өмір сүру жағдайының нашарлауына және олардың өлімінің артуына әкелді. Осыған байланысты ауыл шаруашылығында араларды қорғау, омарташыларды қолдау және омарта өндірісін оңтайландыру үшін цифрлық технологияларды қолданатын ара шаруашылығы (ТП) деп аталатын жаңа бағыт пайда болды.

Бұл мақалада Қазақстан Республикасындағы аралар тіршілігінің мониторингі үшін заттар интернеті (IoT) жүйесін және датчиктердің әртүрлі түрлерін пайдалануды қоса алғанда, ара шаруашылығы саласындағы соңғы жетістіктер қарастырылады. Деректерді жинау және талдау сипатталған, сонымен қатар қазіргі заманғы сын-қатерлер жағдайында ара шаруашылығының тиімділігі бағаланады. Мақалада ұсынылған шешімдердің тұрақтылығы мен ауқымдылығы, сондай-ақ олардың экономикалық шығындары қарастырылады.

Бұл мақала Қазақстан Республикасында ара шаруашылығының дамып келе жатқан технологияларына шолу мен пайдалану әлеуетін ұсынады. Бұл елдегі ара шаруашылығын қорғау және қолдау үшін инновациялық тәсілдерді қолдануға мүдделі омарташылар, зерттеушілер және өнеркәсіптік кәсіпорындар үшін пайдалы ресурс бола алады.

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# ПРОГРАММНОЕ ОБЕСПЕЧЕНИЕ В МОРФОМЕТРИИ ДЛЯ ОПРЕДЕЛЕНИЯ ПОРОДНОЙ ПРИНАДЛЕЖНОСТИ МЕДОНОСНЫХ ПЧЁЛ
# SOFTWARE IN MORPHOMETRY FOR DETERMINING THE BREED AFFILIATION OF HONEY BEES

## ANNOTATION

In modern beekeeping, an important role is played by the use of technologies that help to manage the processes of selection and breeding work on bee families as efficiently and accurately as possible. One of these tools was morphometric analysis, a method used to study the shape, structure and size of various parts of the body of bees.

Morphometric analysis provides valuable information about many aspects of bee life. It allows beekeepers to assess the health status of bees, their reproductive capabilities, as well as to detect possible pathologies or deviations. Thus, morphometric analysis is a key element in ensuring the productivity and health of bee colonies.

Modern technologies greatly simplify and accelerate the process of morphometric analysis. There are many software solutions on the market designed specifically for morphometric analysis in beekeeping. They offer a variety of functionality, including automated measurements, data visualization, statistical processing, and more.

The article combines an overview on the issue of software for conducting morphometry of honey bees and recommendations on the choice and use of this software. The software for classical and geometric morphometry was systematized and analyzed according to their functional capabilities.

***Key words:*** *bees, beekeeping, morphometry, geometric morphometry, software.*

**Introduction.** Classical morphometric analysis is based on studying and comparing the size and shape of different parts of the body of bees [1]. Initially, this analysis was carried out manually, requiring considerable time and high accuracy, since even small errors could lead to erroneous conclusions. A large number of samples was necessary for the reliability of the results, which further increased labor costs. However, this method has been an invaluable source of information, improving our understanding of bee biology and breeding efficiency.

The development of computer technologies has led to a significant simplification and acceleration of morphometric analysis. State-of-the-art software solutions automate the analysis of sample images, perform accurate measurements, and provide extensive data for analysis. This not only saves time for performing the analysis, but also increases its accuracy, eliminating the possibility of human error.

DuPraw first applied the concept of numerical taxonomy to the classification of honey bees [2, 3, 4], andё its further development was continued thanks to the work of Ruttner and his colleagues [5]. Ecotypes or races usually differ slightly in the average values of some characteristics, so additional statistical analyses are required to distinguish them [2, 3, 4].

Kozhevnikov paved the way for morphometric analysis of individual chitin components of bees [6]. In his monograph "Materials on the natural history of the bee (Apis mellifera L.)" [6, 7], he carefully studied the existing data on the genus Apis, in particular, Apis mellifera L. Based on his morpho-anatomical studies, Kozhevnikov formulated a number of conclusions regarding the taxonomy of the genus, morphology and anatomy of bees. This work was continued in the studies of his student Alpatov and Mikhailov.

Since the beginning of Kozhevnikov's research, morphometry has involved the study of various types of characteristics, including color features, linear and angular dimensions, and computational characteristics such as indices and sums. The latter were supplemented with another feature - "wing shape", which is used in" geometric morphometry " [6].

The front wing of a bee has the largest number of measurements, indices, and data for analysis [8, 9]. However, due to the lack of generally accepted standards, there are differences in the measurement and analysis of wing morphometric characteristics. The wing venation pattern is of particular interest in the taxonomy of insects in general, and therefore different methods of morphological analysis of the forewing are currently used.

Wing morphometry, based on classical principles, includes the analysis of a variety of physical characteristics of the wing, including its length and width [1], as well as the structure of the veins. DuPraw made a significant contribution to the introduction of angle measurement in the practice of bee morphometry, identifying 17 key angles [2]formed at the junction of wing veins. Subsequently, Ruttner revised this approach and reduced the number of measured angles to 11 [5, 9] (Figure 1).

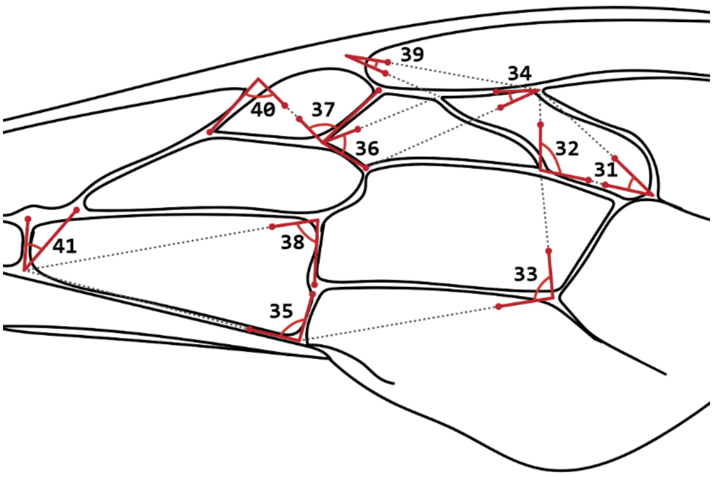


Figure 1 – 11 corners located between the centers of intersections of the veins on the right front wing according to Ruttner [9], the numbering is the author's.

Modern research continues to develop new approaches and technologies that allow for a deeper understanding of the anatomy and functions of bees. It is important to constantly review and adapt existing methodologies to ensure that they are relevant and effective in the light of new discoveries and technological innovations.

Modern research in the field of morphometry increasingly involves the use of geometric morphometry [10, 11, 12], and the methodological basis for this approach was formulated in the works of Thompson d'Arcy [13]. Geometric morphometry is an effective analytical tool based on the theory of shape, allowing you to work with the coordinates of placemarks, which, in the context of studying the anatomy of bees, are located at the intersections of the veins of the bee wing.

The advantage of geometric morphometry is that numerical data is represented in the form of geometric images [14]. This improves the visual perception of the objects under study and provides researchers with a more accurate perspective.

Working with this method begins with superimposing objects of research on their centroids at the intersection of the axes of space. The centroid dimensions of objects are then normalized to one, which allows them to be aligned and eliminates the influence of the"size factor". Alignment is achieved through an isometric transformation that minimizes the difference between the values of centroids calculated for all labels (Procrustes method), or for the selected pair of labels (baseline method). The subsequent isometric "rotation" of objects relative to the reference serves to minimize the total difference in coordinate values for all [15].

Taken together, geometric morphometry is a powerful tool for studying bee anatomy, complementing and developing classical morphometric methods. As a result of applying this approach, a deeper and more accurate understanding of the structure of the objects under study is achieved.

**Relevance**. Morphometric analysis has become a fundamental tool in a number of scientific fields, including biology, medicine, anthropology, geology, and even in such fields as archaeology and art. Studying the shape and structure of objects can provide valuable information about interactions between organisms and their environment, evolutionary changes, pathological conditions, and other important aspects. In the context of beekeeping, morphometric analysis helps to determine the breed affiliation and line of the colony under study, which allows for better selection, breeding and research work.

Currently, there are many software solutions available for morphometric analysis, each of which has its own characteristics, advantages and disadvantages. However, there is still no clarity in the scientific community as to which of these tools are most suitable for specific research purposes.

This makes reviewing and evaluating the available software for morphometric analysis an urgent task. Providing objective, informed and accessible information will help researchers choose the most appropriate tools for their tasks, improving the efficiency and accuracy of research, as well as reducing the time and cost of training and adapting to new software.

**Materials and methods of research.** During the preparation of this review, systematic selection and evaluation criteria were used for software designed for morphometric analysis. Our goal was to cover both commercial and free software, as well as take into account open source software.

Theselection criteria were aimed at programs that are the most popular and widely used in the scientific community, and which are designed specifically for morphometric analysis.

The software evaluation took into account the following criteria: functionality (including the ability of the software to process various types of data and perform basic and advanced morphometric analysis tasks), usability, availability and quality of training resources, cost, and compatibility with various operating systems.

Information for the review was collected through a systematic review of the scientific literature, official websites, and software manuals. We also used each of these software solutions to perform morphometric analysis test tasks to gain practical experience with them. A survey of specialists in the field of morphometry was conducted to get their opinions and feedback on the software.

Each of the considered software is described in detail in the corresponding section of the review. These descriptions include general information about the program, information about the developer and version of the program, an overview of the main features, a description of the user interface, and information about available training resources.

After describing each software, we performed a comparative analysis based on the evaluation criteria mentioned above. This includes direct feature comparison, test task results, cost analysis, and overall value assessment for potential users in the scientific community.

**Research results.** The methodology for measuring the morphometric characteristics of a bee's wing has undergone a significant evolution since the beginning of the 20th century [16], when researchers such as Kozhevnikov, Alpatov, and Mikhailov used manual measurement methods. With the advent of new technologies, combined approaches have been developed, including analog and digital equipment, as well as specialized software, which has led to a significant increase in measurement accuracy [17, 18].

An important step in morphometric analysis is to obtain a digital image of the object. Various systems are used for this purpose, and they can be divided into the following categories:

1. Systems based on the use of microscopes, macroscopes, stereomicroscopes, and other similar devices. Various digital video and still cameras without a lens, mounted on microscopes using special adapters, are used as image capture devices. When using these devices, make sure that there is no optical distortion.

2. When using a flatbed scanner to scan the prepared product, it is important to perform the procedure quickly enough to avoid dilution of glycerol and leakage of moisture, which can degrade the quality of the resulting image and complicate measurements. To protect the scanner glass and speed up the process, we recommend using a transparent film.

A key role is played by software that is specialized for image analysis and allows you to perform accurate measurements. Unlike manual measurements, the corresponding software allows you to measure polylines, angles, areas, and so on.

For further analysis, you need to perform placemark placement and then get the placemark coordinates file. One of the most common programs with the necessary functionality is TpsDig2 [19]. TpsDig2 is a software developed specifically for digitizing landmarks and contours used in geometric morphometric analysis. The program was developed by F. James Rohlf at Stony Brook University One of the features of the program is the ability to perform various operations to improve the image, including zooming, adjusting the image brightness profile, as well as support for AVI and MOV files.

The output data of the program is presented in TPS format, the files of which include the name of the image file for each sample [20]. This allows you to visualize landmarks directly on the corresponding image. Files in the TPS format are created in the standard ASCII format, which makes it possible to edit them and convert them to other formats for use in various software [21].

In addition, TpsDig has functionality for calculating the areas of closed areas, perimeters, and linear distances, which can be useful for more detailed morphometric analysis. Thus, this program is a powerful tool for working in the field of geometric morphometry.

WingsDig is a program that specializes in digitizing bee wings (Figure 3) [22]. The software is very similar to TpsDig2, but despite the similarity in operating modes and command set, the philosophy of working in WingsDig is significantly different. The program was developed by I. Dovgunyk for the Association of Sailors of Ukraine and is available for free use for non-commercial purposes.

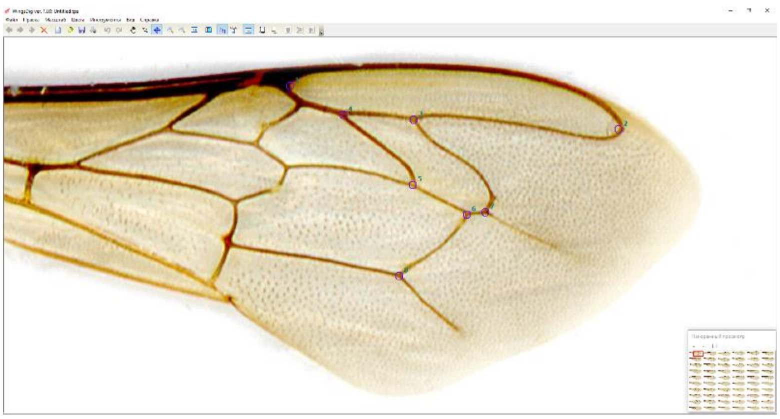

Figure 2-WingsDig software. Interface for dotting (digitization).

One of the unique features of WingsDig is the presence of a permanent internal " TPS object "(file template), which is created when the program is loaded. This TPS object contains (or may contain) a collection of images of bee wings (or scans), each of which, in turn, includes (if digitized) a set of points.

Thus, WingsDig provides users with the ability to performa thorough and detailedую digitization of bee wings, with a particular focus on geometric morphometry.

PhyloNimbus is a web-based application specifically designed for researchers working in the field of morphometry, including geometric morphometry [23, 24]. It provides functionality for collecting two-and three-dimensional landmarks, linear measurements, as well as curves and semicircular marks.

One of the main advantages of PhyloNimbus is its flexibility: it is able to load coordinates in various file formats, which makes it as convenient as possible for researchers working with a variety of data types.

In addition, the app is highly compatible, supporting a variety of operating systems, including Windows, Mac, and Linux, as well as all major browsers. This makes PhyloNimbus easy to use and accessible to a wide range of users, regardless of their technical platform. When working with the program, pre-registration in the web application is required.

StereoMorph is a software package for R (a programming language for statistical data processing and graphics) [25]that provides tools for collecting 2D and 3D landmarks and curve data. It includes a web application for digitization, functions for automatic calibration using two or more standard digital cameras using a simple checkerboard. In addition, StereoMorph provides functions for restoring, aligning, and combining sets of three-dimensional landmarks and curves [26].

This software package is cross-platform, supporting Mac, Windows, and Linux operating systems. With compatibility with most web browsers, including Chrome, Firefox, and Safari, it provides a user-friendly and flexible experience for researchers.

The authors of StereoMorph are Aaron Olsen and Annat Haber, researchers specializing in biology and geometric morphometry. This is a tool developed by researchers for researchers, which makes it tailored to the needs and flow of work specifically in this area. The complexity of working with a software package is the need for knowledge and experience with the R programming language.

CooRecorder is a commercial program designed to register the coordinates of points selected in digital images [27]. The program is part of the CooRecorder+CBeeWing software package, where CooRecorder performs the point placement function. It is a useful tool for researchers and professionals working with large amounts of data that require statistical analysis.

The program's functionality allows you to scan objects using a standard computer scanner or even a film scanner if the objects are small and transparent. The resulting image can then be displayed on a computer screen, magnifying it for easy viewing and analyzing details.

The CooRecorder program significantly facilitates the process of registering the coordinates of points of interest in the image. Instead of manually recording the coordinates of each point, the user simply clicks on the points of interest in the image, and their coordinates are automatically recorded in a file. This file can then be used for analysis in another program, which significantly saves time and reduces the possibility of errors during manual data entry.

Modern approaches to morphometry analysis include manual, semi-automatic, and automatic measurement modes [28]. Although these latter methods can significantly reduce analysis time and increase the accuracy of bee species identification, they require high-quality images to be used effectively.

The research process in morphometry begins with the systematic collection of data through precise measurements, which are usually recorded in a specialized notebook. When using computer-based measurement tools, the data can be directly transmitted to the appropriate software capable of mathematical data processing. An important step is to check the obtained data for compliance with the results calculated manually using formulas presented in the specialized literature.

After data is collected and verified, they are transferred to computer software for mathematical processing. The software used depends on the level of complexity of the task: MS Excel can be used for simple tasks, while more complex methods of multivariate statistical analysis, such as principal component analysis (PCA), canonical analysis (CVA), and discriminant analysis, require more advanced software, such as Statistica [29].

In the analysis process, only primary, measurable features are used, excluding their sums or indices. Two main methods are often used: PCA and k-means clustering. These methods are used to determine whether the test samples represent one or more groups. If the groups have been clearly defined, the data is further analyzed using discriminant analysis, which helps determine the significance of group differences and the accuracy of redistributing samples into groups.

However, keep in mind that the sample structure may create the illusion of two or more distinct groups, especially if the sample is heterogeneous. Differences found in non-uniform sampling may disappear with a more uniform sample. It is also important to remember that true groups are often characterized by dramatic morphological changes that depend on their geographical origin.

CBeeWing is a commercial specialized software designed for analyzing points registered in the CooRecorder program. This is part of the CooRecorder+CBeeWing software package, where the main function of CBeeWing is to analyze these points [27].

The main task of this software is to analyze morphometric indices, including the cubital index (Ci), dumbbell index (Hi), and discoidal displacement (DsA). These metrics are used to characterize the shape and structure of a bee's wing [10, 11, 30].

CBeeWing performs its analytical function, focusing mainly on two bee breeds: Apis mellifera mellifera and Apis mellifera carnica. This reflects the program's focus on analyzing the wing morphometry of these particular species.

Identify, developed by Adam Tofilski [31], is a software for semi-automatic classification based on the principles of geometric morphometry. This tool was originally developed for identifying insect species, but its use is not limited to this: it can be used to classify any objects whose shapes represent differences.

Identifycan also be used as an alternative to TpsDig2 for two-dimensional digitization of landmarks (Figure 3-A). Currently, this software is mainly used for identifying subspecies and pedigrees of honeybees (Figure 3-B).

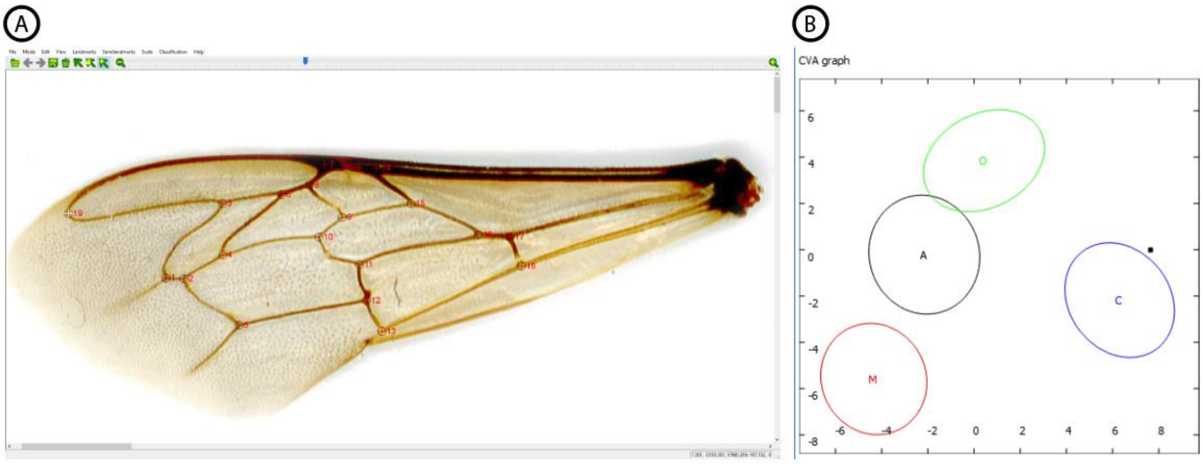

Figure 3 – Identify software. A: dotting interface. B: interpretation of the results of the analysis of pedigrees.

A unique feature of Identify is its flexibility in setting up classification. The user can configure or create new classification templates in XML format in accordance with research goals, provided that they have the necessary knowledge in the field of working with XML.

"Breed by Wings" is a software solution developed by Anatoly Kartashev based on Excel and VBA (Visual Basic for Applications). This tool is designed to analyze data in TPS format based on eight points on bee wings [32].

The program specializes in data analysis of four bee breeds: Apis mellifera mellifera, Apis mellifera Caucasica, Apis mellifera Ligustica and Apis mellifera carnica. The analysis uses metrics such as the qubital index (Ci), dumbbell index (Hi), and discoidal offset (DsA) (Figure 4).

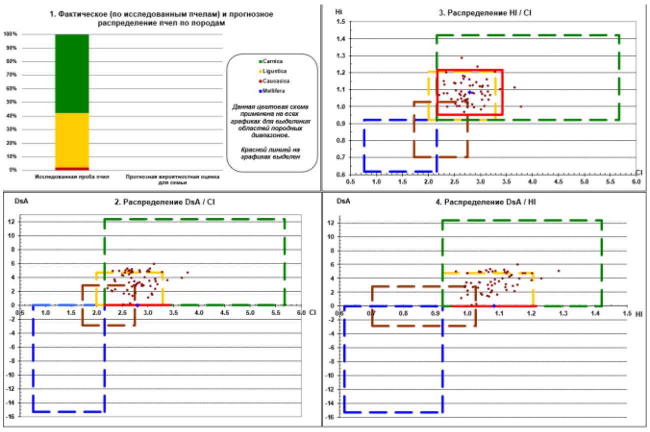


Figure 4 - Software "Breed by wings". Interpretation of results based on indexes.

After analyzing these metrics, the program compares the results obtained with the breed ranges, thus revealing the breed affiliation of each sample. So, "Breed by wings" is a simple and useful tool for determining the breed affiliation of bees based on the analysis of their wings.

MorphoXL is a software solution developed by I. Dovgunyk based on Excel and VBA (Visual Basic for Applications). This tool was created to analyze data in TPS format based on eight reference points [33].

The program is able to analyze data from five bee breeds: Apis mellifera mellifera, Apis mellifera Caucasica, Apis mellifera Ligustica, Apis mellifera carnica and Apis mellifera sossimai. The analysis uses indicators such as the cubital index (Ci), dumbbell index (Hi), and discoidal displacement (DsA).

After performing the analysis, MorphoXL compares the obtained values with the breed ranges, on the basis of which it makes a conclusion about the breed affiliation of each sample.

It should be noted that the program has a limit on the number of processed samples-no more than 100 wings per analysis. To work with MorphoXL, you must have MS Excel installed, since the program operates on its basis.

Apislab Portable is an advanced software solution developed on the basis of Excel and VBA (Visual Basic for Applications). This solution was created at the Kazakh Research Institute of Animal Husbandry and Feed Production, which is located in Almaty, Kazakhstan [34]. This product was the result of further development of the ideas laid down in the software solutions " Breed by wings " [32] and" MorphoXL " [33].

The essence of Apislab Portable is to analyze TPS data, which is based on marks made at eight or twelve points. At the same time, the program is able to process information about five breeds of honey bees, including Apis mellifera mellifera, Apis mellifera Caucasica, Apis mellifera Ligustica, Apis mellifera carnica and Apis mellifera sossimai.

When performing an eight-point analysis, Apislab Portable extracts data for parameters such as the qubital index (Ci) (Figure 5), dumbbell index (Hi), and discoidal offset (DsA). After that, it compares the data obtained with breed ranges, which allows you to determine the breed affiliation of each studied specimen.


Figure 5 – Apislab Portable Software.Interpretation of the results: frequency of distribution of the qubital index.

In addition, the program also has the ability to analyze TPS data at twelve points. This advanced analysis provides additional information about the precubital index (PCi), as well as two experimental indices: the EDHP offset and the EDBH offset.

Apislab Portable is integrated with MS Excel and requires it to work correctly. This means that before using the software solution, you must install MS Excel on your desktop device. This simple and convenient solution allows you to perform complex data analysis directly in the software environment that many users are familiar with.

Based on the obtained data, a comparative table was compiled during testing (Table 1), in which the software under study was compared in terms of the availability of image digitization functionality (dot placement), data analysis and interpretation, which implies assigning significant conclusions to data. Within the framework of the study, such conclusions are the definition of breed affiliation or the ratio to bee lines. The data can only be interpreted if the software contains, or allows you to import, a reference database for breeds or lines. Also, an important characteristic of the software is its availability or free of charge, most of the software in question is free for non-commercial use. A secondary characteristic is the support of the operating system of a particular system. Since all the software under consideration supports working from under the Windows operating system, you should pay attention to supporting other operating systems, if you work from under them.

Table 1 – Comparative table of morphometry software

| Name | Features | | | | | | |
|---|---|---|---|---|---|---|---|
| | Digitization of images | Data analysis | Free of charge | Free | Windows support | Linux support | macOS support |
| support | TpsDig 2 yes | no | no | yes | yes | no | no |
| WingsDig | yes | no | no | yes | yes | no | no |
| PhyloNimbus | yes | yes | no | yes | yes | yes | yes |
| StereoMorph | yes | yes | no | yes | yes | yes | yes |
| CooRecorder | yes | no | no | no | yes | no | no |
| CBeeWing | no | yes | yes | no | yes | no | no |
| Identify | yes | yes | yes | yes | yes | no | no |
| "Breed by wings" | no | yes | yes | yes | yes | no | no |
| MorphoXL | no | yes | yes | yes | yes | no | no |
| Apislab Portable | no | yes | yes | yes | yes | no | no |

**Conclusion**. Morphometric analysis has become a valuable tool in beekeeping, allowing researchers and beekeepers to study the physical characteristics of bees and link them to genetic factors, the health and productivity of bee colonies. While historically this analysis was limited by the speed and accuracy of manual measurements, the development of computer technologies, especially artificial intelligence and neural networks, offers new opportunities for improving and automating morphometric analysis.

However, it is important to emphasize that the choice of software for morphometric analysis should be justified not only by its technical characteristics, but also by the research or application goals, as well as by the availability and training requirements. Switching to automated analysis also requires a deeper understanding of statistics and morphometry.

It is important to keep in mind that any software that provides results about pedigrees or lineages bases its analysis on a built-in database or reference data. These data are pre-collected and analyzed information sets that are used as a reference or reference point for subsequent analyses.

For example, when determining the bee species, the program can compare the obtained data with the already known characteristics of various breeds stored in its database. Thus, the analysis is based on already existing data provided by the program, and its accuracy largely depends on the accuracy of this reference data.

However, it should be noted that breed ranges by index, i.e. ranges of values of certain characteristics that are considered typical for a particular breed, may not be described for all breeds. This means that if you try to determine breed membership for an animal whose breed is not included in the program's reference data, the program may not provide an accurate answer.

Therefore, when you use software to determine breed affiliation or lineages, it is important to be aware of these limitations and take them into account when interpreting the results obtained.

Based on our research and our review, we recommend the following:

1. Conduct a detailed study: before choosing a specific program for morphometric analysis, it is recommended to conduct a detailed study of the various available options and make sure that they meet your requirements and goals.
2. Get the necessary training: therapid application of morphometric analysis software requires an understanding of its functions and operation.
3. Be prepared for changes: тtechnologies continue to evolve, and this should be taken into account when planning for the future. Be prepared for the new opportunities that new developments in the field of AI and neural networks can offer.

In conclusion, bee morphometry is an important tool for understanding and improving beekeeping. The use of modern technologies, such as artificial intelligence and neural networks, promises to provide new opportunities for improving this approach.

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**ТҮЙІН**

Қазіргі ара шаруашылығында ара колонияларында селекциялық-асыл тұқымды жұмыс процестерін барынша тиімді және дәл басқаруға көмектесетін технологияларды қолдану маңызды рөл атқарады. Осындай құралдардың бірі морфометриялық талдау болды-аралар денесінің әртүрлі бөліктерінің пішінін, құрылымын және өлшемдерін зерттеу үшін қолданылатын әдіс.

Морфометриялық талдау аралар өмірінің көптеген аспектілері туралы құнды ақпарат береді. Бұл омарташыларға аралардың денсаулығын, олардың репродуктивті мүмкіндіктерін бағалауға, сондай-ақ ықтимал патологияларды немесе ауытқуларды анықтауға мүмкіндік береді. Осылайша, морфометриялық талдау ара колонияларының өнімділігі мен денсаулығын қамтамасыз етудің негізгі элементі болып табылады.

Заманауи технологиялар морфометриялық талдау процесін едәуір жеңілдетеді және жеделдетеді. Нарықта ара шаруашылығында морфометриялық талдау жүргізу үшін арнайы әзірленген көптеген бағдарламалық шешімдер бар. Олар әртүрлі функционалдылықты ұсынады, соның ішінде автоматтандырылған өлшеу, деректерді визуализациялау, статистикалық өңдеу және т.б.

Мақалада бал арасының морфометриясын жүргізуге арналған бағдарламалық жасақтамаға шолу және осы бағдарламалық жасақтаманы таңдау және пайдалану бойынша ұсыныстар біріктірілген. Классикалық және геометриялық морфометрияға арналған бағдарламалық жасақтама олардың функционалдығы бойынша жүйеленген және талданған.

**РЕЗЮМЕ**

В современном пчеловодстве важную роль играет применение технологий, которые помогают максимально эффективно и точно управлять процессами селекционно-племенной работы над пчелиными семьями. Одним из таких инструментов стал морфометрический анализ – метод, используемый для изучения формы, структуры и размеров различных частей тела пчел.

Морфометрический анализ предоставляет ценную информацию о многих аспектах жизни пчел. Он позволяет пчеловодам оценить состояние здоровья пчел, их репродуктивные возможности, а также обнаружить возможные патологии или отклонения. Таким образом, морфометрический анализ является ключевым элементом в обеспечении продуктивности и здоровья пчелиных семей.

Современные технологии значительно упрощают и ускоряют процесс морфометрического анализа. На рынке существует множество программных решений, разработанных специально для проведения морфометрического анализа в пчеловодстве. Они предлагают различные функциональные возможности, включая автоматизированные измерения, визуализацию данных, статистическую обработку и многое другое.

В статье совмещен обзор по вопросу программного обеспечения для проведения морфометрии медоносной пчелы и рекомендации по выбору и использованию данного программного обеспечения. Программное обеспечение для классической и геометрической морфометрии было систематизировано и проанализировано по их функциональным возможностям.