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Morphometric characteristics of Ukrainian steppe bees depending on the method of controlled queen mating

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Abstract. Bee breed is an important factor in determining bee family development and productivity, as it affects honey production, disease resistance, climate adaptation, and bee behaviour characteristics. The purpose of the study was to establish the relationship between the methods of mating queens and the morphological characteristics of bees of the Ukrainian steppe breed and the productive indicators of bee colonies. To conduct the research, 43 bee colonies with queen sisters of the Ukrainian steppe breed mated by different methods of natural mating were established in the Vinnytsia oblast. According to the results of mating, there were 22 queen bees in the control group, and 21 queen bees in the experimental group. The queens of the first control group mated in a normal natural way without any restrictions. The queen bees of the experimental group mated under time and space control. Based on the results of the research, the relationship between the integrity of the colony and its morphological features and productive indicators was established. Thus, experimental families have different degrees of belonging to the Ukrainian steppe breed, control – 59% and experimental – 87.2% ($p < 0.001$). According to the cubital index, the advantage was 8.2% ($p < 0.001$) in favour of the experimental group. The best family integrity on the hantel index was observed in families in which queens were mated in a controlled time and space, with a difference of 3.32% ($p < 0.001$). In the control group, where uncontrolled mating of queens was performed, more bees were found for discoid displacement with an excess of the standard indicator for the breed. Families in the experimental group were stronger by 14.5% ($p < 0.001$) compared to the control group. They provided 41.9% more honey, built 22.1% more honeycombs ($p < 0.01$), and the need for Kandy feeding was 31.8% less ($p < 0.001$). In addition, the bees of the experimental

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group had pronounced hygienic behaviour and required less labour costs. The practical significance of the study lies in the possibility of establishing patterns of action of factors on a particular breed and confirms the need to implement breeding programmes in beekeeping

Keywords: hantel index; cubital index; discoid displacement; productivity; preservation; climatic conditions; feed consumption

Introduction

The beekeeping industry plays an important role in ensuring the country's food security, which is linked to many other industries. Bees pollinate many plant species, being used to increase yields. Beekeeping products include not only honey, a valuable dietary product, but also wax, propolis, venom and other products that are widely used, in particular for human health. Today, beekeeping is mainly pollinated and honey-based. Without the use of bee pollination, it is difficult for farmers, gardeners, horticulturists, and other workers who grow insect-pollinated crops to obtain high yields. Therefore, workers in agriculture, horticulture and other industries should be interested in the development of beekeeping and the use of bees for plant pollination (Nevsky & Sverdan, 2021).

The effectiveness of the development of beekeeping, as well as a single apiary farm, depends on many factors. Admittedly, the key factor of productivity is the availability of feed resources and weather and climatic conditions, but such a component as genetic potential is also responsible for the efficiency and profitability of beekeeping production. Adaptability to local conditions is key to the efficiency of using bee colonies, because this factor depends not only on productivity, but also on the survival of bee colonies in critical periods, the strength of families during the active season, and resistance to certain diseases, in particular to varroatosis. Therefore, it is worth noting that such a process as breeding is a cheaper, more efficient and environmentally friendly factor in increasing production (Brovarskyi & Papchenko, 2014). At the same time, mixing local breeds with imported ones is dangerous because it generates substandard material. And this is confirmed by a number of researchers from all over the world. The German scientist Ruttner (1988) reported that high productivity of interbreeding hybrids can be obtained only in the first generation and from the third generation the average productivity regularly decreases. In the 1960s, researchers became interested in the interbreeding hybridisation of bees, which was forcibly introduced in apiaries, which ultimately led to significant changes (Alpatov, 1948). After three generations, when all the source material had already been hybridised and the native bees had been lost over large areas, the bred bees had increased their irritability, viciousness, and drone resistance several times, and their resistance to disease decreased. It is difficult to correct such an error due to the biological characteristics of bees, considering also such a feature of drone development as parthenogenesis (Lattorff *et al*, 2005; Papp *et al*., 2015). Researchers have established that the current distribution of breeds does not correspond to traditional zoning. The conclusion of their study is that common practice of importing genetic material *Apis mellifera* from different regions of Ukraine leads to uncontrolled hybridisation and poses a threat to the preservation of native honey bee breeds (Cherevatov *et al*., 2020).

In nature, bees themselves contribute to the crossbreeding by their way of life. In the absence of isolation, any bee breed is influenced and pressured by other breeds, but here nature controls and selects useful signs of bees over a long period of time. Studies have shown an insufficient level of breed purity as a result of the spontaneous, uncontrolled hybridisation that has been carried out in recent years. Kerek (2020) argues that the crossbreeding of bees in the country's apiaries has not spared even the highest regions of Ukraine, which can be called semi-isolated.

Economically useful signs of bees have now undergone changes due to unfavourable natural and climatic conditions (prolonged cold springs, frequent prolonged droughts), impoverishment of the food supply due to a decrease in the acreage of honey crops and the cultivation of monocultures. In such conditions of keeping bee colonies, there is a need to study a number of issues of directed breeding aimed at improving its economically useful features and creating highly productive local types that can tolerate fluctuations in the main factors of weather conditions. A breeding trait under these conditions, which is directly related to the productivity of bees, is adaptability to certain conditions of honeybee capture (Cherevko *et al.*, 2018).

In Ukraine, the zoned breeds are carpathian, Ukrainian steppe and polissian (Adamchuk & Bilotserkivets, 2015). Ukrainian steppe bee breed *(Apis mellifera sossimai)* is most widespread in Ukraine and occupies more than 70% of its territory. However, as a result of decades of hybridisation with other local breeds (carpathian *(Apis mellifera carpatica)* and polissian *subspecies Apis mellifera mellifera*), as well as with previously popular central russian (*Apis mellifera mellifera*), grey mountain caucasian *(Apis mellifera caucasica)* and popular now Italian (*Apis mellifera carnica* and *Apis mellifera ligustica)*, as a result of the unconscious use by beekeepers of bee breeds that are not registered for Ukraine, the purity of the drone background of beekeeping farms is blurred, as a result of which the economically useful features have changed (Cherevatov *et al.*, 2020). In addition, bees are susceptible to reduced genetic diversity because they are haplodiploid (Grozinger & Zayed, 2020). Considering the fact that drones develop from unfertilised haploid eggs by parthenogenesis, there is a need to use targeted breeding of Ukrainian steppe bees (zoned for the Vinnytsia oblast) to improve their economically useful characteristics (Dzitsiuk & Lytvyniuk, 2014).

Therefore, depending on their habitat, bees develop certain morphometric and behavioural qualities that they need to ensure their normal life processes. Each breed, and even the breed type, has its own unique properties and some of them, in the absence of appropriate conditions, may not manifest themselves in the homeland of this breed (for example, wintering breeds of southern latitudes in northern regions with a long non-flying period). And because of this, it is not always possible to predict the result of imported bee breeds that are not typical of the zones (Brovarskyi & Papchenko, 2014).

Keeping native bees in apiaries, which have adapted to living conditions in a certain area over the course of evolution, is an important condition for ensuring the effectiveness of this process. Preference should be given to the breed of bees that comes out of wintering with the least losses and quickly recovers in the spring. Each breed of bee, depending on the localisation zone and types of honey collection in this area, shows its abilities differently. In the forest-steppe zone of Ukraine, the most common and popular are Ukrainian steppe bees (Khamid, 2014).

One of the tasks of breeding in beekeeping is to preserve breeding material, create highly productive bee populations, and improve the productivity of bee colonies. The Ukrainian steppe bee breed is characterised by specific morphological features and differs from others in productive features. However, haphazard crossing with non-zone bees in Ukraine has led to local breeding.

The purpose of the study is to establish patterns between morphological features and compliance of phenotypes with the standard of the Ukrainian steppe bee breed in the natural and controlled method of mating queen bees.

Materials and Methods

The research was conducted in a private apiary in Volodymyrivka village, Vinnytsia region. The apiary farm has supported the breed by purchasing over the past five years (2018-2022) of purebred queens of the Ukrainian steppe breed, in the amount of 20% annually, and breeding was carried out along the maternal lines.

The first stage is obtaining bee colonies. For this purpose, based on the research, the Nikot-100 queen breeding system, 48 queen cells (24 in each group), and three parent families were used, which were kept in 10-frame beehives on a 435×145 mm frame.

The Nikot-100 queen breeding system was used to produce queen bees of sister origin. For mating queens of the control group, in addition to their own drone background, which potentially included 50 bee colonies from the apiary under study and about 250 families from other private apiaries located within a radius of 500 m, and about 170 families located within a radius of 2 km. The queen bee was placed in the Nikot-100 system on May 15, 2021, after it was isolated and the eggs were placed in care families for growing larvae until the queen cells were sealed. On May 30, 2021, 48 queen cells were placed in micronuclei. In the future, two groups of analogues were formed for the study, which, according to the results of successful mating, included 43 sister bee colonies. Micronuclei were placed at one location, at a distance of 50 m from the pollinating-honey part of the apiary.

The second stage began with checking the queen bees for the seeding quality, marking with a marker and wing capping, after which they were placed in layers that contained 2 forage combs and 8 combs of different ages of brood, which were seeded by bees, and 10 frames of the dryer (10-frame body per frame size 435×145 mm). Planting queen bees in the formed layers took place only with the help of a perforated cap with a check of their acceptance on the third day. Layers were formed on June 15-16 and were intended for use in pollination of sunflower seeds from July 19 to August 10, 2021. The formed layers were placed on specialised platforms in a staggered order, to equalise the influence of factors such as geographical location, the presence of wind and shade.

At the third stage, the degree of belonging of bees to the Ukrainian steppe breed, productive indicators of bee colonies, wintering features, the degree of safety, hygienic behaviour, and the intensity of feed consumption were determined.

To organise a time-controlled flight, the experimental farm used 12 double micronuclei for queens and 3 parent families placed in hull hives with a separate grid for monitoring the flight activity of drones. Parents' families were provided with a daily evening flight from 18:00 to 06:00. The micronuclei were also equipped with flight barriers, which prevent the queen from leaving before a certain time. On Day 22, micronuclei were transferred in the winter garden until the next day before 17 o'clock. At 17:30, the micronuclei were opened together with the parent families, as a result of which a mass flyby and mating of queens took place. At approximately 20:30, the micronuclei were closed and the operations of the previous day were repeated again the next day, after which the gate valve was returned to a position that allowed only worker bees to exit.

In the course of research, the breed affiliation of the resulting offspring of worker bees was primarily determined. The assessment was carried out visually, based on the uniformity of the colony and the colour of the tergites of the abdomen of worker bees. For morphometric analysis, six samples were taken from each analogue group, which included 60-70 bees no older than three days of age. Each sample was taken from two families, according to the method, a perforated cap was applied to the sealed brood, after the bees left the cells, they were preserved in an alcohol solution in disposable containers, which were marked with numbers 1-12, without indicating belonging to a specific group (Brovarskyi *et al.*, 2017). The assessment was performed using the Morphoxl – programme for morphometric analysis of bee wings. 618 wings from 12 bee colonies and at least 50 bee wings from one bee family were used for evaluation. Using the Morphoxl software suite, measurements of the bee's wing and their relationship to each other were determined, namely, the cubital index, the hantel index, and the angular discoid displacement. This study was conducted at the state educational institution "Hadiach higher professional agricultural school". The cubital index was calculated as a percentage. To do this, the measurements of the sides of the third cubic cell of the front wing were determined, the results of the measurements of the smaller side were divided by the measurements of the larger side and multiplied by 100%. Discoid displacement was determined using a stereomicroscope. For this purpose, the scale with divisions of the eyepiece-micrometre of the stereomicroscope was combined with the centreline of the radial cell of the bee's front wing. In this case, the line perpendicular to the scale must pass through the intersection point of the longest vein of the cubital cell with the lower vein of the radial cell. The hantel index was determined by the ratio of the length of segments of the wing cubital cell, one of which is a straight line, the second – a line connecting the uneven edges of the opposite section.

Results and Discussion

The weather and climatic conditions of the two years of study cannot be called typical, the decrease in the number of honey plants and the cultivation of monocultures negatively affected the nectar supply of the area, the quality of wintering, the development and productivity of bee colonies, so the indicators of biological characteristics of bee colonies involved in the research process do not always meet the standard "Technological requirements for breeding and breeding work in the field of beekeeping" (2016).

During the first stage of research, namely obtaining fertile queens, for their subsequent planting in layers, it can be stated that the method of limited space and time mating of queens does not actually reduce the number of successful mating, and does not entail additional losses of breeding material compared to the natural flight of queen bees. The control group included 22 queen bees fertilised by free mating, and the control group included 21 queen bees fertilised by mating controlled in time and space.

The tables below show the results and their compliance with standards (breed ranges) (2015, 2020).

According to Table 1, bee colonies in the control group have a high degree of variation and are slightly outside the range of breed values according to the cubital index (0.931-3.783), which is a consequence of free mating with a rich drone background. At the same time, the experimental group has significantly smaller deviations from the breed ranges and does not cross its upper limit. But it is also necessary to consider the coefficient of variation (colony integrity), as a sign of stable transmission of economically useful traits. The control group had a coefficient of variation from 15.4 to 26.1%, and the experimental group – from 7.3 to 15.6%. The average value for this indicator in the control group was 20.0 ± 1.49%, while in the control group it was significantly lower – 11.8%. The difference between the groups was 8.2% ($p < 0.001$).

Table 1. *Indicators of the cubital index of Ukrainian steppe bees*

No. of sample	Cubital index (breed range – 1.86-3.0)					
	control group			experimental group		
	variability	average value	variation coefficient, %	variability	average value	variation coefficient, %
1	1.587…3.731	2.404 ± 0.064	19	1.723…2.790	2.200 ± 0.033	11
2	1.438…3.152	2.182 ± 0.054	17.7	1.880…2.472	2.146 ± 0.022	7.3
3	1.279…3.783	2.349 ± 0.073	21.4	1.719…2.973	2.247 ± 0.041	13.4
4	1.256…3.110	2.046 ± 0.058	20.5	1.833…3.612	2.420 ± 0.052	15.6
5	1.389…2.650	2.049 ± 0.044	15.4	1.791…2.984	2.187 ± 0.039	13
6	0.931…3.699	2.155 ± 0.077	26.1	1.760…2.692	2.112 ± 0.030	10.3
By group	-	2.197 ± 0.0612	20.0 ± 1.49	-	2.219 ± 0.0444	11.7 ± 1.17***

Note: *** – $p < 0.001$

The cubital index is not always an accurate breed classifier due to the variability of the feed base and the influence of bee feeding conditions at different stages of their development. Therefore, the hantel index is used to confirm the breed of bees. The hantel index also shows better family integrity in the experimental group – 6.95% and 10.27% for the control group. The difference between the groups was 3.32% ($p < 0.001$) (Table 2).

Table 2. *Results of the hantel index of the wing of a bee of the Ukrainian steppe breed*

No. of sample	Hantel index (breed range 0.829-1.113)					
	control group			experimental group		
	variability	average value	variation coefficient, %	variability	average value	variation coefficient, %
1	0.776…1.283	0.995 ± 0.014	9.8	0.840…1.106	0.982 ± 0.009	6.3
2	0.779…1.157	0.974 ± 0.013	9.3	0.859…1.179	0.984 ± 0.010	7.2
3	0.795…1.382	1.006 ± 0.020	13.3	0.831…1.167	0.0995 ± 0.010	7.1
4	0.752…1.106	0.942 ± 0.012	9.2	0.832…1.168	0.995 ± 0.010	6.9
5	0.827…1.275	1.014 ± 0.015	10.4	0.756…1.034	0.893 ± 0.008	6.5
6	0.781…1.228	0.939 ± 0.012	9.6	0.765…1.094	0.898 ± 0.010	7.7
By group		0.978 ± 0.0132	10.27 ± 0.631		0.957 ± 0.0198	6.95 ± 0.206***

Note: *** – $p < 0.001$

The obtained data on the hantel index in some samples slightly went beyond the breed range (0.829-1.113). Although the average score in the experimental group was 0.957, the control group – 0.978, which was within the range. The angular discoid displacement also in both groups of bee colonies is in the breed range (1.89-5.68) and shows the uniformity of offspring and indicates the level of breeding due to the saturation of different drone backgrounds (Table 3).

Table 3. *Morphometric characteristics of Ukrainian steppe bees by angular discoidal displacement*

No.	Angular discoid displacement (breed range – 1.89-5.68)					
	control group			experimental group		
	variability	average value	hybridisation degree	variability	average value	hybridisation degree
1	-4.443...8.614	2.886±0.351	Acceptable	-1.125...5.688	2.534±0.238	Insignificant
2	-3.188...7.985	1.943±0.013	Acceptable	-1.422...6.236	2.355±0.247	Insignificant
3	-3.402...8.779	2.802±0.351	Hybrid	-0.365...6.983	3.017±0.027	Acceptable
4	-2.318...6.016	2.55±0.285	Insignificant	-1.104...7.352	3.109±0.238	Insignificant
5	-1.529...7.140	3.28±7.140	Acceptable	-1.798...4.715	0.817±0.226	Absent
6	-1.265...8.625	3.096±0.331	Acceptable	-3.137...6.269	1.056±0.260	Insignificant

The Morphoxl software suite detects the following levels of bee hybridisation gradation: missing; insignificant; acceptable; hybrid. In the conducted experiment, this level is more acceptable for the control group, and insignificant for the experimental group. That is, in the control group there are more samples in which these values go beyond the range towards increase (more than 5.68), in the experimental group there were a small number of such values. Table 4 shows the results, which combine all previous indicators and shows a forecast of the breed composition of bees for each colony. The data obtained indicate that the average value of bee samples belonging to the breed in the control group was 59.0%, and in the experimental group – 87.2%, which is 28.2% higher ($p < 0.001$).

Table 4. *Summary indicators of morphometric indicators of the Ukrainian steppe bees*

Group	Belonging to the breed under study (%)						Group average (%)
	Sample						
	1	2	3	4	5	6	
Control	70.6	56.9	48.9	58.5	70.2	49.1	59.0±3.93
Experimental	94.2	90.2	83	92.3	80.8	82.7	87.2±2.33***

Note: *** – $p < 0.001$

Studies of economically useful characteristics were also conducted, in particular, on honey productivity, the number of honeycombs built up, the strength of the bee family before wintering, and the effectiveness of feed use (feeding in spring). The data were averaged and entered in Table 5.

The highest productive indicators were obtained from a group of bee colonies with queens that controlled mating in space and time. During the experimental period, 41.9% ($p < 0.001$) more honey was received from established families. Bee colonies on the eve of wintering were stronger by 0.98 cells, or 14.5% ($p < 0.001$), which had a positive effect on the consumption of Kandy feed in the spring. Stronger families consumed 31.8% ($p < 0.001$) less than this feed. Moreover, during the season, the bees of the experimental group rebuilt 22.1% ($p < 0.01$) more honeycombs.

Table 5. Summary data on the average productivity of bee colonies at the end of the season

Group	Number of families in the group	Strength of families, cells (before wintering)	Produced honey, kg	Number of built-up honeycombs (435×145 mm), units	Kandy consumed in spring, kg
Control	22	6.78 ± 0.138	37.4 ± 0.91	24.8 ± 1.29	4.68 ± 0.138
Experimental	21	7.76 ± 0.194***	53.1 ± 2.01***	30.3 ± 1.20**	3.19 ± 0.088***

Note: ** – $p < 0.01$; *** – $p < 0.001$

During visual observation of the uniformity of the colony, it was found that the body colour of bees is mostly grey, sometimes with brown spots on the first two tergites of the abdomen, which fully meets the standards of the Ukrainian steppe bee breed. In addition, the families of the experimental group were more homogeneous in productivity, did not have early development (as of 23.03.2022), did not loosen the club and, as a result, required less attention from the beekeeper. Families of the control group generally had lower productivity, 9 out of 22 had early development, which led to overspending of feed, 6 of them did not clean the bottom of the hive well, and one did not clean at all, despite the strength of 7 cells. As a result, such bee colonies required increased attention from the beekeeper.

During the wintering period in the experimental groups, not a single bee family died, and all the queens retained their reproductive capacity at the beginning of the 2022 season (in one family of the experimental group, a humpback brood was noticed and subsequently such a defect disappeared without any operations on the part of the beekeeper). Over the past three years (2020-2022), an early flyby of bee colonies was observed at the end of the second decade of February, at a temperature of +12-+15°C, this provoked some families to start the reproductive activity of queens. With the beginning of prolonged cold snaps, during the research period from 26.02.2022 to 16.03.2022 (daytime temperature dropped from +10°C to -2°C, and night temperature was up to -5°C), negative changes were observed in the bee nest, which led to the death of part of the brood, the number of which at the time of inspection on 23.03.2022 was 3-4 honeycombs (435×145 mm) and the weakening of these bee colonies. In 2022, there were two non-mass flybys of bees on 02.01.2023 and 19.01.2023, which was not observed before, at least in the last 5 years.

Smoliński *et al.*, (2021) investigated the effect of temperature on the Autumn abundance of *Varroa destructor* in bee colonies during 1991-2020 in Central Europe. Researchers tested the hypothesis that temperatures can affect autumn tick populations with different time periods that regulate the number of bees and brood, and found that increased spring (March-May) and autumn (October) temperatures increase autumn infestation of bee colonies with *Varroa destructor*. Critical temperature values cover periods of bee activity, i.e., immediately after the first cleaning flights of bees and directly before the last autumn ones. These effects were potentially associated with increased bee reproduction at certain times of the year, rather than with a long period of activity or an accelerated onset of spring.

There is also a study showing the impact of climate change on the prevalence of infectious diseases such as acute bee paralysis virus, deformed wing virus, and chronic bee paralysis virus in wild bee populations (bumblebees and solitary bees), which is positively associated with the prevalence of these viruses in honeybees. This highlights the need for good breeding practices in beekeeping, including such a trait as resistance to *Varroa destructor*, which is a breed feature, to reduce the infection rate of honeybees. According to the projected climate change, temperatures will continue to rise, which may affect the prevalence of viruses in wild bees and, as a result, in bee populations (Piot *et al*., 2022)

A number of Ukrainian researchers are working on the problems of preserving the honey bee gene pool, and they believe that the solution to this is to create breeding programmes that improve the efficiency and behaviour of endangered breeds, while maintaining their adaptation to the environment (Hrechka & Senchylo, 2022; Cherevatov *et al*., 2014; Kerek, *et al*., 2017).

This process of hardware is typical not only for Ukraine, and the first consequences can already be traced in research. But in those countries where they managed to stop the crossbreeding of bees in time and began to comply with the requirements of the legislation, there were no such problems. In Ukraine, the process of deliberate and uncontrolled hybridisation is currently taking place, so beekeeping should function in close cooperation between beekeepers and science (Razanova & Skoromna, 2020).

Honeybees are a rather complex object of breeding. This is primarily conditioned by the way of life and the specifics of reproduction. In turn, their productivity depends on a combination of factors, namely: the strength of families during the honey harvest, the state of the food supply, the conditions of the beekeeping season, and on the skilful care of bees. The influence of genotype is of great importance (Kerek *et al*., 2017). The establishment of bee colonies as an integral biological unit takes place not only under the influence of the presence of feed reserves in nature, but also the climatic conditions of the range, which corrects the main economic and useful features, rational use of feed reserves and timely development, the rate of which corresponds to these climatic conditions (Razanova *et al*., 2021; Saranchuk *et al*., 2021). In addition, not the least position among the survival mechanisms is occupied by the adaptation of bees to existing pests and pathogens.

The fascination with the "best properties" of uncharacteristic breeds can be disastrous for bees, plants and people, as happened with Africanised bees in Brazil in 1957. Nowadays, due to their predominant properties and excessive aggressiveness, these bees displace native breeds already in the United States (Kadri *et al*., 2016). But this does not mean that all bees need to be propagated on such a trait as peacefulness, because it is scientifically proven that this trait directly correlates with tick tolerance. That is, more aggressive bees are less affected by the tick, because they clean it off better, and this, in turn, ensures the maintenance of healthy and strong families, their wintering, development, and productivity. And as a result, less labour and economic costs are required for the production of a unit of bee products. This trait should not be confused with the inadequate aggressiveness that occurs during uncontrolled interbreeding hybridisation (Cherevko *et al*., 2018; Kerek, 2020).

However, to develop appropriate genetic models and breeding strategies, it is necessary to consider the genetic aspects and population characteristics of honeybees. Petersen *et al.* (2020) point to the fact that obstacles to breeding honeybees are the lack of pedigree due to free mating, and low penetration of genetic improvement into the general population. The conducted studies of morphometric characteristics of bees of the Ukrainian steppe breed confirm the results of Ukrainian and foreign researchers on the level of purebred breeding in apiaries (Kerek, 2020). According to these characteristics, the belonging of bees to the breed with uncontrolled mating of the queen was 59.0%, and with the control of this process in time and space – 87.2%, which is 28.2% higher ($p < 0.001$). These results indicate that the level of hardware of bee colonies is at a high level, due to the fascination of amateur beekeepers with breeds that are not typical for the Vinnytsia oblast and Ukraine as a whole, and with such a rich drone background, the method of pedigrees along the maternal line is not enough. Apiary farms are recommended to organise a time-limited flight of queen bees or purchase more queens from certified breeders, which will ensure the disclosure of the productivity potential of bee colonies, their safety during wintering and resistance to infectious and invasive diseases.

The main breeding characteristics are a strong wintering ability, resistance to diseases, and different ability to collect nectar in the low and high honey harvest seasons (Panziera *et al.*, 2022). Maucourt *et al.* (2020) and Arechavaleta-Velasco *et al.* (2021) note that traits such as honey production, spring development, winter feed consumption, hygiene behaviour, and Varroa destructor infection are inherited. In addition, genetic correlations between these traits are positive or zero, and these traits can be used for the genetic selection of honeybees. In the conducted studies, bee colonies in which queens mated under control in space and time received 43.0% more honey, they were stronger by 15.7%, rebuilt the honeycomb by 27.3% more and consumed less Kandy in the spring by 31.9%.

Genetic improvement of the health and productivity of zoned honeybees through the genetic breeding programme is a sustainable solution that would reduce the import of honeybees and help support the Ukrainian honeybee industry. Genetic correlations between bee productivity, behaviour, worker bees, and the queen are established in the studies by Arechavaleta-Velasco *et al.* (2021), which also proposed models for assessing the breeding value of honeybees.

Research is underway to explore the diversity of reproductive and morphological traits that may be useful in breeding programmes to improve the productivity of honey bee colonies and their survival in modern conditions. Many phenotypic correlations are related to the size of queen bees, with weak correlations found between morphology and reproductive traits (Facchini *et al.*, 2021).

Cherevko (2018) states that the production of hybrids and the use of heterosis in purebred breeding is no less effective compared to crossing different breeds. In purebred breeding, the success of hybridisation is achieved due to the genetic diversity of bee colonies within the breed. The hybridisation process gives the phenomenon of heterosis in the first generation and such crosses can be carried out between different types of the same breed, which was confirmed by the research (Kerek, 2020), using the Carpathian bee breed and its subtypes *Vuchkovsky* and *Kolochavsky* (Kerek *et al*, 2017).

Papp also substantiates the effectiveness of using the newly created type of Carpathian bee breed *Synevyr* but despite the fact that this type proved to be the best in those sesearch conditions, the author allows hybridisation between adjacent types *Hoverla, Rakhiv* and *Vuchkivsky* to obtain the heterosis effect (Papp *et al.*, 2021). For example, for the Carpathian bee breed, the conditions for maintaining breed purity can be conditionally called somewhat simpler, due to a certain uniqueness of the area of the Carpathian region, the remote location of apiary farms among themselves, and the presence of virtually semi-closed flyovers, due to which the degree of crossbreeding is orders of magnitude less than on apiary farms in the forest-steppe.

Hrechka & Senchylo, O. (2022) investigated economically useful indicators, in particular, the winter hardiness of the Ukrainian steppe bees. In their work on the intra-breed type of the Ukrainian steppe breed *Hadyatsky* compared to the local population, they described the benefits of using breeding tools on the economic value of bee families, in particular on development and productivity. Holinei (2017), based on the results of the study, found that local breeds are crossbred and their morphological features are more characteristic of the Carpathian and Ukrainian steppe breeds, as a result, the honey productivity of these bee colonies decreases. During visual observation of bees by body colour, compliance with the standard of the Ukrainian steppe bee breed was revealed.

Conclusions

The results obtained suggest that families of the experimental group in which the queens mated under control in time and space have potentially better winter hardiness capabilities, as evidenced by a 31.8% lower ($p < 0.001$) need for feeding in the spring. They were stronger by 14.5% ($p < 0.001$), had higher honey productivity by 41.9% ($p < 0.001$), and rebuilt 22.1% ($p < 0.01$) more honeycombs. This reflects the negative impact on the productivity and safety of bees of uncontrolled crossbreeding, because the drone background potentially included about 250 families from other private apiaries located within a radius of 500m and about 170 more families located within a radius of 2 km, with queens of unknown origin.

According to morphometric and visual indicators, all families met the standard of the Ukrainian steppe breed: the average indicator of the cubital index was in the range of the breed 1.86-3.0, the hantel index – 0.829-1.113, and the discoid displacement – 1.89-5.68. However, in the samples, there were indicators that significantly went beyond the range of the breed in the control group, in the experimental group there were a small number of such indicators. Bees from queens mated by the free method of the control group had a degree of belonging to the Ukrainian steppe breed of 59.0%, in the experimental group, where queens mated according to the method of time and space restriction, this indicator was 87.2 % ($p < 0.001$). Some bee colonies of the control group did not clean the bottom of the hive well in the spring after wintering, 6 out of 22, so they needed increased attention from the beekeeper. Moreover, 9 out of 22 had a tendency to early production of offspring by bee colonies, which is not typical for the Ukrainian steppe bee breed and in the conditions of the Vinnytsia oblast, which led the families of the experimental group to lose part of the brood and noticeably weaken.

Further research will be aimed at studying the egg production of queen bees and the dynamics of bee brood development. The practical significance of the results is also used for conducting experiments on the influence of individual feed factors, microclimate factors for the use of new structural components of the hive on this breed, which is a determinant of the reliability and repeatability of the results, establishing patterns, and confirming the need to implement breeding programmes in beekeeping.

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Conflict of Interest

None.

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Морфометричні ознаки бджіл української степової породи залежно від способу контрольованого парування маток

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Анотація. Порода бджіл є важливим фактором, що визначає розвиток бджолиних сімей та продуктивність, оскільки вона впливає на виробництво меду, стійкість до хвороб, адаптацію до кліматичних умов та характеристики поведінки бджіл. Метою дослідження було встановлення залежності між способами парування маток і морфологічними ознаками бджіл української степової породи та продуктивними показниками бджолиних сімей. Для проведення досліджень у пасічному господарстві Вінницької області було сформовано 43 бджолосім'ї з бджоломатками-сестрами української степової породи, спарованих різними способами природного парування. За результатами парування в контрольній групі було 22 бджолині матки, дослідній – 21 матка. Матки першої контрольної групи спаровувалися звичайним природнім обльотом без будь-яких обмежень. Матки дослідної групи спаровувались за контролю в часі та просторі. За результатами досліджень встановлено взаємозв'язок між цілісністю колонії та її морфологічними ознаками і продуктивними показниками. Так, піддослідні сім'ї мають різні ступені приналежності до української степової породи, контрольної – 59% та дослідної – 87,2 % ($p < 0,001$). За кубітальним індексом перевага становила 8,2% ($p < 0,001$) на користь дослідної групи. Краща цілісність сімей за гантельним індексом прослідковується у сім'ях, в яких маток спаровували контрольовано у часі та просторі, з різницею у 3,32% ($p < 0,001$). У контрольній групі, де проводилося безконтрольне парування маток, за дискоїдальним зміщенням виявлено більше бджіл з перевищенням стандартного показника по породі. Сім'ї дослідної групи, порівняно з контрольними, були сильнішими на 14,5% ($p < 0,001$). Від них отримано більше меду на 41,9%, ними відбудовано більше стільників на 22,1% ($p < 0,01$), а потреба у підгодівлі канді була меншою на 31,8% ($p < 0,001$) менша. Крім того бджоли дослідної групи мали яскраво виражену гігієнічну поведінку та вимагали менше трудових затрат. Практичне значення дослідження полягає у можливості встановлення закономірностей дії факторів на конкретну породу та підтверджує необхідність реалізації селекційних програм у бджільництві

Ключові слова: гантельний індекс; кубітальний індекс; дискоїдальне зміщення; продуктивність; збереженість; кліматичні умови; витрати корму