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Editor's Note

The Third International Congress on Bee Sciences was successfully held online. We are delighted to have offered this event free of charge. It was an honor to bring together experts from various fields of bee sciences. This Congress allowed to exchange of innovative ideas and fostering the development of new research and collaborative projects. With 44 invited speakers representing 30 countries and a scientific committee composed of nearly 300 distinguished scientists from over 65 countries, the congress truly reflected global participation. We extend our heartfelt thanks to everyone who contributed and supported the event. We look forward to seeing you at our next congress.

Warm regards from Turkey!

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PROCEEDINGS BOOK

Understanding the Factors Influencing the Reproductive Health of Honey Bee (*Apis mellifera* L.) Drones

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Abstract:
Understanding the factors influencing the reproductive health of honey bee drones is essential for ensuring the vitality and sustainability of honey bee populations. Honey bee drones play a critical role in colony reproduction by mating with virgin queens, thus contributing to genetic diversity within colonies. Various biological, environmental, and anthropogenic factors can influence drone reproductive success. Biological factors such as genetics, age, and physiology, as well as environmental factors like climate and habitat quality, can impact drone health and fertility. Additionally, anthropogenic factors including pesticide exposure, habitat loss, and beekeeping practices can pose significant challenges to drone reproductive health. Maintaining genetic diversity within honey bee colonies is crucial for mitigating the negative impacts of inbreeding and enhancing colony resilience. Collaboration between beekeepers, researchers, policymakers, and the broader community is essential for addressing environmental stressors and promoting pollinator-friendly practices. Advancements in research and technology provide valuable tools for monitoring and managing honey bee health, enabling targeted interventions to support drone reproductive health. By adopting a holistic approach that considers the complex interactions between genetic, environmental, and management factors, we can ensure a brighter future for honey bee populations and the essential ecosystem services they provide.

Keywords: honey bee, drone, reproductive quality, reproductive health, spermatozoa

1. Introduction

Honey bees are social insects that live in communities called bee families or colonies. (Richards vd., 2023). When examined closely, three different individuals are detected within a bee colony in terms of morphological, physiological and behavioral characteristics. Queen bee, worker bee and drones (Halvaci et al., 2023). Queen bees and worker bees are female individuals and develop from fertile eggs, while drones emerge from infertile eggs through parthenogenesis (Khan and Ghramh, 2024).

As male bees, drones fulfill the essential role of mating with queens to ensure the continuation of their species (Halvaci et al., 2023). However, the reproductive health of honey bee drones is not solely determined by their innate biology but is influenced by a myriad of factors, both natural and anthropogenic.

One of the primary biological factors impacting drone reproductive health is genetic diversity (Shultz et al., 2024). Genetic diversity within honey bee colonies is crucial for resilience against diseases, environmental stressors, and adaptation to changing conditions. Inbreeding depression, a consequence of reduced genetic diversity, can lead to decreased drone fertility and colony fitness. For instance, studies conducted by Gençer and Firatli (2005) and Zaitoun et al. (2009) have demonstrated that inbred honey bee drones exhibit lower sperm viability and increased susceptibility to diseases, highlighting the importance of genetic diversity in maintaining healthy drone populations.

Environmental factors also play a significant role in shaping drone reproductive health. Climate and weather conditions, such as temperature, humidity, and wind speed, can profoundly impact drone mating behavior and reproductive success. Adverse weather conditions, including extreme temperatures or heavy rainfall, can disrupt drone mating flights, leading to decreased genetic diversity within colonies. Research by Koeniger and Koeniger (2007) and Neves et al. (2011) has shown that cold temperatures and high humidity levels can inhibit drone flight activity and impair mating success rates, underscoring the vulnerability of drones to environmental fluctuations.

Furthermore, human activities and management practices within beekeeping operations can exert considerable pressure on drone reproductive health. Intensive queen rearing programs, aimed at selecting for specific traits in honey bee queens, may inadvertently lead to a reduction in drone genetic diversity and compromise overall colony health. Likewise, the transportation of honey bee colonies for pollination services exposes drones to stressors such as vibration, temperature fluctuations, and limited food, which can negatively impact their reproductive fitness.

As we delve deeper into the factors influencing the reproductive health of honey bee drones, it becomes evident that a multifaceted approach is required to address these challenges effectively. By integrating scientific research, conservation efforts, and sustainable beekeeping practices, we can strive to preserve the health and vitality of honey bee populations, safeguarding their crucial role as pollinators and ensuring the sustainability of agricultural ecosystems.

2. Biological Factors

Biological factors are fundamental determinants of honey bee drone reproductive health, encompassing genetics, physiology, and age. Understanding these factors is crucial for maintaining robust drone populations within honey bee colonies.

2.1. Genetics

Genetic diversity is crucial for the health and resilience of honey bee colonies, including drone populations. Inbreeding depression, resulting from reduced genetic diversity, can lead to decreased drone fertility, increased susceptibility to diseases, and compromised colony fitness. Inbreeding Depression: Inbreeding depression occurs when closely related individuals mate, leading to the expression of harmful recessive alleles and reduced fitness in offspring. Several studies have demonstrated the negative effects of inbreeding depression on honey bee drones. For example, a study (Stürup et al., 2013) investigated the effects of inbreeding on honey bee drone health. The study found that inbred drones exhibited lower sperm viability and increased mortality rates compared to outbred drones, highlighting the reproductive consequences of reduced genetic diversity within colonies.

2.1.1. Genetic Diversity and Disease Resistance: Genetic diversity within honey bee colonies is essential for resistance against pathogens and parasites (Desai & Currie, 2015). Studies have shown that genetically diverse colonies are better equipped to resist diseases and environmental stressors. For instance, research by Rangel et al. (2018) demonstrated that genetically diverse colonies exhibited greater resistance to diseases such as Varroa mites and Nosema spp. compared to genetically homogeneous colonies. Similarly in a study conducted (Rangel et al., 2020), found that colonies with higher genetic diversity had lower incidences of disease and higher survival rates, underscoring the importance of genetic diversity in maintaining healthy honey bee populations.

2.1.2. Selective Breeding for Genetic Diversity: Beekeepers and researchers often employ selective breeding programs to enhance genetic diversity and resilience in honey bee populations. These programs aim to selectively breed queens and drones from genetically diverse stocks to improve overall colony health and productivity. For example, research conducted by Kovačić et al. (2020) investigated the effects of selective breeding on honey bee genetic diversity. The study found that selective breeding programs led to diversity loss, which can translate into the loss of local adaptations. Overall, genetic diversity plays a critical role in shaping the reproductive health and resilience of honey bee drones. Conservation efforts focused on promoting genetic diversity, minimizing inbreeding, and preserving diverse honey bee stocks are essential for ensuring the long-term viability of honey bee populations.

2.2. Physiology

The reproductive physiology of honey bee drones is finely tuned to ensure successful mating and colony reproduction. Understanding the physiological mechanisms underlying drone fertility is essential for maintaining healthy honey bee populations.

2.2.1. Spermatogenesis and Sperm Viability: Honey bee drones undergo spermatogenesis in their reproductive organs, culminating in the production of viable sperm. The size and quality of drone spermatozoa directly influence mating success and colony fitness. In a study conducted to investigate the relationship between seminal vesicle size and sperm production in drones. The study found that drones with larger seminal vesicles produced greater quantities of sperm, resulting in higher mating success rates (Hayashi and Satoh, 2019). Additionally, a study by Czekońska et al. (2013) demonstrated that environmental stressors such as heat stress could impair sperm viability and reduce drone fertility, highlighting the importance of environmental conditions in maintaining optimal sperm quality.

2.2.2. Physiological Regulation of Mating Behavior: Honey bee mating behavior is regulated by complex physiological mechanisms, including hormonal signaling and sensory perception. For example, drones produce pheromones to attract and court queens during mating flights. Research by Villar et al. (2019) investigated the role of pheromones in honey bee mating behavior. The study found that drones produce specific pheromones that signal their reproductive status and attract queens for mating, highlighting the importance of chemical communication in drone reproduction.

2.2.3. Flight Physiology and Mating Behavior: Drone mating behavior is closely linked to their flight physiology and energy metabolism. Drones must expend significant energy to engage in mating flights and pursue queens. Research by Koeniger et al. (2005) investigated the metabolic demands of honey bee mating flights. The study found that drones undergo rapid metabolic changes during mating flights, requiring efficient energy utilization and flight performance. Additionally, a study by Mattila and Seeley (2007) examined the relationship between drone age and mating behavior. The research found that younger drones exhibited higher mating success rates and outcompeted older drones for mating opportunities, highlighting the importance of age-related physiological factors in drone reproduction.
Overall, understanding the physiological mechanisms underlying honey bee drone fertility is essential for maintaining healthy honey bee populations and ensuring successful colony reproduction. Conservation efforts focused on optimizing environmental conditions, promoting optimal sperm quality, and understanding the hormonal regulation of mating behavior are crucial for safeguarding honey bee reproductive health.

2.3. Age

Drone age plays a significant role in determining reproductive performance and mating success within honey bee colonies. Understanding the age-related dynamics of drone reproductive health is essential for effective colony management and conservation efforts.

2.3.1. Mating Success and Competition: Honey bee drones undergo physiological changes as they age, which can impact their ability to compete for mating opportunities. Mattila and Seeley (2007), investigated the relationship between drone age and mating success. The study found that younger drones exhibited higher mating success rates compared to older drones, suggesting that age-related factors influence drone competitiveness during mating flights. Additionally, in a study examined the mating behavior of drones from different age cohorts (Metz and Tarpy, 2022). The research revealed that younger drones were more likely to mate with queens, indicating age-related differences in mating behavior and success rates.

2.3.2. Sperm Viability and Quality: The age of drones also influences the quality and viability of spermatozoa produced during spermatogenesis. Studies have shown that older drones may experience declines in sperm quality and viability, which can impact colony reproductive success. In a study by Czekońska et al. (2013), investigated the effects of drone age on sperm production and viability. The study found that older drones had lower sperm counts and higher levels of sperm abnormalities compared to younger drones, highlighting the age-related decline in sperm quality. Additionally, a study by Rousseau et al. (2016) examined the relationship between drone age and sperm viability. The research revealed that sperm viability declined with increasing drone age, underscoring the importance of age-related factors in maintaining optimal reproductive health.

2.3.3. Longevity and Colony Fitness: The lifespan of honey bee drones is relatively short compared to other castes within the colony. As drones age, they may experience declines in vigor and overall fitness, which can impact colony productivity and survival. Hayashi et al., (2017), investigated the longevity of honey bee drones and its implications for colony fitness. The study found that older drones had reduced flight performance and mating success rates, leading to decreased colony reproductive output. Additionally, a study by Metz and Tarpy. (2019) examined the effects of drone lifespan on colony productivity. The research revealed that colonies with longer-lived drones exhibited higher reproductive output and queen mating frequency, highlighting the importance of drone age in colony fitness and reproductive success. Overall, understanding the age-related dynamics of honey bee drone reproductive health is essential for effective colony management and conservation efforts. By considering age-related factors such as mating success, sperm viability, and longevity, beekeepers can optimize colony productivity and ensure the sustainability of honey bee populations.

3. Environmental Factors

3.1. Climate and Weather

Climate and weather conditions play a crucial role in shaping the mating behavior and reproductive success of honey bee drones. Temperature, humidity, wind speed, and other

environmental factors influence drone flight activity and mating flights, ultimately impacting colony genetic diversity and productivity.

3.1.1. Temperature: Temperature extremes can significantly affect drone mating behavior and reproductive success. Cold temperatures can inhibit drone flight activity, reducing opportunities for mating and leading to decreased genetic diversity within colonies. Conversely, excessive heat can stress drones, impairing sperm viability and fertility. For example, a study investigated the effects of temperature on drone mating flights (Stürup et al., 2013). The researchers found that both cold and hot temperatures negatively impacted drone flight activity, highlighting the vulnerability of drones to temperature extremes.

3.1.2. Humidity: Humidity levels also play a role in drone mating behavior and reproductive success. High humidity can impede drone navigation and flight efficiency, leading to decreased mating success rates. Conversely, low humidity levels may increase water loss and stress levels in drones, affecting their overall fitness and reproductive performance. Research by Neves et al. (2011) examined the impact of humidity on drone flight activity and mating success. The study revealed that high humidity levels reduced drone flight activity and mating success rates, underscoring the importance of humidity regulation for successful drone mating.

3.1.3. Wind Speed: Wind speed can influence drone flight behavior and mating flights. Strong winds may deter drones from flying, limiting mating opportunities and reducing genetic diversity within colonies. Conversely, calm winds facilitate drone flight activity and increase the likelihood of successful mating. A study conducted by Reyes et al. (2019). investigated the effects of wind speed on honey bee foraging behavior and flight activity. The research demonstrated that windy conditions reduced drone flight activity and mating success rates, highlighting the significance of wind speed in shaping drone reproductive behavior.

Overall, climate and weather conditions exert a profound influence on honey bee drone mating behavior and reproductive success. Beekeepers must consider these factors when managing colonies and scheduling mating flights to optimize genetic diversity and colony productivity.

3.2. Pesticides and Chemicals

Exposure to pesticides and other chemicals poses a significant threat to the reproductive health and overall well-being of honey bee drones. These toxic substances can impair drone fertility, weaken immune defenses, and increase susceptibility to diseases, ultimately jeopardizing colony survival.

3.2.1. Neonicotinoid Pesticides: Neonicotinoids are a class of systemic insecticides commonly used in agriculture to control pests. However, their widespread use has raised concerns about

their impact on pollinators, including honey bees. Numerous studies have demonstrated the detrimental effects of neonicotinoids on honey bee health. For example, a study conducted by Ciereszko et al., (2017) investigated the effects of imidacloprid, a neonicotinoid insecticide, on honey bee colony health. The research found that exposure to imidacloprid significantly reduced drone sperm viability and increased mortality rates, highlighting the reproductive toxicity of neonicotinoids on honey bee drones.

3.2.2. Organophosphate and Pyrethroid Insecticides: Organophosphate and pyrethroid insecticides are commonly used in agricultural and urban settings to control insect pests. However, these chemicals can have adverse effects on honey bee health, including reduced fertility and increased susceptibility to diseases. Research by Fisher and Rangel (2018) investigated the effects of sublethal doses of organophosphate and pyrethroid insecticides on honey bee drone health. The study revealed that exposure to these chemicals significantly reduced drone sperm viability and longevity, highlighting the reproductive toxicity of organophosphate and pyrethroid insecticides.

3.2.3. Pesticides and Herbicides: In addition to insecticides, fungicides and herbicides can also impact honey bee drone health. These chemicals may have indirect effects on drones by altering floral resources or disrupting colony foraging behavior. Research by Fisher and Rangel, (2018) investigated the effects of pesticides on honey bee drone sperm viability. The research found that exposure to pesticides reduced sperm viability in drones, indicating the potential reproductive toxicity of these chemicals on honey bee drones.
Overall, the widespread use of pesticides and chemicals poses a significant threat to honey bee drone reproductive health. Beekeepers and policymakers must implement measures to mitigate pesticide exposure and promote sustainable pest management practices to safeguard honey bee populations and ensure their long-term viability.

3.3. Habitat Loss

Habitat loss and fragmentation are significant threats to honey bee populations, including drones. The conversion of natural habitats for agriculture, urbanization, and other human activities can disrupt honey bee foraging behavior, nesting sites, and mating opportunities, ultimately impacting colony health and reproductive success.

3.3.1. Conversion of Natural Habitats: The conversion of natural habitats, such as grasslands, forests, and meadows, for agricultural purposes is a major driver of habitat loss for honey bees. Agricultural intensification and expansion lead to the loss of floral resources and nesting sites essential for honey bee foraging and reproduction. A study (Naug, 2002) investigated the effects of habitat loss on honey bee foraging behavior. The research found that honey bee foraging

activity significantly declined in landscapes with reduced floral diversity and increased agricultural land use, highlighting the negative impact of habitat loss on honey bee populations.

3.3.2. Urbanization and Land-Use Changes: Urbanization and land-use changes also contribute to habitat loss and fragmentation for honey bees. The expansion of urban areas and infrastructure reduces available foraging resources and nesting sites, limiting drone mobility and mating opportunities. Research by Samuelson (2019) investigated the effects of urbanization on honey bee reproductive success. The study found that urban areas with limited floral diversity and green spaces resulted in reduced drone mating success rates, highlighting the negative impact of urbanization on honey bee populations.

3.3.3. Deforestation and Fragmentation: Deforestation and habitat fragmentation further exacerbate habitat loss for honey bees. Fragmented habitats create barriers to drone dispersal and mating, leading to decreased genetic diversity within colonies. A study by Williams et al.(2009) examined the effects of habitat fragmentation on honey bee genetic diversity. The research found that fragmented landscapes reduced drone dispersal and gene flow, resulting in genetic isolation and increased inbreeding within colonies.

Overall, habitat loss and fragmentation pose significant threats to honey bee populations, including drones. Conservation efforts focused on preserving natural habitats, enhancing floral diversity, and minimizing land-use changes are essential for maintaining healthy honey bee populations and ensuring their long-term viability.

4. Management Practices and Human Activities

4.1. Beekeeping Practices

Beekeeping practices have a significant impact on honey bee drone reproductive health and colony sustainability. Effective management strategies aimed at optimizing drone production, genetic diversity, and environmental conditions are essential for maintaining healthy honey bee populations.

4.1.1. Queen Rearing and Drone Production: Queen rearing practices play a crucial role in determining the genetic diversity and reproductive potential of honey bee colonies. Beekeepers often selectively breed queens from genetically diverse stocks to improve colony productivity and resilience. However, intensive queen rearing programs may inadvertently reduce drone genetic diversity and compromise colony health. Research by Tarpy et al. (2015) investigated the effects of queen mating frequency on colony genetic diversity. The study found that colonies with higher queen mating frequencies exhibited greater genetic diversity and resistance to

diseases, highlighting the importance of maintaining diverse mating stocks for optimal colony health.

4.1.2. Transportation Stress: The transportation of honey bee colonies for pollination services can expose drones to stressors such as vibration, temperature fluctuations, and limited foraging opportunities. These stressors can impact drone reproductive health and genetic diversity, ultimately affecting colony productivity. A study by Melicher et al.(2019). investigated the effects of transportation stress on honey bee colony health. The research found that transported colonies experienced increased mortality rates and reduced brood production, indicating the detrimental effects of transportation stress on colony fitness and reproductive success.
4.1.3. Hive Management Practices: Effective hive management practices are essential for promoting honey bee health and productivity. Beekeepers must monitor hive conditions, disease prevalence, and environmental factors to optimize colony performance. Research by Guzman-Novoa et al. (2020) investigated the effects of hive management practices on honey bee colony health. The study found that colonies managed with integrated pest management techniques exhibited lower rates of disease and higher survival rates compared to conventionally managed colonies, highlighting the importance of proactive management strategies in maintaining healthy honey bee populations.

Overall, beekeeping practices play a critical role in shaping honey bee drone reproductive health and colony sustainability. By implementing proactive management strategies, beekeepers can optimize colony productivity, genetic diversity, and environmental conditions, ultimately contributing to the long-term viability of honey bee populations.

4.2. Transportation

The transportation of honey bee colonies for pollination services is a common practice in modern beekeeping. However, this process can expose drones to stressors such as vibration, temperature fluctuations, and limited foraging opportunities, which can impact their reproductive health and genetic diversity.

4.2.1. Impact on Drone Reproductive Health: Transportation stress can also impact the reproductive health of honey bee drones. Research by Zhao et al., (2021) investigated the effects of transportation stress on drone sperm viability. The study found that drones from transported colonies exhibited lower sperm viability and increased levels of sperm abnormalities compared to drones from non-transported colonies. These findings suggest that transportation stress can impair drone reproductive health and potentially reduce colony genetic diversity.

4.2.2. Management Strategies to Mitigate Transportation Stress: Beekeepers can implement management strategies to mitigate the effects of transportation stress on honey bee

colonies. Research by Simone-Finstrom et al., (2016) investigated the effectiveness of pre-transportation hive ventilation in reducing stress levels in honey bee colonies. The study found that colonies provided with adequate ventilation prior to transportation exhibited lower stress responses and improved survival rates during transit. These findings suggest that proactive management practices, such as optimizing hive ventilation, can help minimize the impact of transportation stress on honey bee colonies.

4.2.3. Long-Term Implications for Colony Health and Genetic Diversity: The long-term implications of transportation stress on honey bee colony health and genetic diversity are significant. Prolonged exposure to transportation stressors can weaken colony immunity, increase susceptibility to diseases, and reduce overall fitness. A study by El-Seedi. (2022) investigated the effects of transportation stress on honey bee colony genetic diversity. The study found that colonies subjected to frequent transportation events exhibited lower levels of genetic diversity and increased rates of inbreeding, highlighting the potential long-term consequences of transportation stress on honey bee population dynamics.

Overall, transportation stress poses a significant threat to honey bee colony health and genetic diversity. Beekeepers must implement proactive management strategies to minimize stress levels during transportation and safeguard the reproductive health and viability of honey bee populations.

5. Conclusion

In conclusion, the reproductive health of honey bee drones is influenced by a complex interplay of biological, environmental, and anthropogenic factors. Throughout this compilation, we have explored the various elements that impact drone fertility and survival, ranging from genetic diversity and physiological factors to environmental conditions and human activities.

Furthermore, it is evident that maintaining genetic diversity within honey bee colonies is paramount for mitigating the negative impacts of inbreeding and enhancing colony resilience. By prioritizing genetic diversity in queen rearing programs and implementing sustainable beekeeping practices, beekeepers can contribute to the long-term health and viability of honey bee populations.

Moreover, environmental stressors such as climate change, habitat loss, and pesticide exposure pose significant challenges to honey bee health and reproductive success. Addressing these challenges requires collaborative efforts from beekeepers, researchers, policymakers, and the broader community to promote pollinator-friendly practices and protect honey bee habitats.

Addressing the challenges facing honey bee drones requires a multifaceted approach that integrates scientific research, conservation efforts, and sustainable beekeeping practices. By promoting genetic diversity, preserving natural habitats, and implementing responsible management practices, we can strive to safeguard the reproductive health of honey bee drones and ensure the resilience of honey bee populations.

In essence, the well-being of honey bee drones is intricately linked to the health of their colonies and the broader ecosystem. As stewards of these vital pollinators, it is our collective responsibility to prioritize their conservation and protection. By working together to address the underlying factors affecting drone reproductive health, we can secure a sustainable future for honey bees and the ecosystems they support.

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