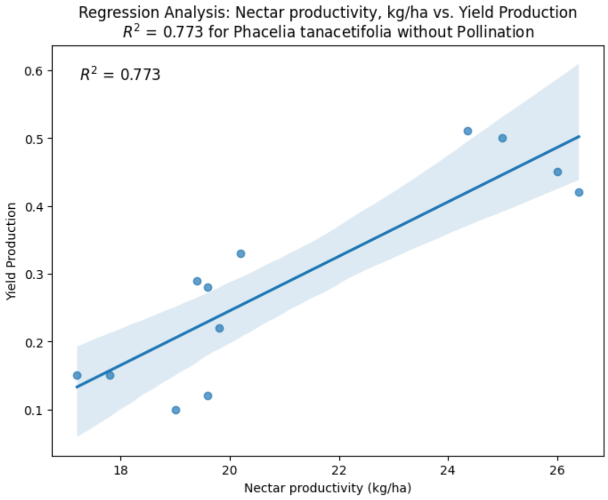
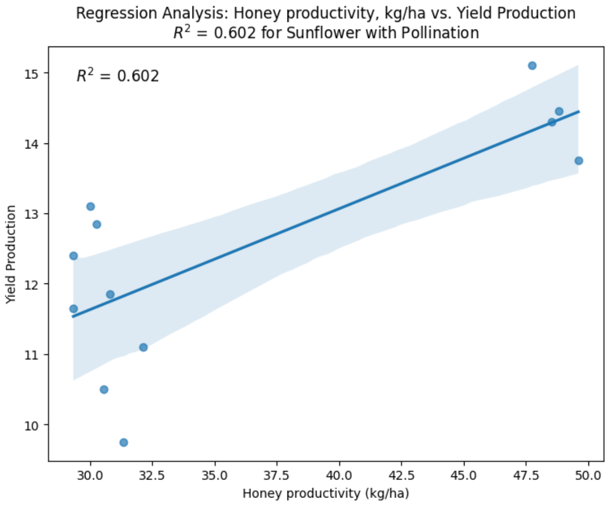


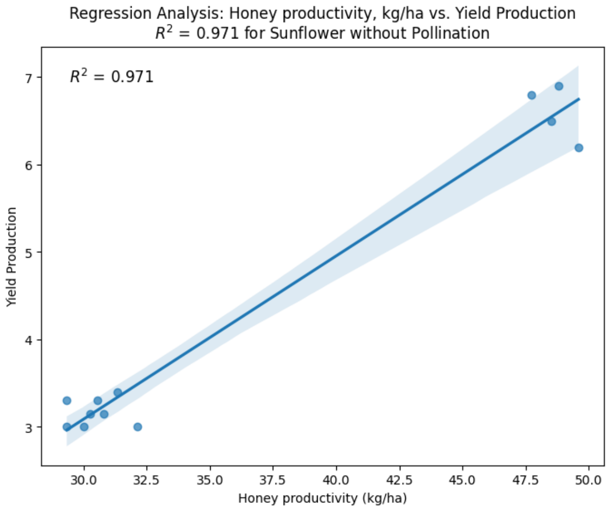
Phacelia tanacetifolia with pollination



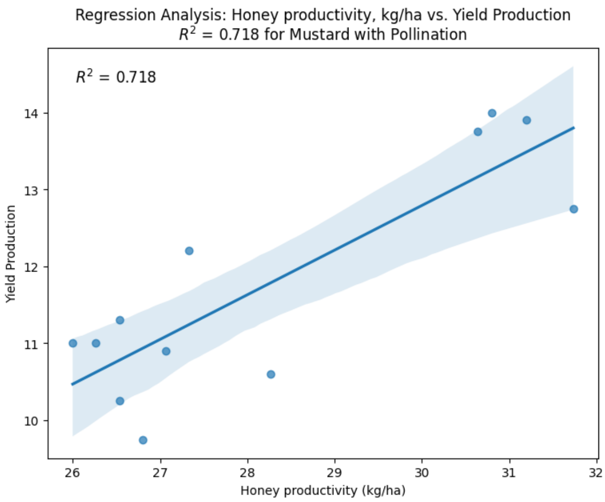
Phacelia tanacetifolia without pollination



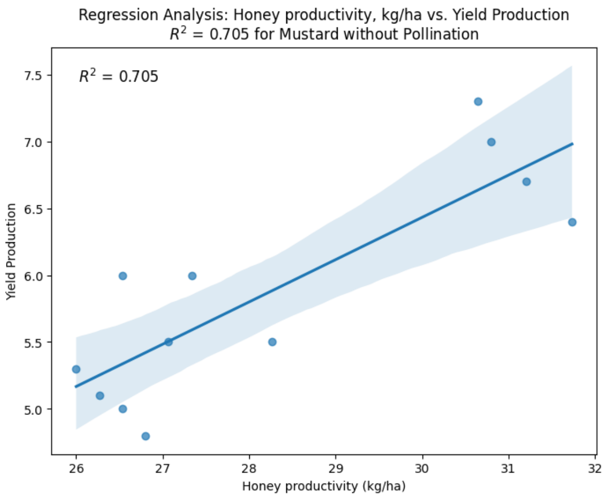
Sunflower with pollination



Sunflower without pollination



Mustard with pollination



Mustard without pollination

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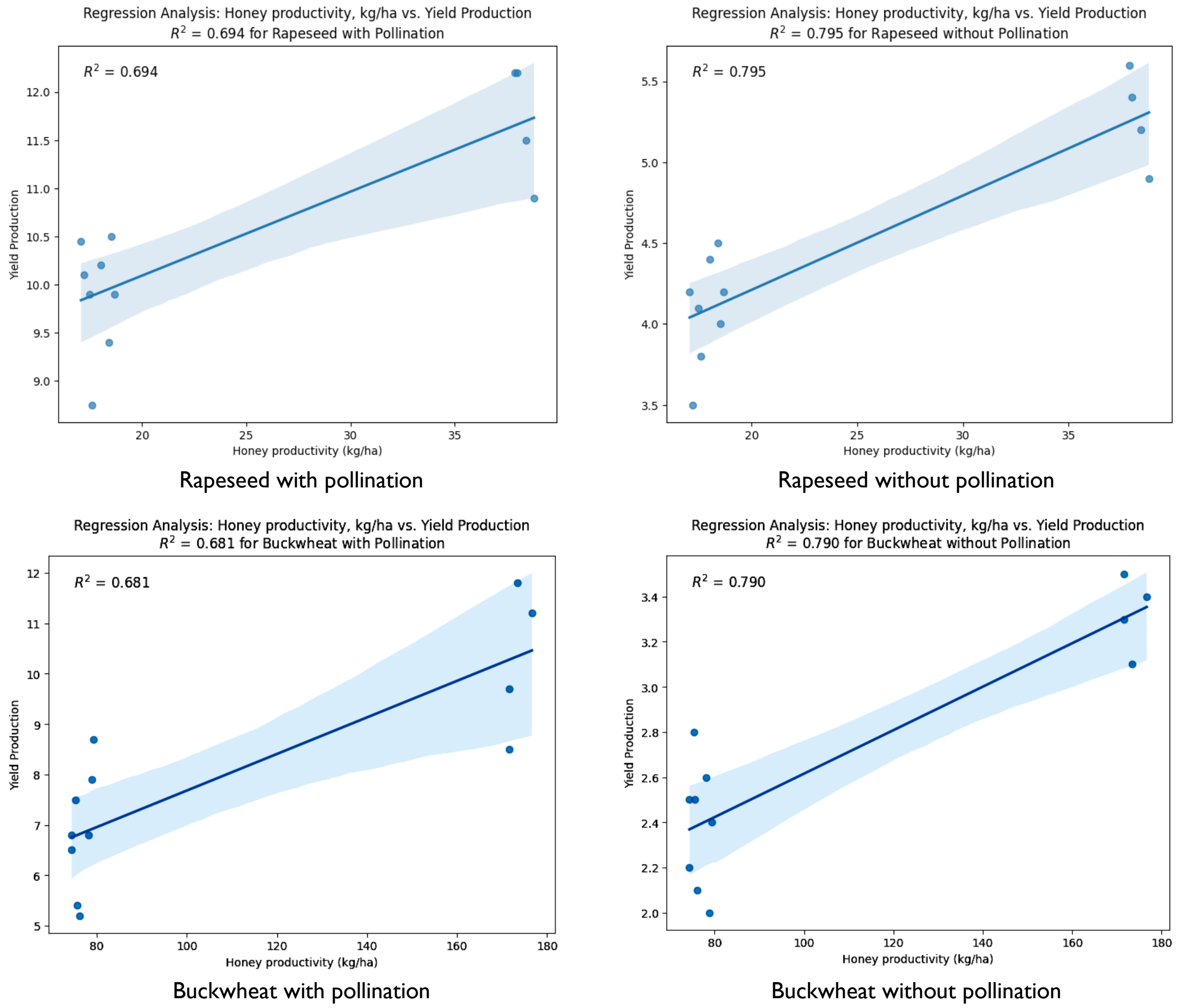

Fig. 9: Correlation analysis for the Honey productivity indicators (kg/ha).

The exploratory analysis did not reveal a statistically significant relationship between nectar productivity and crop yield, Pearson r = -0.015, p = 0.972; Spearman ρ = 0.048, p = 0.911. Nectar productivity showed a positive but non-significant association with flowering duration, Pearson r = 0.527, p = 0.179, and with mean honey bee visitation, Pearson r = 0.368, p = 0.370. Mean honey bee visitation also showed a positive but non-significant association with crop yield, Pearson r = 0.503, p = 0.204 (Table 9).

Table 9: Exploratory correlation analysis based on crop-level mean values

Relationship	Pearson r	p-value	Spearman ρ	p-value	Interpretation
Nectar productivity vs. yield	-0.015	0.972	0.048	0.911	Not significant
Nectar productivity vs. flowering duration	0.527	0.179	0.342	0.408	Positive but not significant
Nectar productivity vs. mean bee visitation	0.368	0.370	0.527	0.180	Positive but not significant
Mean bee visitation vs. yield	0.503	0.204	0.347	0.399	Positive but not significant
Flowering duration vs. yield	-0.210	0.617	-0.244	0.560	Not significant

These results indicate that crop recommendations for the honey conveyor should not be based on yield–nectar correlation alone. Instead, the most promising crops should be selected using a combined assessment of nectar productivity, flowering duration, attractiveness to honey bees, and pollination response (Knauer et al., 2024; Nauanova et al., 2024). Under this integrated criterion, yellow sweet clover, sandy sainfoin, and buckwheat remain the most valuable crops for inclusion in a continuous honey conveyor under the arid steppe conditions of Northern Kazakhstan (Faurat et al., 2024; Semenikhina et al., 2025).

Analysis of honey quality indicators indicates that honey from sandy sainfoin and buckwheat has high quality due to low acidity and high diastase number (Khudyakova et al., 2025). Blue hybrid alfalfa and sunflower also show promising results, but honey from these plants has a slightly higher acidity.

When interpreting the results of this study, it is important to take into account several limitations. The field trials' three-year duration and single-site location might not have adequately captured longer-term trends or broader spatial variability, suggesting that a larger multi-site study would strengthen the validity of our findings. Additionally, uncontrolled extreme events like late frosts and heatwaves could skew results, and interannual weather fluctuations; particularly in rainfall during critical flowering periods, probably affected nectar yields and may have obscured the true potential of the studied crops (Turbekova et al., 2023; Kradetskaya et al., 2026).

The use of a single cultivar for each crop, such as "Shortandyrskaya" buckwheat and "Lazurnaya" alfalfa, limits the ability to extrapolate the findings because different cultivars may have distinct nectar or bloom characteristics. Although the monitoring scope was centered on nectar and honey parameters, it did not identify pollinator species or include continuous counts of bee visitation, so our evaluation of pollination effects remains indirect. Lastly, the direct application of our findings may be limited because the use of pure monoculture stands for experimental clarity does not accurately represent the mixed-species composition of actual agricultural landscapes.

Future research priorities are indicated by these limitations. Breeding efforts should concentrate on producing cultivars with improved stress tolerance and nectar yield, such as heat-resistant buckwheat varieties or sainfoin with higher sugar content. To confirm a continuous nectar supply, research at the landscape scale must move from monocrops to testing integrated "nectar belts" through intercropping or sequential planting. Assessing the synergistic roles of wild and managed pollinators within diverse floral communities and comprehending pollinator foraging behavior under drought and high temperatures are crucial in light of climate change. Long-term honey quality assessment should also be part of future research to link agronomic practices to bioactive compounds and to explore low-input, sustainable management strategies that work in concert with soil conservation, nectar production, and comprehensive climate adaptation plans.

4. CONCLUSION

A comparative assessment of various honey crops grown in the steppe zone of the Akmola region revealed that buckwheat, yellow sweet clover, and sand sainfoin are the most valuable crops for the honey conveyor due to their high nectar productivity and flowering period. Buckwheat and yellow sweet clover demonstrated the best results in nectar productivity, which makes them especially valuable for beekeeping. Meanwhile, sunflower and mustard have a high yield and lower nectar productivity rates. Some crops, such as alfalfa and phacelia, showed low nectar productivity and yield rates, which makes them less preferable for crops.

An effective honey conveyor requires a combination of crops with high nectar productivity and a long flowering period, which ensures constant access to nectar for bees. Crops should be selected depending on the goals: to maximize nectar productivity, buckwheat and sweet clover should be preferred, while sunflower and mustard are suitable for achieving high yields. Sand sainfoin and buckwheat are the most promising for obtaining high-quality honey.

Declarations

Funding: This study did not get any financial support from any organization/agency.

Conflicts of Interest: The authors declare that they have no conflict of interest.

Data Availability: Data will be available upon request.

Ethics Statement: The study involved managed honey bee colonies (Apis mellifera carpatica) under field conditions and non-invasive observations of bee visitation and crop pollination. No invasive procedures, laboratory animal experiments, or harmful treatments were performed. Therefore, formal ethics committee approval was not required. The study was conducted in accordance with local legislation and institutional requirements for apicultural practice.

Author's Contributions: Sultan Saurov: conceptualization, methodology, field investigation, data collection, formal analysis, statistical interpretation, and writing of the original draft. Nurlan Serekpaev: conceptualization, methodology, supervision, validation, interpretation of results, and manuscript review and editing. Vladimir Zotikov: validation, scientific consultation, interpretation of results, and manuscript review and editing. All authors read and approved the final version of the manuscript.

Generative AI Statements: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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REFERENCES

Ahmad, S., Khalofah, A., Khan, S. A., Khan, K. A., Jilani, M. J., Hussain, T., Skalicky, M., Ghramh, H. A., & Ahmad, Z. (2021). Effects of native pollinator communities on the physiological and chemical parameters of loquat tree (Eriobotrya japonica) under open field condition. Saudi Journal of Biological Sciences, 28(6), 3235-3241. https://doi.org/10.1016/j.sjbs.2021.02.062
Akhylbekova, B., Serekpayev, N., Nogayev, A., & Zhumabek, B. (2022). Pasture Productivity Depending on the Method of Pasture use in the Steppe Zone of Northern Kazakhstan. OnLine Journal of Biological Sciences, 22(4), 476-483. https://doi.org/10.3844/ojbsci.2022.476.483
Akter, M., Hossain, M., Rahman, S., Banu, M., & Akhtar, M. (2023). Insect diversity and pollination effect on buckwheat (Fagopyrum esculentum) yield. Journal of Biodiversity Conservation and Bioresource Management, 9(1), 109-118. https://doi.org/10.3329/jbcbm.v9i1.66636
Al-Kahtani, S. N., Taha, E.-K., Khan, K. A., Ansari, M. J., Farag, S. A., Shawer, D. M., & Elnabawy, E. S. M. (2020). Effect of harvest season on the nutritional value of bee pollen protein. PLoS ONE, 15(12), e0241393. https://doi.org/10.1371/journal.pone.0241393 [Retracted]
Amarilla, L. D., Grilli, G., Huais, P. Y., Labuckas, D., Maestri, D., Ferrarese, M., Tourn, E., Szawarski, N., Grandinetti, G., Ferreira, M. F., Torres, C., Vesprini, J. L., Maggi, M., & Galetto, L. (2025). Pollinators significantly enhance seed set, yields and chemical parameters of oil seed in sunflower crops. Field Crops Research, 322, Article 109736. https://doi.org/10.1016/j.fcr.2025.109736
Anjum, S. I., Ullah, A., Khan, K. A., Attaullah, M., Khan, H., Ali, H., Bashir, M. A., Tahir, M., Ansari, M. J., Ghramh, H. A., Adgaba, N., & Dash, C. K. (2019). Composition and functional properties of propolis (bee glue): A review. Saudi Journal of Biological Sciences, 26(7), 1695-1703. https://doi.org/10.1016/j.sjbs.2018.08.013
Arien, Y., Dag, A., & Shafir, S. (2018). Omega-6:3 ratio more than absolute lipid level in diet affects associative learning in honey bees. Frontiers in Psychology, 9, 1001. https://doi.org/10.3389/fpsyg.2018.01001
Atanasov, A., & Vezirov, C. (2021). Approach to design sequence of field melliferous crops taking intoaccount use of agricultural machinery. In Engineering for rural development: Proceedings of the 20th International Scientific Conference Engineering for Rural Development: Jelgava, Latvia (pp. 80-85). https://doi.org/10.22616/ERDev.2021.20.TF017
Awad, A. M., Owayss, A. A., & Alqarni, A. S. (2017). Performance of two honey bee subspecies during harsh weather and Acacia gerrardii nectar-rich flow. Scientia Agricola, 74(6), 474-480. http://dx.doi.org/10.1590/1678-992x-2016-0101
Butters, J., Murrell, E., Spiesman, B. J., & Kim, T. N. (2022). Native flowering border crops attract high pollinator abundance and diversity, providing growers the opportunity to enhance pollination services. Environmental Entomology, 51(2), 492-504. https://doi.org/10.1093/ee/nvac013
Carisio, L., Schurr, L., Masotti, V., Porporato, M., Nève, G., Affre, L., Gachet, S., & Geslin, B. (2022). Estimates of nectar productivity through a simulation approach differ from the nectar produced in 24 h. Functional Ecology, 36, 3234–3247. https://doi.org/10.1111/1365-2435.14210
Chenikalova, E. V., & Cherkashin, V. N. (2019). Puti povysheniya effektivnosti prirodnykh opyliteley pri organicheskom zemledelii [Ways to improve the efficiency of natural pollinators in organic farming]. International Journal of Applied and Fundamental Research, 8, 25-29. https://doi.org/10.17513/mjpfi.12820
Cîrlig, N. (2022). Brassicaceae Species (Brassicaceae Burnett) in the collection of "Alexandru Ciubotaru" National Botanical Garden (Institute) as potential honey plants. Scientific Papers. Series a. Agronomy, 57(2), 487-494.
Crochard, L., Mariton, L., Fontaine, C., Baude, M., Ragué, M., Bas, D., Gaba, S., Bretagnolle, V., Julliard, R., & Bas, Y. (2026). Buzzy bees: Improving the monitoring of pollinator activity in sunflower fields with continuous acoustic recording and deep learning. Ecological Informatics, 94, Article 103633. https://doi.org/10.1016/j.ecoinf.2026.103633
Defalque, C., Laeremans, J., Drugmand, J., Tcheutchoua, C. F., Meng, Y., Zhou, M., Zhang, K., & Quinet, M. (2025). Drought and High Temperatures Impact the Plant–Pollinator Interactions in Fagopyrum esculentum. Plants, 14(1), 131. https://doi.org/10.3390/plants14010131
Dospekhov, B. A. (1985). Metodika polevogo opyta [Field experiment methodology] (5th ed., supplemented and revised). Moscow: Agropromizdat, 121 p.
Eremia, N., Zagareanu, A., & Modvala, S. (2018). Particularitățile tehnologiei creșterii mătcilor de albine și stupăritului pastoral [Peculiarities of queen bee breeding technology and pastoral beekeeping]: Monograph. Chisinau: ASEM. 356 p.
Faurat, A., Azhayev, G., Satybaldiyeva, G., Kaliyeva, A., Utarbayeva, A., Akhmetov, K., & Bekpergenova, Z. (2024). Pollution, ecological and health risk assessment of heavy metals in urban soils of industrial city in the North-East of Kazakhstan. International Journal of Agriculture and Biosciences, 13(4), 820–835. https://doi.org/10.47278/journal.ijab/2024.183
Golovachev, V. I., & Kirilovskaya, E. V. (1989). Metodika gosudarstvennogo sortoispytaniya sel'skokhozyaystvennykh kul'tur. Vyp. 2: Zernovyye, krupyanyye, zernobobovyye, kukuruza i kormovyye kul'tury [Methodology for state variety testing of agricultural crops. Issue 2: Cereals, grains, legumes, corn and forage crops]. Moscow, 194 p.
Hossain, M., Paul, J., Rahman, M., Fazlullah, M., & Sarkar, S. (2021). Role of honey bee on mustard (Brassica spp.) yield. Journal of Biodiversity Conservation and Bioresource Management, 6(1), 25-30. https://doi.org/10.3329/jbcbm.v6i1.51328
Husband, S., Cankar, K., Catrice, O., Chabert, S., & Erler, S. (2025). A guide to sunflowers: floral resource nutrition for bee health and key pollination syndromes. Frontiers in Plant Science, 16, 1552335. https://doi.org/10.3389/fpls.2025.1552335

Kacemi, R., & Campos, M. G. (2023). Translational Research on Bee Pollen as a Source of Nutrients: A Scoping Review from Bench to Real World. Nutrients, 15(10), 2413. https://doi.org/10.3390/nu15102413
Kashkovsky, V. G. (2021). Soderzhaniye i razvedeniye medonosnykh pchel Apis Mellifera L [Maintenance and breeding of honey bees Apis mellifera L]. St. Petersburg: St. Petersburg branch of the FSUE "Nauka", 423 p.
Khan, K. A., & Ghramh, H. A. (2021). Pollen source preferences and pollination efficacy of honey bee, Apis mellifera (Apidae: Hymenoptera) on Brassica napus crop. Journal of King Saud University – Science, 33(1), 101487. http://dx.doi.org/10.1016/j.jksus.2021.101487
Khan, K. A., Ghramh, H. A., Ahmad, Z., El-Niweiri, M. A., & Mohammed, M. E. A. (2021). Honey bee (Apis mellifera) preference towards micronutrients and their impact on bee colonies. Saudi Journal of Biological Sciences, 28(6), 3362-3366. https://doi.org/10.1016/j.sjbs.2021.02.084
Khudyakova, N. E., Safonova, O. V., Bolbukh, T. V., Okasheva, N. A., & Kocheewa, N. A. (2025). Accumulation and migration of heavy metals in the soil–plants–bees–honey chain under different environmental conditions in Altai. International Journal of Ecosystems and Ecology Science, 15(4), 251–258. https://doi.org/10.31407/ijees15.4
Kirillenko, S. K., & Golovin, V. P. (1985). Nectar secretion in some forage crops. Beekeeping, 5, 11.
Knauer, A., Naef, C., & Albrecht, M. (2024). Pesticide hazard, floral resource availability and natural enemies interactively drive the fitness of bee species depending on their crop fidelity. Science of the Total Environment, 922. https://doi.org/10.1016/j.scitotenv.2024.171058
Komlatsky, G. V., Sokolsky, S. S., & Usenko, T. A. (2020). Pchelovodstvo kak neobkhodimyy faktor razvitiya APK [Beekeeping as a necessary factor of APC development]. Scientific Journal of KubSAU, 157(03), 52-64. https://doi.org/10.21515/1990-4665-157-005
Kradetskaya, O., Mamykin, E., Dashkevich, S., Utebayev, M., Chilimova, I., Dolinny, Y., & Utelbayev, Y. (2026). Impact of agricultural technologies and mineral nutrition on growth, yield, and quality of spring wheat (Triticum aestivum L.). Research on Crops, 27, 222–232. https://doi.org/10.31830/2348-7542.2026.ROC-1302
Kurmanov, R. G. (2023). Resources of melliferous and polleniferous plants of Central Asia and Kazakhstan based on melissopalynological analysis. Vegetation Resources, 59(4), 367-377. https://doi.org/10.31857/s0033994623040076
Langlois, A., Michelot-Antalik, A., Marchant, A., Griat, T., Soderberg, E., Swiderski, C., & Baude, M. (2026). From species to landscape: Quantification of nectar and pollen reveals seasonal gaps for pollinators in intensive arable systems. Agriculture, Ecosystems & Environment, 407, Article 110445. https://doi.org/10.1016/j.agee.2026.110445
Margaoan, R., Papa, G., Nicolescu, A., Cornea-Cipcigan, M., Kösoğlu, M., Topal, E., & Negri, I. (2025). Environmental pollution effect on honey bees and their derived products: a comprehensive analysis. Environmental science and pollution research international, 32(16), 10370–10391. https://doi.org/10.1007/s11356-024-33754-4
Mazzilli, S. R., Abbate, S., Silva, H., & Mendoza, Y. (2023). Apis mellifera visitation enhances productivity in rapeseed. Journal of Apicultural Research, 62(2), 402-410. https://doi.org/10.1080/00218839.2020.1856558
Merembayev, T., Amirgaliyev, Y., Saurov, S., & Wójcik, W. (2022). Soil salinity classification using machine learning algorithms and radar data in the case from the South of Kazakhstan. Journal of Ecological Engineering, 23(10), 61-67. http://dx.doi.org/10.12911/22998993/152281
Ministry of Agriculture of the Republic of Kazakhstan. (2011). Methodology for conducting variety testing of agricultural plants, approved by the order of the Ministry of Agriculture of the Republic of Kazakhstan of May 13, 2011, No. 06-2/254. https://online.zakon.kz/Document/?doc_id=31016934&ysclid=me6c2a1mc5517968642
Nauanova, A., Shaikhin, S., Ospanova, S., Makenova, M., Shumenova, N., & Bostubayeva, M. (2024). Enhancing spring barley grain yield with local biofertilizers in the semi-arid steppe zone of Northern Kazakhstan. International Journal of Design & Nature and Ecodynamics, 19(2), 371–378. https://doi.org/10.18280/ijdne.190202
Ongalbek, D., Tokul-Ölmez, Ö., Şahin, B., Küçükaydın, S., Aydoğmuş-Öztürk, F., Sıcak, Y., Yeskaliyeva, B., & Öztürk, M. (2024). Classification of buckwheat honey produced in Kazakhstan according to their biochemical ingredients and bioactivities by chemometric approach. Food Chemistry, 451, 139409. https://doi.org/10.1016/j.foodchem.2024.139409
Pankov, D. M. (2011). Sposob opredeleniya zavisimosti urozhaynosti semyan entomofil'nykh kul'tur ot opyleniya pchelami [Method to detect dependence of entomophilous crops seeds productivity on pollination with bees] (RU Patent No. 2420950. IPC A01H 1/02). Federal Service for Intellectual Property, Patents and Trademarks.
Papa, G., Maier, R., Durazzo, A., Lucarini, M., Karabagias, I. K., Plutino, M., Bianchetto, E., Aromolo, R., Pignatti, G., Ambrogio, A., Pellecchia, M., & Negri, I. (2022). The Honey Bee Apis mellifera: An Insect at the Interface between Human and Ecosystem Health. Biology, 11(2), 233. https://doi.org/10.3390/biology11020233
Pătruică, S., Alexa, E., Obiștioiu, D., Cocan, I., Radulov, I., Berbecea, A., Lazăr, R. N., Simiz, E., Vicar, N. M., Hulea, A., & Moraru, D. (2022). Chemical composition, antioxidant and antimicrobial activity of some types of honey from Banat Region, Romania. Molecules, 27(13), 4179. https://doi.org/10.3390/molecules27134179
Plos, C., Stelbrink, N., Römermann, C., Knight, T. M., & Hensen, I. (2023). Abiotic conditions affect nectar properties and flower visitation in four herbaceous plant species. Flora: Morphology, Distribution, Functional Ecology of Plants, 303. https://doi.org/10.1016/j.flora.2023.152279
Requier, F., Garnery, L., Kohl, P. L., Njovu, H. K., Pirk, C. W., Crewe, R. M., & Steffan-Dewenter, I. (2019). The conservation of native honey bees is crucial. Trends in Ecology & Evolution, 34(9), 789-798. https://doi.org/10.1016/j.tree.2019.04.008
Rodney, S., & Purdy, J. (2020). Dietary requirements of individual nectar foragers, and colony-level pollen and nectar consumption: A review to support pesticide exposure assessment for honey bees. Apidologie, 51(2), 163-179. https://doi.org/10.1007/s13592-019-00694-9
Ryssaliyeva, L., Salnikov, V., Lin, Z., & Raimbekova, Z. (2025). Seasonal sensitivity of drought indices in Northern Kazakhstan: A comparative evaluation and selection of optimal indicators. Sustainability, 17(21), 9413. https://doi.org/10.3390/su17219413

Sakhraoui, A., Ltaeif, H. B., Sakhraoui, A., Villalba, J. J., Castillo, J. M., & Rouz, S. (2024). Sainfoin (Onobrychis viciifolia) a legume with great ecological and agronomical potential under climate change. The Journal of Agricultural Science, 162(4), 307-331. https://doi.org/10.1017/s0021859624000327
Selamoglu, Z., Naeem, M. Y., Ubaev, F., & Salybekova, N. (2025). Beekeeping in Kazakhstan: Production, practice and prospects for sustainable development. Eurasian Journal of Medical and Biological Sciences, 5(2), 89-95.
Semenikhina, S., Keubassova, G., Kalieva, A., Issayev, G., Admanova, G., Berkaliyeva, A., Bissalyyeva, R., Almanov, Z., Tashimova, A., & Almat, S. (2025). Needle-Based Assessment of Urban and Industrial Air Pollution in Aktobe. World Journal of Environmental Biosciences, 14(3), 110-119. https://doi.org/10.51847/iI1jiJHVsy
Serekpayev, N., & Saurov, S. (2025). Comparative assessment of nectar bearing capacity of single-species agrophytocenoses in conditions of arid steppe of the Akmola Region. 3i Intellect Idea Innovation, 1, 209-215. https://doi.org/10.52269/22266070_2025_1_209
Sergienko, A. V., Komlatsky, V. I., Kononenko, S. I., Svistunov, S. V., & Fomin, A. S. (2018). Organizatsiya opyleniya sel'skokhozyaystvennykh kul'tur v Krasnodarskom kraye [Organization of pollination of agricultural crops in the Krasnodar Territory]. Krasnodar: OOO “Operativnaya poligrafiya i dizayn”, 60 p.
Stybayev, G., Serekpayev, N., Yancheva, H., Baitelenova, A., Nogayev, A., Khurmetbek, O., & Mukhanov, N. (2021). Succession dynamics, quality, and production in improved and natural pastures in Northern Kazakhstan. Bulgarian Journal of Agricultural Science, 27(Suppl. 1), 95-102.
Szczurek, A., Maciejewska, M., & Batog, P. (2023). Monitoring system enhancing the potential of urban beekeeping. Applied Sciences, 13(1), 597. https://doi.org/10.3390/app13010597
Turbekova, A., Balgabaev, N., Turbekov, S., Solovyov, O., Savin, T., Tokbergenov, I., Zhumagulov, I., Yermekov, F., & Topayev, S. (2023). Influence of water-saving irrigation technology on the yield of grain crops in the northern region of Kazakhstan. Caspian Journal of Environmental Sciences, 21(5), 1093–1104. https://doi.org/10.22124/CJES.2023.7397
USSR State Committee on Standards. (1984). GOST 12038-84 Semena sel'skokhozyaystvennykh kul'tur. Metody opredeleniya vskhozhesti [Agricultural seeds. Methods for determination of germination]. Moscow: IPK Izdatel'stvo standartov, 38 p.
Vassilev, K. V., Assenov, A. I., Velev, N., Grigorov, B. G., & Borissova, B. B. (2019). Distribution, characteristics and ecological role of protective forests in Silistra Municipality, Northeastern Bulgaria. Ecologia Balcanica, 11(1), 191-204.
Wang, W. J., Lin, Y. T., Chen, H. F., Huang, M. Y., Ren, Z. X., & Zhao, J. L. (2025). Diurnal nectar secretion dynamics in Roscoea cautleoides (Zingiberaceae) reveal the role of non-sugar chemicals in plant–pollinator interaction. Current Plant Biology, 41. https://doi.org/10.1016/j.cpb.2025.100443
Willcox, B. K., Potts, S. G., Brown, M. J. F., Alix, A., Al Naggar, Y., Chauzat, M.-P., Costa, C., Gekière, A., Hartfield, C., Hatjina, F., Knapp, J. L., Martínez-López, V., Maus, C., Metodiev, T., Nazzi, F., Osterman, J., Raimets, R., Strobl, V., Van Oystaeyen, A., ... Senapathi, D. (2023). Emerging threats and opportunities to managed bee species in European agricultural systems: A horizon scan. Scientific Reports, 13, Article 18099. https://doi.org/10.1038/s41598-023-45279-w
Wright, G. A., Nicolson, S. W., & Shafir, S. (2018). Nutritional physiology and ecology of honey bees. Annual Review of Entomology, 63, 327-344. https://doi.org/10.1146/annurev-ento-020117-043423
Żarczyński, P. J., Mackiewicz-Walec, E., Krzebietke, S. J., Sienkiewicz, S., & Żarczyńska, K. (2025). Phacelia tanacetifolia Benth. as a Multifunctional Plant: Support for Pollinators and Sustainable Agricultural Practices. Agronomy, 15(8), 1843. https://doi.org/10.3390/agronomy15081843
Žiganova, M., Ābele, A., Iesalniece, Z., & Meri, R. M. (2022). Mercerization of agricultural waste: sweet clover, buckwheat, and rapeseed straws. Fibers, 10(10), 83. https://doi.org/10.3390/fib10100083

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