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Bee anatomy: a comprehensive overview of bee morphology and physiology

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Abstract

The species and anatomy of the bee, a member of the insect class (Insecta), have very interesting importance. Although there are many production-oriented studies on bees and beekeeping in our country, it is very important to get enough information on general morphological structures, bee anatomy, bee biochemistry, bee segments, hive systematics, etc. Bees play a major role in the production of pollinators and various food crops, which are very important for the ecosystem. Therefore, understanding the morphology of bees and accessing accurate information is vital for sustainable agriculture and food security. In addition, our country is a bridge between Asia and Europe and constitutes a very important habitat for bees. However, it is very difficult to reach sufficient resources and products, especially on bee anatomy, bee behavior, and beekeeping. For this reason, in this article, bee morphology, various bee races, division of labor in the hive, reproduction stages, and social order of bees are discussed in detail.

Keywords: Bee Anatomy, Bee Biochemistry, Bee Segments, Hive Systematics

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Arı anatomisi: arı morfolojisi ve fizyolojisine kapsamlı bir bakış

Öz

Böcekler sınıfının (Insecta) bir üyesi olan arının türleri ve anatomisi oldukça ilgi çekici bir öneme sahiptir. Ülkemizde arılar ve arıcılık üzerine üretime yönelik birçok çalışma olmasına rağmen, arıların genel morfolojik yapıları, arı anatomisi, arı biyokimyası, arı segmentleri, kovan sistematiği vb. konularda yeterli bilgi edinilmesi oldukça önemlidir. Arılar, ekosistem için çok önemli olan tozlayıcıların ve çeşitli gıda ürünlerinin üretiminde büyük rol oynamaktadır. Bu nedenle arıların morfolojisini anlamak ve doğru bilgiye ulaşmak sürdürülebilir tarım ve gıda güvenliği için hayati önem taşımaktadır. Ayrıca ülkemiz Asya ve Avrupa arasında bir köprü konumunda olup arılar için çok önemli bir habitat oluşturmaktadır. Ancak özellikle arı anatomisi, arı davranışları ve arıcılık konularında yeterli kaynak ve ürüne ulaşmak oldukça zordur. Bu nedenle, bu makalede arı morfolojisi, çeşitli arı ırkları, kovandaki iş bölümü, üreme aşamaları ve arıların sosyal düzeni detaylı olarak ele alınmıştır.
Anahtar Kelimeler: Arı Anatomisi, Arı Biyokimyası, Arı Segmentleri, Kovan Sistematiği

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1. Introduction

Around 100,000 insect species around the world are classified in taxonomy. Bees include around 23,000 species within this class. Bees are a type of insect that has adapted in a give-and-take relationship with other living things in the ecosystem and evolved over millions of years. In a bee colony, there are three different species: queen bees, worker bees, and drones. The queen and worker bee are female individuals and are formed from fertilized eggs. Drones develop from unfertilized eggs. The queen controls important mechanisms such as creating new generations by laying eggs, preparing the bees in the colony for the honey season with the hormonal scent of pheromone, encouraging worker bees to collect pollen, and controlling the hive's water needs [1]. Under normal conditions, worker bees perform all the work in the hive with extraordinary cooperation, except for laying eggs. These include nectar and water transportation to the hive, wax secretion and comb building, royal jelly secretion, queen and brood care, hive cleaning and ventilation, and honey ripening [2]. All body parts of the bee can be categorized into three thoracic parts, six visible abdominal parts, legs, and antennae. These parts are largely covered by a layer of hair to help the bee collect pollen and regulate body temperature. The developmental stage of a bee consists of 4 different periods: egg, larva, pupa, and adult. The period inside the comb cell (the brooding period) lasts 16 days for the queen, 21 days for the worker bee, and 24 days for the drone. The queen lays unfertilized eggs in large cells and fertilized eggs in small cells according to the size of the honeycomb cell. The head is located in the front part of the bee's body, and the surface of the chitinous skeleton is covered with hairs. The head is connected to the thorax by a thin, playful neck. On the head are the eyes, sensory structures (sensilla), feeding organs, and mouthparts (figure 1) [3–7].

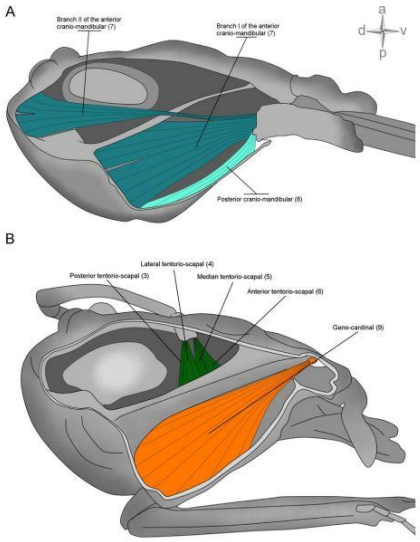

Fig. 1. External head muscles of Megalopta sodalis (Halictinae). A, *Sagittal muscle*; B, *mandibular, antennal and maxillary muscles* [8].

The eyes of the bee; consist of two types of eyes, three simple eyes (osel eye, point eye) in addition to a pair of compound eyes (comb eyes) in the form of honeycombs. compound eyes; It is used for the bee to see long distances and to distinguish between structures and colors. Simple eyes, on the other hand, enable the bee to see in low light and up close [9]. Each simple eye consists of thousands of subunits. compound eye; It consists of 4,000 simple eyes for the worker bee, 3,000 for the queen, and more than 8,000 for the drone. Each unit of the eye sees a small part of the object, and then the image becomes clear with the combination of the images, thus the vision event is provided [10]. Antennas called sensors are in a pair in the middle of the head. Antennae are covered with sensitive hairs. The antennae structures, which are short in size, are articulated and have the ability to move in all directions by the muscles (figure 2). These jointed structures consist of different numbers of knuckles in queen bees and worker bees. It consists of 12 nodes in queen bees and 13 nodes in worker bees. The task of the sensors; enables us to taste, smell, feel by touch, and estimate distance, and it does this thanks to the hairs that cover the antennae. Bees have the ability to sense wind speed and air temperature with the help of nerve endings in the antennae [11].

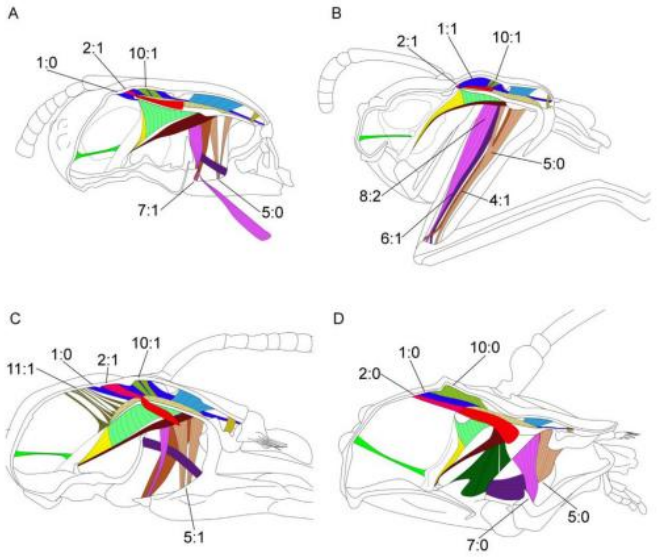

Fig. 2. Comparative morphology of Apidae female bee head exoskeleton muscles, side view. A, *Hylaeus sp. (Colletinae*); B, *Agapostemon semimelleus (Halictinae);* C, *Scaptotrigona bipunctata (Apinae);* D, *Trypoxylon lactitarse (Crabronidae)* [4].

Because bees' antennae are highly sensitive, they can easily smell honey from a distance. The mouth parts of the bees perform the sucking and chewing processes. The mouth structure of bees includes the upper lip, upper jaw, lower lip, and lower jaw parts. Thanks to the main and auxiliary jaws; honeycomb formation is provided, the enemy is neutralized and the wax is kneaded by crushing [12]. Since its jaw is straight, it does not damage the skin of the fruits and therefore does not cause any harm to agriculture. It has 80 knuckle tongues that can move in all directions. Depending on the bee breed, the tongue length varies around 6-7 mm and is very thin. In the middle part of the tongue, there is a canal covered with very small hairs. The nutrients reaching the mouth by passing through the channel are absorbed through this channel. The organ responsible for the suction task is the suction pump. This pump is a large muscular sac located in the head. The salivary secretions are responsible for moisturizing the nutrient material [13]. The taste organ, which allows the removal of jelly-like liquids that the tongue cannot grasp, is called the spoon (tassel). The tongue structure bends inwards after fulfilling its function. The thorax consists of 3 rings called segments, and these segments are called prothorax (anterior chest), mesothorax (mid-chest), and metathorax (posterior chest). The chest, which is the center of the bee's ability to move; has two pairs of wings; It consists of three pairs of legs, front, middle and rear. For this reason, they are also called six-legged in the class of insects to which bees belong. The chest area is composed of muscle tissue and is the power generation center because it contains heat and a large amount of mitochondria. All of the wings and legs are located on the thorax. The first ring structure of the abdomen is combined with the last ring structure of the thorax. These wing and leg structures found in the bee are in a pair from each segment of the three anterior segments [14]. Apart from the ability to move; one pair of forelegs do head and antennae cleaning, and a pair of middle legs provide hold. It fills the pollen into the pollen basket from the thorax and from the front legs to the hind legs; The hind legs, on the other hand, take part in transporting the pollen to the hive with the pollen basket above it. The brush and pollen sac are on the back two legs. The brush consists of many hairs located under the shin of the leg and their ends pointing downwards [15]. Pollen sac; It is a triangular-shaped bag covered with hairs in which the bee collects propolis and pollen. The Trachea located in the chest in the form of two pairs provide breathing through a transparent tube. Their two pairs of wings consist of two very thin membranes and are supported by chitinized veins [16]. The wings have four wings, one on each side, on the last two segments of the bee. The front wings are more veined and wider, and

these wings fulfill the function of flying, guiding during flight, and staying stationary in the air for a certain period [17]. Bees flap their wings 190 times per second and move at a speed of 25 km/h. The abdomen is separated from the thorax by a thin knuckle. Abdominal part including the needle, stomach, intestines, reproductive organs, nasanof (fragrance) glands, digestive organs, and wax glands; consists of sections called the abdominal segment (abdomen). The wax glands disappear as the bee ages [18]. Comparative morphological studies in bees are mostly limited to the skeleton, and the musculature of bees has not been investigated in this respect. Here we explore the head's external musculature from an evolutionary perspective. The musculature of 34 bee species belonging to six main lineages and 26 tribes and two opioid wasps were described, illustrated, and compared [19]. A standardized terminology for extrinsic musculature has been proposed and aligned with the Hymenoptera Anatomy Ontology (HAO). The abdomen is connected to each other by thin and elastic membranes, and the bee can easily move its abdomen with these elastic membranes. Thanks to these membranes, the mobility required for the digestive, respiratory, and circulatory organs in the abdomen is provided. The abdominal structure consists of these parts. The sections consist of the sternum in the lower part and the tergum in the upper part. The parts where the segments overlap are called the lower sternum. There are salivary glands, chin glands, and subpharyngeal glands in the abdomen. While the chin gland provides the production of royal jelly, which provides nutrition for the worker bee, it is the source of the chemical called pheromone in the queen bee. There are 10 abdominal segments in the larva of the honey bee, but in a mature bee, there are 9 abdominal segments as the first abdominal segment is included in the thorax. Since the last abdominal segments of the female worker bee and queen bee differentiate to form the sting, there are 6 abdominal segments and 7 abdominal segments in the drone [20]. Worker bees have wax sacs in the last four segments of the abdomen, from which wax is secreted. The scent glands that provide communication with other bees are located on the dorsal side of the abdominal segments. The needle part consists of saw-like protrusions at the end of the abdomen and is a pointed organ used for defense in queens and worker bees. The needle is attached to the venom sac. Because the sting is notched, the worker bees retract the sting after stinging the living thing. bee family; It contains three different individuals, namely queen bee, drone and worker bee [21].

1.1. Queen Bee

Although it is also known as the queen bee, there is only one in the colony outside of the main renewal time. It is like the mother of the other bees in the colony. The queen bee, consisting of a fertilized egg, has an incubation period of 16 days. She is the only female in the hive to reach sexual maturity [20]. It is selected when it is in the form of a larva by worker bees, and it is distinguished from other species because it is fed with royal jelly until it reaches a certain sexual maturity. Its role in the colony; These can be listed as encouraging the worker bees responsible for collecting pollen, providing the water requirement in the colony, ensuring the formation of new bees by laying eggs, and maintaining the continuation of the generation. This control is carried out by hormonal secretion called pheromone [17]. Queen bee; It ensures its development in a special eye of its own. 6-7 days after it leaves the room it is in, it goes on a mating flight with suitable conditions (sunny, windless weather) and secretes a chemical called pheromone and the drones follow the queen [22]. The queen, which mates with 8-10 drones during flight, takes millions of sperm cells from the drone while mating. If mating is completed, it returns to the hive and starts to lay eggs after 7 days. The queen bee, which cannot complete her mating, goes on a few more mating flights in the following days. pheromone chemical; While there is a queen in the colony, it prevents the formation of a new queen, ensures the development of the ovaries of the worker bees and is responsible for the order in the colony. If the queen bee in the colony is destroyed for some reason and the queen cannot grow, the ovaries of a few of the worker bees develop and form a false queen, and these bees are formed from infertile eggs. The queen bee provides its nutrition and cleaning with worker bees [23–25]. It cannot feed itself, worker bees feed the queen by giving royal jelly to her mouth. The queen goes out of the hive only to mate throughout her life. The lifespan of the queen bee is between 3 and 7 years, and as the age increases, the number of laying eggs decreases and the number of infertile eggs increases. Although it is the longest bee in the colony, the queen bee with a good yield can lay 1500-3000 eggs in a day. As the queen ages and her productivity decreases, it is necessary to replace the queen bee every 1-2 years. They do not have the ability to care, and raise offspring, but only fulfill the function of laying eggs [26].

1.2. Worker Bee

Although they are the smallest individual in the colony, they are female bees that are formed from fertilized eggs. In the larval stage, after the first three days, it is fed with a pollen-honey mixture of lower quality than that of the queen bee. It completes its development within 21 days and the duties of the worker bees that come out of the comb cell begin [25]. It is the most abundant bee in the colony. Each colony has 10,000-80,000 worker bees, depending on seasonal conditions, and the number of worker bees increases in summer. Worker bees that occur in the winter months have a longer lifespan, and the lifespan of the worker bees that occur in the summer months is in the range of 35-40 days due to the workload in the hive. They took on all the tasks in the colony, except for spawning. They have duties inside the hive for the first 20 days and outside the hive after 20 days. Worker bees working outside the hive are called field bees, and worker bees working inside the hive are called house bees. Taking care of and feeding the queen bee, looking after and feeding the offspring (larvae), maturing the honey by carrying propolis nectar, pollen, and water into the hive, forming a honeycomb with beeswax secretion, secreting royal jelly, guarding the hive entrance and not letting the bees inside the hive that are not in the hive . They undertake many tasks such as cleaning, and regulating the temperature and humidity of the hive by circulating air with their wings. These tasks are distributed depending on the age of the worker bees. worker bees; they have a prickly needles, and when they sting a living thing, they leave their needles on that creature and die after a while [27].

1.3. Drone

The drone, which is the largest and plumpest individual in the colony, develops from an unfertilized egg. In some cases, it can also occur from a fertilized egg and is a copy of the queen bee [28]. Drones with white eye color from fertilized eggs are killed by worker bees or thrown out of the hive when they are in the larval stage. Their lifespan is around 21-30 days and they complete their development in 24 days. Although mating with the queen bee is her main duty, they do not have stingers and therefore cannot defend themselves. The drone mates with the queen in the air, and as a result of mating, the drone dies. Since their tongues are short, they cannot take nectar or pollen from flowers. When suitable environmental conditions are provided in the colony, drones are more common after April and May, but they are also abundant during the swarming season. It is larger than the queen and worker bees and shorter in length than the queen bee [29]. It is not found in the colony during the winter months and grows in the colony during the summer months. Depending on the climatic conditions or the conditions in the colony, their number varies between 500-2000. After a while, the worker bees throw the drones out of the hive to regulate the lack of nutrients in the colony and the number of drones in the colony, and the drones are thrown out of the hive die because they starve. The most time they fly during the day is between 14.00-16:00 when the weather is warm, and they do not leave the hive before the temperature reaches 18-20℃. The drone eggs, which are 5-7 days old, can now fly and fulfill the functions of defecating by flying, recognizing the environment, and mating [30].

2. Bee Breeds

The homeland of honey bees in Europe, Africa, and Asia. It is 30-50 million years ago that bees reached their present forms and variations. Bees have attained these forms with the changing of flowering plants, which are their main food source, over time. Bees differ from other types of insects by their physiological differences. Its prominent features are its structure covered with hard hairs, the special nectar-catching structure of the mouth structures, and the presence of areas that help to carry pollen on the body and feet [13]. In the Apis community: There are honey bee species such as Apis cerana, Apis florea, Apis mellifera, Apis koschevnikovi, Apis laboriosa, Apis andreniformis, Apis dorsata. Only the homeland of Apis mellifera is the Eastern Mediterranean, Western Europe, and Africa. Others are native to South East Asia. They have lived in different ecotypes or populations within the

same race for more than 30 million years. Adaptations to different regions have occurred over this long period [31,32].

2.1. Honey bee (Apis mellifera) and its Taxonomy

The honey bee is a bee species in the genus Apis and its Latin name is Apis mellifera, meaning "bee carrying honey", their bodies are covered with hairs. Honey bees are indispensable creatures for herbal agriculture and ecological balance. Various products such as propolis, honey, pollen, beeswax, royal jelly, and bee venom are used in human nutrition and for the treatment of diseases [24]. Another benefit of honey bees is to ensure that plants are pollinated and that beautiful and quality plant products are obtained from those plants [33]. Honey bees; live on honeycombs made of beeswax in colonies of queen bees, drones, and worker bees. The honey bees living in this colony continue their lives in order and cooperation among themselves. There is communication between the bees in the colony for the activities that take place inside the hive and outside the hive (for example, joy and cleanliness) [34]. They provide this communication through chemicals known as pheromones secreted from their bodies and by performing various dances [35]. Honey bees vary in all regions of the world except the polar regions. It collects pollen and nectar from flowers to meet its own nutritional needs. Honey bees; To fly, to stay in the air for a certain time and at a fixed point, to adjust the direction of flight, it has two pairs of very thin membrane wings. honey bees; To ensure the continuation of its generation, to protect its food and nest, and to protect the bee colonies in the nest, it defends itself in various ways with its high sensitivity [36]. If it performs this defense process with its stingers, only drones do not have stingers in the colony. The reason for this is that the only duty of drones is to inseminate the queen and the drone dies after insemination [37]. Honey bees exhibit similar behaviors under the same environmental conditions because these creatures act instinctively. The life span of honey bees, which is 28-35 days, varies depending on the season. During the winter season, female individuals such as queen and worker bees are in the majority of the colony. Honey bees can easily perceive yellow and green colors; They cannot detect black, gray, and red color. When the life expectancy of honey bees, which is around 28-35 days, expires, they mostly die outside the hive, but they can also die inside the hive. When there is death in the hive, the worker bees carry the dead bees and throw them away. In addition to this situation, unproductive, disabled, and aged honey bees are thrown out of the hive and removed. Since honey bees are creatures with high reproductive ability, the honey bee that is born as an adult can pass to the egg-laying stage within a week. Colony productivity increases as colony strength and the number of worker bees increase [38]. Honeybees, which started their lives as eggs, go through four developmental stages because of complete metamorphosis in their lives, which are; egg, larva, pupa, and adult stages. Until the egg placed in the honeycomb cell in the hive becomes an adult bee; It takes 21 days for worker bees, 24 days for drones, and 16 days for queens. First of all, the queen lays eggs in the cells of the honeycomb, and while the drone is formed from this infertile egg, the queen and worker bee are formed from the fertile egg [21].

The egg stage lasts for a total of 3 days for all bees. Bee's egg; The ends are round and cylindrical, and the egg is positioned vertically when it is placed in the honeycomb cell in the hive [39]. The egg, which is positioned vertically, slides to the side after a while and is positioned horizontally at the base of the honeycomb after three days, and then the eggshell is torn and transformed into a larva. Honey bees secrete special secretions that break the shell. Large cells were made on the honeycomb to raise drones, and small cells were made to raise worker bees. The queen puts the fertile egg in the small chamber made on the honeycomb and the unfertilized egg in the large chamber [21].

Honey bees; In this stage of development, although the volume, shape, and color change rapidly, pore formation is observed on the rings that make up their bodies. Mouth parts that are responsible for fulfilling the nutritional function are formed. The larval stage lasts for 6 days and the cocoon stage varies for 5 days [40]. During this phase, the bees start to be fed with royal jelly for the first three days, and then they are fed according to gender. After the first three days, the queen is still fed with royal jelly, while the worker bee and drone are fed with a pollen-honey mixture. Although the amount of royal jelly varies according to the type of larva given, the highest amount and best quality royal jelly is given to the queen bee larvae. Due to the difference in quantity during feeding at this stage, different types of individuals such as queen bees or worker bees develop. Toward the end of this phase, the feeding

process ends. The comb cell is closed by the worker bees outside and the larva inside the comb, and the pupal stage begins [41]. After the queen lays her eggs, that is, at the end of the 8th day, including the egg stage, the mouth of the eyes with worker bee larvae is sealed and the larva turns into a cocoon on the 9th day with a special glandular secretion in the head. This stage, which is formed by the larva standing motionless in its cocoon on the 10th day, is called the prepupa stage, which means before the pupal stage. The prepupae turns into pupa on the 11th day, and these two stages last 12 days in total for worker bees, 7 days for queen bees and 15 days for drones. The pupa, which is described as healthy, is bright and white in color and then turns into dark brown and shades. Pupal stage closed; fry, larva and egg stages are also called open brood. After the pupal stage, the bee has become adult and comes out by opening its comb. It takes 24 days for drones, 16 days for queens, and 21 days for worker bees from the time the egg is deposited in the comb cell until it becomes an adult bee [30], [31].

2.2. African Bee (Apis mellifera scutellata)

This type of bee is angry, it is very difficult to catch diseases, it is a species that leaves the hive and has the ability to produce swarms. It has adapted to tropical and temperate climates. It was brought to Brazil from Africa in 1956 to increase honey production. They escaped from the quarantine zone they were in in 1957. African bees were found in South America, North America, and Texas in 1990, respectively [43]. The African bee, also known as the "killer bee", is known to cause the death of many human and animal species, thanks to the special alarm hormone it secretes. Due to the aggressive behavior of this bee species, American beekeepers had to quit their jobs for a while. The United States of America has developed many practices to prevent the entry of this species into the country. But beekeepers are quite satisfied with this species. This is because they are resistant to diseases and attract a lot of attention due to their high swarming ability. With today's developing technology, American countries have come to a position to export honey [44].

2.3. Italian Bee (Apis mellifera ligustica)

The Italian bee, whose hometown is Italy, has spread all over the world from Italy. It is known as the most common bee breed today. Its habitat is quite large and has managed to survive in both continental and Mediterranean climates. It has a very wide living space from Canada to China, from China to Europe, from Europe to America. It is the most researched and developed bee species. Some of its features can be listed as follows; It is a calm, yellow-colored, and long-lived bee species with a high colony formation rate [35]. Pure Italian bees do not have black rings on the abdomen. It has black dots only at the end of the last abdominal ring. Italian bees with this physiological feature are called "GOLDEN BEE". In countries such as China, Australia, and America, honey yield reaches up to 100 kg per year. Royal jelly is a product of 1-2 kg per year. They are not very prone to catching propolis. They are more prone to looting. The Italian bee was specially bred for honey and milk production. This bee species can produce honey and swarms in early spring. It is one of the species that has the ability to form a strong population. Italian bees, also known as Apis mellifera ligustica, are more capable of combing and wrapping honey than other bee species, which underlies a strong sense of population formation. As long as Italian bees are given honeycomb and honey, they do not attempt to swarm [45].

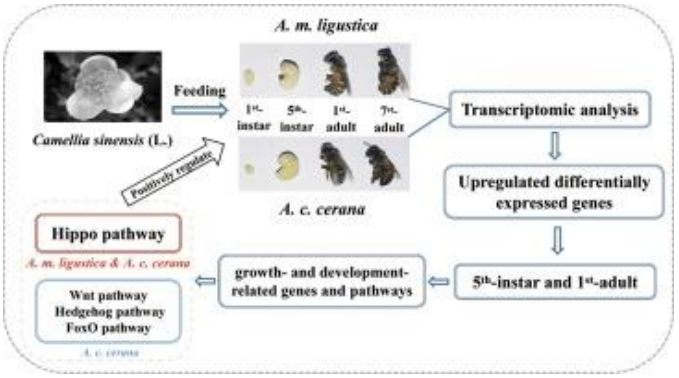

Fig. 3. A. cerana exhibits a different biogeographical distribution than A. mellifera, and these plants are divided into Asian species and Western species of the Apis genus according to their distribution [46].

Recently, both A. cerana and bee products A. mellifera have attracted great interest because of the ecological and economic value of bee products, as well as their research models for studying social behavior, neurobiology, and pesticides. In the case of natural selection, it is a species that is very prone to swarming and honeycomb production. In the Mediterranean and Aegean Regions, it is possible to divide into 8-10 hives on average per year. Although their cleaning properties are quite advanced, they are biologically resistant to European foulbrood disease. Italian bees have a low power of coming into spring by consuming the least amount of food and with the least colony and population pots. Despite this, it is preferred by beekeepers in countries such as Canada and Finland. However, it is known that if the Italian bees wake up early during the long winter periods, the offspring experience chills [23].

2.4. Carniolan Bee (Apis mellifera carnica)

His hometown is Yugoslavia region and Austria. It also shows distribution in Thrace and the Balkans. Carniolan bees are quite similar to Italian bees in terms of size and some behaviors. The Carniolan bee is a docile, hard-working species with high honey production. Their external appearance is dark gray and black, although rarely, it is possible to see brown spots on the 2nd and 3rd levels of the abdomen. This bee species survive the winter in small populations because of limited honey production. In the spring they progress quite rapidly, forming large populations. Carniolan bees have a very regular work division, their comb structure is beyond enormous, and their adaptability is quite good compared to other species. They wrap the honey they produce with a white glaze. They do not like to collect propolis and plunder. They have been trained in many countries, including European countries and America. The breed trained in the Americas was called the New World Carnioan. The financially very expensive New World Carni way has become quite skilled in terms of its general characteristics. The negative feature of this bee species is its high swarming tendency, but this is not a negative feature for bee farms that produce swarms. Still more natural Carniolan bees are bred in Yugoslavia and Austria. The aspirants of the bred bees come to work from European and American countries [47].

2.5. Caucasian Bee (Apis mellifera caucasica)

His hometown is Artvin, Ardahan, Kars, Caucasus, and Georgia. They have adapted to mountainous areas and regions with harsh climates. Physiologically, it has a dark brown color and a gray hairy structure. Brown spots can be seen in the first levels on the abdomen. Although Caucasian bees in Artvin, Ardahan, and Kars regions do not differ physiologically, Caucasian bees in transition regions may be light colored. In this bee species, which has a low propensity to swarm, the rate of plundering and propolis collection is just as high. As a result of some research, they discovered that Caucasian bees show low resistance to Nosema disease. Although the tendency to collect

propolis was not seen as important in ancient times, the ability of Caucasian bees to collect propolis attracts a lot of attention today, with the discovery of antimicrobial and pharmacological properties of propolis. Various countries, especially China, have started to import and breed Caucasian bees [17].

As we can see in Italian and Carniolan bee species, Caucasian bees are also very hardworking and docile bees. Honey yield is high in high areas with a harsh climate. Due to their adaptability to cold climates, their wintering abilities are also quite high. They spend the winter in small colonies. After spending the winter, they enter a rapid development process in the summer and build solid colonies. With its long tongue structure, which is one of the physical features, it provides the advantage of easily collecting pollen from even tuberous flowers. Due to their adaptability to harsh climates, they can work without interruption even at low temperatures. This bee species, which wakes up late in the spring due to its adaptation to cold climates, is not very productive in temperate climates. This causes honey yields to be low compared to other bee species. Caucasian bees are an indispensable bee species for harsh climates [48].

2.6. Anatolian Bee (Apis mellifera anatoliaca)

The bees living in the region excluding the Caucasus and Syria are called Anatolian bees. If we examine Anatolia geographically, it is a bridge connecting Asia to Europe. Anatolia is a region that shows a transition state not only with its topographic map but also in terms of vegetation. It also contains many endemic plants found in Asia and Europe. Anatolian geography, covering a very wide area, provides a habitat for many bee races that have adapted to the region with its high mountains and different climatic characteristics [35]. If we give an example of these bee races: The Anatolian bee, Iranian bee, Caucasian bee, and Syrian bee are some of these races. Ecotypes of Anatolian bees in the region show diversity such as the Gökçeada bee, Central Anatolian bee, Muğla bee, Black Sea Region bee, and Hatay bee. The most common bee species is the Muğla bee, which is specific to the Aegean Region. It is common in the entire Aegean region and is very similar to Carniolan and Italian bees in terms of physiological characteristics. The Anatolian bee, which is geographically distributed over a wide area, varies in color, wing structure, and morphology according to variations such as temperature, pressure, precipitation regime, and vegetation. Its color distribution varies from brown to yellow and it has a very high adaptability and wintering ability. Similar to the Italian breed, it is a productive breed with a high development rate. In the spring, honey production begins quickly. Having gained a large population at the end of the summer, the Muğla bee fills the honeycombs with pine honey in the fall and its work slows down. Muğla bees, which adapt well to a temperate and warm climate, attract more attention in the region compared to other bees [49].

3. Reproduction In Bees

To recognize the honeybees taxonomically, belong to the Apiidae family of the Hymenoptera order of the Insecta class of the Arthropoda branch of the animal kingdom. This house is of the apis type. Honeybees are socially active creatures that live in groups just like us humans. Honeybees are very short creatures in terms of generation intervals, and these features have given them the ability to progress in the short term. Thanks to this ability, their efficiency can be increased. As in other living things, honeybees also rely on mate selection in their genetic changes. In order to contribute to genetic progress, drones that will mate with queens must be carefully selected. However, in natural mating practice, it is very difficult to identify drones due to the biology of queens [50]. There are no isolated parts in natural pairing, which prevents controlled coupling. This reduces targeting in selection. This situation negatively affects the rate of genetic progression. In order to avoid these negative effects, drones should mate in isolated areas or artificially mate under laboratory conditions in order to eliminate the problems arising from the mating biology of selected queens. Although natural mapping is easy in theory, it is quite difficult in practice. Bees love to fly high, but creating a controlled space is difficult because many bee populations live close together. When these conditions are collected, it is very difficult to specifically match the selected queen with the drone. Artificial mating is the most reliable way to avoid all these difficulties and uncertainties and also to increase genetic progress [51].

3.1. Reproductive Biochemistry of Honey Bees

The life of honeybees begins in the egg. When observed biologically, the bee eggs developing in the queen begin to develop in the two large ovaries of the first queen, and then the developing bee eggs are sent to the side oviduct. The eggs that pass through here travel in the middle oviduct to be sexed. Here, the sex wins. If the egg is fertilized, it creates the female bee, if the unfertilized male bee. In the middle oviduct, it provides the fertilization process with the spermatheca organ, which is connected to the canal. This organ checks whether the egg that comes with the sperm pump is fertilized or unfertilized. 5-6 million sperm, which the queen needs throughout her life, are stored in the spermatheca organ of the queen. The life of the queens depends on the number of sperm they store, their lifespan is usually 2 years [52]. Physiologically, they have a larger appearance compared to other bees. The function of queens is to mate with drones. It can produce more than 1500 eggs in 24 hours. It informs its colony that it is alive and healthy thanks to the 9-hydroxy decanoic acid it secretes [53]. At the same time, this pheromone secreted makes all the females in the colony sterile and prevents the drones from preparing other queen cells. This pheromone enables the bees included in the colony to recognize each other. If we examine the reproductive system of the queen, we can observe that it consists of a pair of ovaries, median oviducts, a pair of lateral oviducts, spermatheca, and a vagina. The task of the ovaries is to ensure the maturation of the eggs, this process is carried out by the tubes called ovarioles. There are 160-180 ovarioles in the ovaries. Ovarian maturing eggs come to the lateral oviduct, and then to the median oviduct, respectively. From here it passes into the vagina. Between the spermatheca, which is connected to the vagina with a thin channel, and the vagina entrance, there is an indentation to cover the vigina extending towards the spermatheca canal. This recess has a valve-like function. Its name is also “Valvula vaginalis”. The function of this valve is to occlude the vagina after mating. This prevents the semen from flowing out and helps to press the semen toward the spermatheca. During mating, the queen opens the Valvula vaginalis with its muscles, and the semen from the drone is injected into the lateral oviduct. When the queen goes on a mating flight, she usually mates with 8-10 drones. As a result of this mating, drones inject 70 to 80 million spermatozoa. The total injected spermatozoon cannot fit into the small volume (1mm3) of the spermatheca, many of them flow out. 5-6 million spermatozoa that can fit in a small volume reach the spermatheca [54]. These injected semen remain viable as long as the queen is alive. The queen makes multiple mating to eliminate the possibility of inbreeding as a result of mating with a drone from the same bucket. If we take a look at the formation of worker bees and drones, if they are fertilized with spermatozoa released from the spermatheca just before the egg leaves the vagina, worker bee formation is observed, if not, drone formation is observed. Male bees have a haploid chromosome structure because they are formed from unfertilized eggs. It takes 24 days for them to complete their development. They reach maturity at the end of 24 days. They then reach sexual maturity in 12-14 days. The queen lays her eggs in each of the honeycombs, which have been cleaned with the help of worker bees. It sticks the egg vertically to the bottom of the eyes with its needle. When we physically examine the honeybee's egg, we see its smooth structure and white color. The sausage-shaped eggs are usually 1.5 mm in size. If the egg is not fertilized on the first day of egg development, the nucleus divides into the zygote if it is [55]. At this stage, the structure of the embryo does not become clear, but on the third day, it becomes clear. The head of the bee that will emerge is on the upper part, not attached to the bottom of the egg. Other parts are in the curved part. The first physical change of the egg takes place between 72-84 hours. In this change, the embryo contracts and tears the membrane of the egg. As a result of tearing, the liquid inside the egg begins to wrap around the outside of the embryo. Embryo contraction continues until its head touches the base of the cell. When it touches the cell base, the distinctive larval form now resembles the letter "C". Worker bees carefully feed the formed larvae with royal jelly for the first 24 hours. During the other 24 hours, they are fed with additional nutrients by the worker bees. The function of drones is to mate with the queen [56]. Unlike other bees, they are slightly larger. Their lifespan is between 21 and 32 days in spring and 90 days in summer. When we examine the reproductive organs of drones biologically, it is possible to observe that they consist of a pair of testicles, a pair of large mucous glands, a pair of large mucous glands, vasa deferens, seminal vesicles and penis. In the period when the internal organs fuse and form into an adult, spermatozoa production begins in the testicles. The ejaculation abilities of the young drones are not developed because the spermatozoa do not leave the

test. When they become adults, they will separate and ejaculation will be possible. When mating begins, the drone also sets out from the semen ejaculation line and reaches the endo phallus. It is the last stop of the sperm before they pass to the queen. Then, with the suppression of the mucus released from the mucus glands, the sperm queen is transferred to the vagina, which is the reproductive organ [29]. After mating, the drones die because they leave a certain part of the Endophallus in the abdomen of the queen. If the drone has reached maturity, it is quite simple to become semen. Mature semen is found in drones older than 12 days. Its form is yellow-cream. If the semen to be taken from the drone is possible, the afternoon is the most suitable time. This is because in the afternoon when drones are most suitable for breeding. The methods of semen retrieval from drones are electrical stimulation, rubbing by hand, and the use of chemicals to stimulate drones, respectively [57]. After the drone secretes the semen, it also secretes mucus, the function of this mucus is to prevent the involuntary outflow of semen from the queens. The average amount of semen in a mature drone is 1.7 mm3 and ranges between 1.5-1.75 mm3. Drones have one of the densest spermatozoa in the animal kingdom (7.5 x 109 spermatozoa/ml). Larger drones are preferred for mating because the size of drones is directly proportional to the amount of semen [58].

The mating of bees was only elucidated at the beginning of the eighteenth century. Until it was announced by Janscha in 1775, it was thought that queens did not mate with drones and it was accepted that the eggs were fertilized in the honeycomb. Janscha, on the other hand, reveals that the queens fly to know the environment and mate with the drone in the air. It is quite difficult to observe mating in the air. Huber's work on this subject in 1792 shed light on great studies. According to Huber's studies, the queen makes a 2-5 minute flight to know the environment for 3-5 days. Then on the 5th and 6th days, it leaves the hive to mate. Flights to mate are in the range of 1-3 times. The queen bee is to reinforce the progression of sperm to the spermatheca with the flight to know the environment of 2 minutes [59]. Queen bees can fly repeatedly for a day until they reach the desired sperm saturation. According to the impressions of the explorers, about 63% of the 303 queens made a mating flight once; a second time, 6% flew to mate a third time. While each flight takes approximately 25 minutes, the time between consecutive flights is 19-120 minutes. As the time between flights increases, the next time becomes shorter and the activity of the next flights decreases [60]. In order to observe the natural mating, first of all, the queen was attached to the front of the camera with the help of support in the region where the drones come together. Then it was put at about 10 meters. The needle chamber of the queens is kept open so that mating can take place without any problems. After observing the queen, the drone approaches and clings to the queen with its 6 legs. Then the drone's abdomen is folded down and mating takes place. After this rapid mating, the drone becomes paralyzed and falls freely. After this mating, the stinger of the queen is cleaned by the worker bees and the queen becomes suitable for mating again. After mating, spermatozoa from drones are stored in the semen sac found in the queen. The spermatozoa stored here maintain their vitality as long as the queen is alive. The honeycomb diameters are measured with the 1st pair of queens' legs. Then, the queen lays fertilized worker bee and queen eggs in these cells, and unfertilized eggs in drone cells. The queen lays an average of 250,000- 300,000 eggs per year. A total of 4- 5 million spermatozoa are stored in the sperm sacs [61].

3.2. Artificial Insemination Application in Honey Bees

It is possible to obtain more qualified and larger queens by double inoculation with artificial insemination. There are some difficulties that artificial seeds bring along. Breeding drones is a seasonal event. It is always difficult to find the drones needed in the colony. Queen and drone breeding is a joint event. The natural phase is expected for the queen bee to mate. The reproductive organs and tissues of the queens, which are 6- 7 days old, have not yet reached the desired maturity. When the queens are 8- 10 days old, they start flying only to mate. In artificial insemination, mating activities begin in 8- 15 days old queens. The 15-day period is important because the tissue elasticity begins to decrease in queens past 15 days, which creates difficulties in artificial insemination. Another issue is the selection of drone bees in insemination is a very important issue. It is known that drones become adults in 24 days, and reach sexual maturity in 14 days. Considering these conditions, the breeding of drones should be started at least 40 days before. It should be close to the honeycomb where the queen bee will be reared with the help of a grid. The drone bee should be placed in specially raised cells in the honeycomb. The queen lays unfertilized

eggs in drone cells. After 24- 25 days, drones will begin to form, and the drones that are formed are marked. After 14- 15 days, drones suitable for artificial insemination are ready [62].

3.3. Queen Bee Insemination

After the drones reach sexual maturity, the thorax, the thorax, of the drone is held with the index and thumb of the right hand. Then, it is compressed towards the abdomen, and ejaculation is provided. The sperm is spread on the endo phallus to form a thin layer with the mucus secreted by the drone. The obtained semen is drawn with an injector. Care should be taken that the injector does not come into contact with the mucus layer and the mucus is not drawn into the injector while the sperm is drawn with the injector. If care is not taken, the injector may become clogged. The semen extraction process continues until the total semen volume is 8-10 mm^3. Then the queen is stunned with the help of CO_2. They are taken into the tube and placed with the last 5-6 segments of their abdomen outside. The tube with the queen must remain connected to the CO_2 tube because the queen must remain unconscious throughout the procedure [63].

He puts the queen under the microscope, the ventral and dorsal hooks and the sting circle of the queen are opened. Then the queen's stinger is inserted through the hole on the dorsal hook. Care must be taken when handling the injector. Starting from the vagina, the injector tip is advanced towards the vaginal valve with slow movements, when the oviduct is reached, the button of the injector is turned to the right, and semen passage is provided [58]. The injector is drawn from the queen, if there is no semen on the drawn injector, artificial insemination has been concluded correctly. The dorsal hook is removed from the sting of the queen and the queen is removed from the tube. It is waited for the queen to come to her senses and then it is placed in its colony. For rapid spawning, the queen is exposed to CO_2 in 10-minute periods. After these processes, as in natural mating, the spermatheca of the queen is approximately 5- 6 million spermatozoon and is stored here. The path followed by the sperm is very close to natural mating, the sperm that cannot reach the spermatheca comes out. From the bees of artificial insemination, the worker bees disinfect the sting circle of the queens [64].

4. Social Order Of Bees

Bees are very regular in their social life as well as in their working life. Bees, which have rules within themselves, lead a life in accordance with these rules. Although the duty of each bee in the hive is clear, they never go beyond these duties. They are not suitable for living in all areas, they live in hollows or cavities they find themselves, but they can also live in hives. Each bee has its own comb. They make these honeycombs even in their natural habitats, even if they are in a hive made by humans. All over the world, honeybees weave combs in the same way. These comb cells are both a food area and an area where they raise their young. In bee colonies, the management is in the female bees. Bees avoid polluting the area they live in, and they wait to come out of the hive. Realizing that their life will end, bees get as far away from the hive as possible. The reason for the existence of drones is only to inseminate the queen. Until the queen is old, there are not two original queens in a hive, this is because they are trying to dominate [6]. If found, they'll fight each other to the death and there's a winner. Each hive has its scent. When a bee that does not belong to the bucket wants to enter, it is recognized by its smell and is not allowed in. Bees protect their hives at the expense of their lives, and if they sting another living thing, their lives are terminated. The location of the bee hives is very important, they should not be changed, otherwise, the bees will not be able to find their hives. Each bee leaves its scent on the flowers it collects nectar and pollen so that no other bees will land on those flowers [13] . At the same time, the bees dance and share the location of the flowers they mark with other bees when they return to the hive. The life span of worker bees is a honey collection period, which takes about 40 days. Worker bees do not live long enough to eat the honey they collect in winter. Bee physiology is complex and it is important to understand it. Different technologies are also used to understand the physiology of bees. One of these technologies is nanotechnology. Nanotechnology is widely used in every field today. In the coming days, it is thought that we will encounter much more in daily life in different applications related to bees and beekeeping in the near future [65–90].

5. Conclusion

Bees are one of the most dependent populations on the ecosystem because they collect pollen and nectar and transform various raw materials into products in nature as a way of life. For this reason, bee morphology and anatomy have been a subject of great interest. The anatomy of the bee is divided into three segments: head, thorax, and abdomen. The head is the part where important secretions are made due to its internal structure. The upper jaw glands of worker bees secrete royal jelly at a young age and enzymes that break down sucrose at a later age. The thorax movement in bees consists of four segments and the first ring of the abdomen is combined with the left ring of the thorax. The sensory systems that provide the senses of smell, taste, and touch in bees are in the head. Thanks to the strong muscles and nerve endings in the sensors, they can perceive wind speed and air temperature as well as sensory organs. There are three pairs of legs and two pairs of wings, one in each of the three segments on the thorax. Although the front wings are wider and more veined than the hind wings, they both work together during flight. The wings are composed of two very thin membranes and are supported by a criticized vascular layer. In addition to the movement of the bee, the legs provide antenna cleaning, clinging to the environment, and filling the pollen basket. It is known that the morphological feature of the bee exhibits various adaptations according to climatic conditions and vegetation. There are three types of bees in the hive: queen bee, worker bee, and drone. The developmental stage of a bee goes through 4 different stages: egg, larva, pupa, and adult. The queen bee is the only species capable of laying eggs, the fertilized ones form the worker bees, and the unfertilized ones form the drones. The importance of the queen bee in the colony is the control of the bee community and the creation of an adequate brood population with a balanced division of labor. Methods such as artificial insemination and queen bee insemination are frequently used for the bee's selection ability and genetic improvement. In addition, our country has become a country where various races are raised among the countries of the world, with its geographical location and natural wealth.

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