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Effects of Morphological Characteristics on Colony Strength and Productivity in Honey Bees

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Morphometric measurements, Honey bee, Genetic mixture, Colony productivity, Leg length.

Abstract

Due to migratory beekeeping activities across the country and the sales of queen bees and colonies, genetic mixtures have emerged, raising significant concerns. On the other hand, working with knowledge of some morphological characteristics of the material owned by the breeders can significantly contribute to increased productivity. In this study, three enterprises with 200 or more colonies were selected from Erzincan in the Eastern Anatolia Region and Çorum in the Central Anatolia Region. Samples were collected from the top 5 most productive and the bottom 5 least productive colonies of the identified beekeepers during the swarming season for morphometric measurements, and 41 standard morphological characteristics were studied. When the data between productive and unproductive colonies were evaluated, it was determined that the high tibia length, metatarsus length, hind leg length, and distance between wax surfaces, as well as the low G12 angle, were effective on colony strength and productivity. Since tibia, metatarsus, and hind leg lengths relate to the hind leg, which is primarily responsible for forming and carrying pollen pellets, it is believed that the capacity and size of pollen pellet transport directly impact productivity.. As the wing width of the bee increases, the G12 angle decreases. Based on these findings and evaluations, it is concluded that bees with long legs, wide wings, and a high distance between wax surfaces are stronger and more productive.

Bal Arılarında Morfolojik Karakterin Koloni Gücü Ve Verime Olan Etkileri

Özet

Ülke genelindeki gezginci arıcılık faaliyetleri, ana arı ve koloni satışları nedeniyle genetik karışımlar ortaya çıkmış ve bu yönüyle önemli kaygılar bulunmaktadır. Diğer taraftan yetiştiricilerin sahip olduğu materyalin bazı morfolojik özelliklerini bilerek çalışması verim artışına önemli katkılar sağlayacaktır. Çalışmada Doğu Anadolu Bölgesinden Erzincan ve İç Anadolu Bölgesinden Çorum illerinden 200 ve üzeri koloniye sahip 3'er işletme belirlenmiştir. Belirlenen Arıcıların konaklama yerlerine oğul döneminde gidilerek en verimli ilk 5 kolonisi ile en verimsiz son 5 kolonisinden morfometrik ölçümler için örnekler toplanmış ve 41 standart morfolojik karakterleri çalışılmıştır. Verimli ve verimsiz koloniler arasında veriler değerlendirildiğinde tibia uzunluğu, metatarsus uzunluğu, arka bacak uzunluğu, mum yüzeyleri arası mesafenin yüksek olması ve G12 açısının düşük olması koloni gücüne ve verimine etkili olduğu belirlenmiştir. Tibia, metatarsus ve arka bacak uzunlukları arka bacakla ilgili olmaları bu bacaklarında en önemli görevi poleni bu kısımda palet haline getirip taşıma ile ilgili oldukları için polen palet taşıma kapasitesi ve büyüklüğünün verime direk etki yaptığı düşünülmektedir. Arının kanat genişliği arttıkça G12 açısı küçülmektedir. Bu bulgulardan ve değerlendirmelerden yola çıkılarak uzun bacaklı, geniş kanatlı ve mum yüzeyleri arası mesafesi yüksek olan arıların daha güçlü ve verimli olduğu ortaya çıkmaktadır.

Anahtar Kelimeler

Biyopartikül, Yeşil sentez, Yenilebilir kaplama, Muhafaza süresi.

1.INTRODUCTION

Bee races and ecotypes have acquired their current morphological, physiological, and behavioral characteristics over time, influenced by the geographical structures of the regions they have adapted to. Ecology, climate, vegetation, and natural pests have played significant roles in shaping the present forms of these races and ecotypes. Therefore, it has become necessary to evaluate both morphological and behavioral, as well as physiological descriptions and systematic classifications, by considering the geographical structure of the region (Güler, 2017). Due to widespread migratory beekeeping, queen bee, and colony sales across the country, the existing honey bee races and ecotypes have been exposed to significant genetic mixing. This has led to serious problems in terms of their physiological and morphological characteristics, causing them to lose some of their distinct traits (Doğaroğlu, 1992; Güler, 2006). Various existing bee races around the world are not preferred by breeders due to their low productivity, excessive swarming tendency, or extreme aggressiveness. As a result, foreign improved breeds have been favored, putting native bee races at risk of extinction (Güler et al., 2012). Anatolia's diverse climatic conditions, significant geological differences between regions, and its natural role as a bridge between three continents have played an important role in the differentiation of many species. During their differentiation process, honey bees have adapted to the climate conditions and flora of their respective regions. Humans have turned this adaptation into an economic advantage (Kence, 2006). Adam (1983), who studied the physiological and behavioral characteristics of Anatolian bees during his travels and in England, described the Anatolian bee as an important and valuable race that possesses a combination of traits found individually in many other races and reported that Anatolian queen bees are highly long-lived.

Three conditions are generally considered essential for success in honey bee breeding. These conditions include, first, clearly defining the breeding objective, i.e., determining the direction in which the genotype will be altered; second, reliable productivity controls; and finally, the deliberate mating of queens and drones from selected colonies, which will rapidly increase the number of colonies with positive genes (Kösoğlu et al., 2021). Colony management, queen rearing, and artificial insemination techniques are seen as the most effective ways to achieve success in genetic improvement programs within the beekeeping industry (Oskay, 2008). The pollen load varies depending on the volume of the pollen basket. Therefore, the volume of the corbicula basket is considered an economically important trait in bees. Pollen grains collected from the body with the help of the front and hind leg pairs are first accumulated on the metatarsus of the hind legs. They are then combed and deposited into the pollen basket with the help of a rake brush located on the tibia (Güler, 2006).

Widespread hybridization across the country's geography has led to a reduction in colony population, increased swarming tendency, made colonies more aggressive, and more susceptible to disease and parasite infections, ultimately resulting in decreased productivity. The most critical task in preventing this is recognizing and characterizing existing honey bee populations. Subsequent selection studies will lead to stronger colonies with desired characteristics. Gençer and Günbey (2020) found that in their study of the morphological characteristics of some honey bee genotypes in the Black Sea Region, the average hind leg length measured was 8.157 mm in the Yığılca group, which was higher than the Kafkas (8.023 mm) and Korgan groups (8.031 mm). Kuvancı et al. (2023) compared the morphological characteristics of WCBS (selected material) with the Anatolian, Kafkas, and Yığılca genotypes, finding that femur, tibia, and metatarsus lengths were higher in the Kafkas (2.798, 3.429, 2.145 mm), Yığılca (2.653, 3.299, 2.068 mm), WCBS (2.638, 3.273, 2.022 mm), and Anatolian (2.627, 3.098, 1.971 mm) groups.

The aim of this study, conducted in two different geographical regions of Turkey, is to determine which of the 41 morphological characteristics are related to colony strength and productivity.

2. MATERIALS AND METHODS

Three beekeepers, each with 200 or more colonies, were selected from Erzincan in the Eastern Anatolia Region and Çorum in the Central Anatolia Region. Samples were collected for morphometric measurements from the top 5 most and bottom 5 least productive colonies of these beekeepers during the swarming season.

Sample Collection for Morphological Analysis: Approximately 25-30 young worker bees from sealed brood cells were collected using a brush, euthanized using boiling water, and then transferred into 30 ml glass jars containing 70% ethanol to preserve the samples for preparation and measurement. The samples were then transported to the morphology laboratory at the Beekeeping Research Institute for analysis.

In each sample, 10 worker bees were measured for 41 standard morphological characteristics, including the following: fourth tergite hair length (KU, mm), fourth tergite felt band width (Ta, mm), fourth tergite felt bright area width (Tb, mm), tomentum index (Ti, ratio), tongue length (DU, mm), femur length (Fe, mm), tibia length (Ti, mm), metatarsus length (MU, mm), metatarsus width (MG, mm), metatarsal index (MI, ratio), hind leg length (ABU, mm), third tergite width (T3, mm), third sternite width (S3G, mm), wax mirror length (MSU, mm), wax mirror width (MSG, mm), distance between wax mirrors (MAM, mm), sixth sternite length (S6U, mm), sixth sternite width (S6G, mm), sternum index (S6I, ratio), wing length

(KU, mm), wing width (KG, mm), cubital vein a length (a, mm), cubital vein b length (b, mm), cubital index (CI, ratio), color of the second tergum (T2R), third tergum (T3R), and scutellum (SR), and wing vein angles A4, B4, D7, E9, G18, J10, J16, K19, N23, and O26 (Alpatov, 1929; Dupraw, 1965; Ruttner et al., 1978; Moritz, 1991; Kauhausenkeller et al., 1997; Akyol, 1998; Güler & Kaftanoğlu, 1999a; Güler, 2001; Güler & Bek, 2002; Güler et al., 2010). The measurements were conducted using a stereomicroscope equipped with a morphological measurement software package.

Colony Population Development: The number of frames covered with bees in each colony was recorded every 21 days to assess colony population development (Güler, 1999; Lensky et al., 1996). These assessments were not conducted during the overwintering period.

Honey Yield: Once the honey frames were two-thirds sealed, all colonies were weighed on the same day by placing them in their respective supers marked with their numbers. After the honey was extracted, the supers were re-weighed, and the honey yield was determined by subtracting the initial tare weight (Güler, 2006).

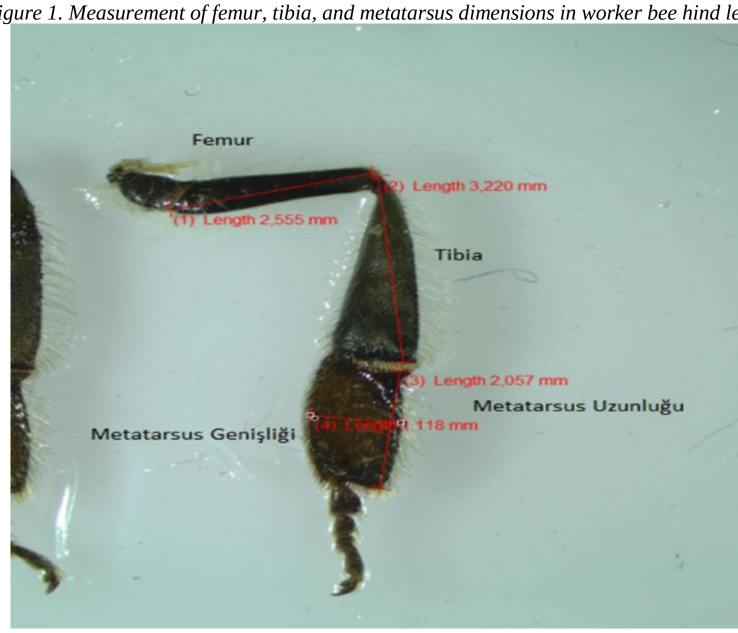
In the study, differences between the most productive and least productive colonies were tested. First, the normality of the data was checked using the Shapiro-Wilk test. If the data were normally distributed, a one-way analysis of variance (ANOVA) was applied. ANOVA is a method used to test the differences between group means. It assumes that the data are normally distributed with means of μ_1, μ_2, ..., μ_k and a common variance of σ^2, and compares these means. For non-normally distributed data, Logarithmic, Box-Cox, Square Root, and Angular transformation methods were applied. A significance level of $p<0.05$ was accepted for all tests. If the ANOVA results were statistically significant, the Least Significant Difference (LSD) multiple comparison method was used to compare group means.

3. RESULTS

The analysis of 41 standard morphological characteristics revealed that the fourth tergite hair length (KU, mm), fourth tergite felt band width (Ta, mm), fourth tergite felt bright area width (Tb, mm), tomentum index (Ti, ratio), tongue length (DU, mm), femur length (Fe, mm), metatarsus width (MG, mm), metatarsal index (MI, ratio), third tergite width (T3, mm), third sternite width (S3G, mm), wax mirror length (MSU, mm), wax mirror width (MSG, mm), sixth sternite length (S6U, mm), sixth sternite width (S6G, mm), sternum index (S6I, ratio), wing length (KU, mm), wing width (KG, mm), cubital vein a length (a, mm), cubital vein b length (b, mm), cubital index (CI, ratio), second tergum color (T2R), third tergum color (T3R), and scutellum color (SR), and wing vein angles A4, B4, D7, E9, G18, J10, J16, K19, N23, and O26 were statistically insignificant. However, significant differences were found in tibia length (Ti, mm), metatarsus length (MU, mm), hind leg length (ABU, mm), distance between wax mirrors (MAM, mm), and G12 wing vein angles ($p<0.05$).

The tibia length refers to the measurement of the distance between the femur and metatarsus. The metatarsus is the first segment of the tarsus following the tibia and is longer and wider than the other segments. The sum of the femur, tibia, and metatarsus lengths determines the hind leg length (Figure 1).

Figure 1. Measurement of femur, tibia, and metatarsus dimensions in worker bee hind legs.



Tibia length (Ti) was found to be 3.369 mm in strong colonies, while it was 3.333 mm in weak colonies (Table 1).

Table 1. Tibia length (Ti, mm) in strong and weak colonies

Colony Type	Tibia Length (Ti, mm)
Strong	a 3.369
Weak	b 3.333

$p < 0.05$

Metatarsus length was measured as 2.129 mm in strong colonies, compared to 2.107 mm in weak colonies (Table 2).

Table 2. Metatarsus length (MU, mm) in strong and weak colonies

Colony Type	Metatarsus Length (MU, mm)
Strong	a 2.129
Weak	b 2.107

$p < 0.05$

In this study, tibia and metatarsus lengths were found to be statistically significant in terms of hind leg length, while femur length was not. Honey bees store pollen grains collected from flowers between the tibia and metatarsus, forming pellets that are then transported. These findings suggest that longer tibia and metatarsus lengths may increase the bee's capacity to store and transport pollen. This, in turn, directly influences colony strength and productivity.

The hind leg length was measured as 8.208 mm in strong colonies, compared to 8.128 mm in weak colonies (Table 3).

Table 3. Hind leg length (ABU, mm) in strong and weak colonies

Colony Type	Hind Leg Length (ABU, mm)
Strong	a 8.208
Weak	b 8.128

$p < 0.05$

The hind leg length is determined by summing the femur, tibia, and metatarsus lengths. The statistical significance of tibia and metatarsus lengths, along with the insignificance of femur length, suggests that the contribution of tibia and metatarsus to hind leg length is critical in influencing productivity and colony strength.

Wax glands are present only in worker bees, which develop and produce wax between the ages of 12-18 days. The segments containing the wax glands feature two bright oval surfaces known as wax mirrors (Figure 3). These surfaces produce wax after hemolymph passes through the cells.

The distance between the two ends of the elliptical wax mirror on the third sternite is measured as the mirror length (MSU), while the longest transverse distance across the ellipse is measured as the mirror width (MSG). The distance between the two wax mirrors (MAM) is measured from the central area.

Figure 2. S3G = sternite width, MSU = wax mirror length, MSG = wax mirror width, MAM = distance between wax mirrors measurements.

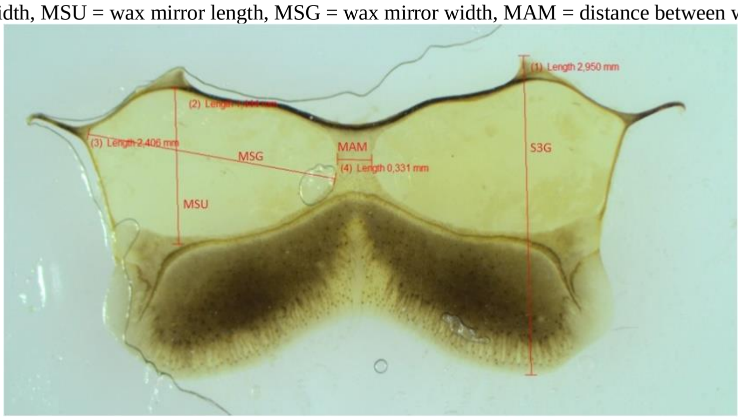


Table 4. Distance between wax mirrors (MAM, mm) in strong and weak colonies

Colony Type	MAM (mm)
Strong	a 0.294
Weak	b 0.279

$p < 0.05$

In the taxonomic classification of honey bees, one of the most commonly used characteristics is the position of the wing veins. The shapes, sizes, and angles between these veins can vary significantly among different races (Figure 3). Among the various wing characteristics, the cubital index is the most frequently used. The cubital index is calculated as the ratio of the length of the third cubital cell to the length of the vein that forms the lower edge of the third cubital cell, which makes an angle with the discoidal cell.

Figure 3. Measurement of the G12 vein angle in the wing of a worker bee

Table 5. G12 vein angle levels in strong and weak colonies

Colony Type	G12 Vein Angle (degrees)
Weak	a 93.380
Strong	b 92.391

$p < 0.05$

While the cubital index is the most commonly used characteristic in wing angle measurements for morphological classification, the findings of this study indicate that the G12 angle is the most important characteristic in terms of colony strength and productivity. Statistically, a linear relationship between the reduction of the G12 angle and increased productivity has been observed.

Colony Performance Values

Bee-covered frames. The number of bee-covered frames in the colonies was examined within the scope of the study. The number of bee-covered frames was determined to be 27.567 in strong colonies, compared to 4.90 in weak colonies (Table 6).

Table 6. Number of bee-covered frames in strong and weak colonies

Colony Type	Bee-covered Frames (no.)
Strong	a 27.567
Weak	b 4.90

$p < 0.05$

Honey Yield

No honey was harvested from the weak colonies, so a comparison of honey yield with strong colonies could not be made. However, when comparing the honey harvested from strong colonies by province, the average honey yield per colony was found to be 37.866 kg in Erzincan and 25.60 kg in Çorum (Table 7).

Table 7. Average honey yield (kg) per colony in high-yielding colonies by province

Province	Honey Yield (kg)
Erzincan	a 37.866
Çorum	b 25.60

$p < 0.05$

4. DISCUSSIONS

This study investigated the effects of morphological characteristics on colony strength and productivity in honey bees. Among the morphological measurements, tibia, metatarsus, and hind leg lengths, along with the distance between wax mirrors and G12 wing vein angle, emerged as key parameters. The findings indicate that these parameters significantly affect colony strength and honey yield.

Tibia and metatarsus lengths were found to have a direct impact on pollen-carrying capacity. The tibia length in strong colonies was measured at 3.369 mm, while it was 3.333 mm in weak colonies. Similarly, metatarsus length was 2.129 mm in strong colonies and 2.107 mm in weak colonies. These results suggest that longer tibia and metatarsus lengths enhance pollen-carrying capacity, positively affecting colony strength and productivity. This finding aligns with previous studies on the impact of pollen-carrying capacity on productivity (Güler, 2006; Kösoğlu et al., 2021). The distance between wax mirrors (MAM) is a critical parameter for wax production. In strong colonies, MAM was measured at 0.294 mm, compared to 0.279 mm in weak colonies. This suggests that a greater distance between wax mirrors enhances wax production, thereby positively affecting colony strength and productivity. This finding is also supported by studies emphasizing the relationship between wax production and colony strength (Güler, 1999; Oskay, 2008).

A reduction in the G12 wing vein angle results in an increase in wing width. In strong colonies, the G12 angle was measured at 92.391 degrees, compared to 93.380 degrees in weak colonies. This finding suggests that increased wing width allows bees to achieve more efficient flight, conserving energy. Energy conservation may enhance the bees' nectar-collecting capacity, thereby positively impacting colony productivity. This finding aligns with previous studies that highlight the role of wing morphology in productivity (Kence, 2006; Güler et al., 2010).

Tongue length is a significant morphological characteristic associated with productivity in the beekeeping community. However, this study found that tongue length was statistically insignificant between productive and unproductive hives. Instead, tibia, metatarsus, and hind leg lengths, along with the distance between wax mirrors and G12 wing vein angle, were found to have significant effects on productivity. These results are consistent with other studies examining the impact of morphological characteristics on productivity (Güler, 2001; Gençer & Günbey, 2020).

The findings indicate that morphological characteristics are not homogenous within colonies in a beekeeping enterprise, directly affecting productivity. Due to widespread migratory beekeeping activities and queen bee sales across Turkey, existing honey bee races have been exposed to significant genetic mixing. This genetic mixing may negatively affect colony strength and productivity. Therefore, the importance of selection studies to preserve and improve the morphological and genetic characteristics of bees is emphasized (Doğaroğlu, 1992; Güler et al., 2012). The different climatic and geographical conditions of Anatolia have affected the morphological and behavioral characteristics of honey bees. Therefore, evaluating bees based on the geographical structure of their regions is essential. For example, the Anatolian bee is known for its longevity and adaptability to different climatic conditions (Adam, 1983). This study conducted in Erzincan and Çorum provinces reveals the impact of different geographical regions on bee morphology and productivity. These findings are consistent with other studies in the literature (Kuvancı et al., 2023).

This study represents an important step in understanding the impact of morphological characteristics on colony strength and productivity in honey bees. The findings emphasize the importance of selection studies in beekeeping and provide criteria that can be used to achieve more productive colonies. Future research with larger sample groups and studies conducted in different geographical regions can support these findings and enhance the success of genetic improvement programs in beekeeping (Moritz et al., 2005).

In conclusion, tibia, metatarsus, and hind leg lengths, along with the distance between wax mirrors and G12 wing vein angle, are important morphological characteristics for colony strength and productivity in honey bees. Considering these characteristics in selection studies can increase productivity in the beekeeping industry and help preserve genetic diversity. This study provides a valuable foundation for researching the relationship between morphological characteristics and productivity in beekeeping and offers important insights for future research.

5. CONCLUSION

One of the most commonly discussed and accepted morphological characteristics in beekeeping is tongue length, which is thought to be significantly associated with productivity. However, our study found that tongue length was statistically insignificant between productive and unproductive hives. Instead, five other characteristics—distance between wax mirrors, G12 wing vein angle, and tibia, metatarsus, and hind leg lengths—emerged as key factors. The fact that three of these characteristics are related to the hind leg highlights the importance of this organ in productivity. The primary function of the hind leg is to collect and transport pollen grains gathered from the body. Considering that the pollen load can vary depending on the volume of the pollen basket, it becomes clear how much the amount of pollen transported in a single trip can contribute to colony development and thus to productivity. As the G12 wing vein angle decreases, wing width may increase. Bees, which perform the act of flight by beating their wings, use the nectar they have collected as an energy source during this process. Based on these considerations, it is evident that bees with wider wings achieve more efficient flight. A linear relationship has also been observed between the distance between wax mirrors and productivity. It is believed that the longer the distance between wax mirrors, the more significant it is in terms of wax secretion.

This study shows that morphological characteristics are not homogenous within colonies in a beekeeping enterprise, directly affecting productivity. It is hoped that this research will provide a foundation for broader studies on this topic.

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