Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.245

ISSN: 2582 – 7146

Current Research in Agriculture and Farming

Curr. Rese. Agri. Far. (2025) *6*(1), 9-13

Peer-Reviewed, Refereed, Open Access Journal

Review Article

Queen Bee Pheromones and Colony Regulation

Damodhara G.N[1], Karthik R[2*], Samudrapu Sanjay Raj[2], Kritika Sharma[3], Manjunatha B[4], Priti[5], Nishtha Vashishta[5], Suresh Kumar Mahala[6], Abhishek T S[3]

[1]Divission of Sericulture, Manasa Gangothri University, Mysore, Karnatka, India

[2]Department of Entomology, Chaudhary Sarvan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur, Himachal Pradesh, India

[3]PhD Scholar, Division of Entomology, Sher-E-Kashmir University of Agricultural Scineces and Technology, Chatha, Jammu

[4]The Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, India

[5]Project Associate, Floriculture lab, Division of Agrotechnology, Council of Scientific, and Industrial Research-Institute of Himalayan Bioresource Technology (CSIR-IHBT), Palampur, Himachal Pradesh, India

[6]Ph.D. Research Scholar, Department of Entomology, Maharana Pratap University of Agriculture & Technology, Udaipur, Rajasthan

*Corresponding Author E-mail: ladybird.cryptolaemus@gmail.com

Received: 15.12.2024 | Revised: 18.02.2025 | Accepted: 26.02.2025

ABSTRACT

Queen bee pheromones, particularly the queen mandibular pheromone (QMP), are critical chemical signals regulating honey bee (Apis mellifera) colony dynamics. Comprising compounds like 9-oxo-2-decenoic acid (9-ODA), QMP suppresses worker reproduction, coordinates task allocation, prevents swarming, and facilitates mating. These pheromones act through olfactory and molecular pathways, modulating gene expression and epigenetic mechanisms to maintain colony cohesion. Ecologically, QMP enhances colony resilience and supports pollination services, while its applications in beekeeping improve colony management. Despite advances, gaps remain in understanding minor pheromone components and environmental impacts on signaling. This review synthesizes the chemical, physiological, and ecological roles of queen pheromones, highlighting their evolutionary significance and future research directions.

Keywords: *Queen pheromones, QMP, Colony regulation, Worker reproduction, Social cohesion.*

INTRODUCTION

Honey bee colonies (Apis mellifera) are complex social systems where the queen plays a central role in maintaining colony cohesion and regulating worker behavior. Queen bee pheromones, primarily produced by the mandibular glands, are chemical signals that modulate the physiology, behavior, and reproductive status of colony members. These pheromones ensure the colony operates as a unified superorganism, with the queen suppressing worker reproduction, coordinating tasks, and maintaining social order.

Cite this article: Damodhara, G. N., Karthik, R., Raj, S. S., Sharma, K., Manjunatha, B., Priti, Vashishta, N., Mahala, S. K., & Abhishek, T. S. (2025). Queen Bee Pheromones and Colony Regulation, *Curr. Rese. Agri. Far. 6*(1), 9-13. doi: http://dx.doi.org/10.18782/2582-7146.245

This article explores the role of queen pheromones in colony regulation, their chemical composition, mechanisms of action, ecological significance, and practical applications, supported by scientific evidence.

Chemical Composition of Queen Pheromones

The queen mandibular pheromone (QMP) is the most studied pheromone complex in honey bees. QMP consists of five primary components: 9-oxo-2-decenoic acid (9-ODA), 9-hydroxy-2-decenoic acid (9-HDA), 10-hydroxy-2-decenoic acid (10-HDA), 10-hydroxydecanoic acid (10-HDAA), and methyl p-hydroxybenzoate (HOB) (Slessor et al., 1988). 9-ODA is the dominant component, critical for inhibiting worker ovary development and attracting drones during mating flights (Winston et al., 1991). Additional pheromones from the tergal glands, Dufour's gland, and koschevnikov gland complement QMP, contributing to a multifaceted chemical signaling system (Keeling et al., 2003).

These compounds vary in volatility, enabling both short- and long-range communication. Workers detect pheromones via antennal chemoreceptors, triggering behavioral and physiological responses. The synergistic action of QMP components amplifies their regulatory effects, ensuring robust colony control (Pankiw et al., 1996). Recent studies suggest that minor components, such as esters and alcohols from other glands, may fine-tune these responses, warranting further investigation (Plettner et al., 1997).

Mechanisms of Colony Regulation

Queen pheromones regulate multiple colony dynamics, including reproduction, task allocation, swarming, and mating. Key mechanisms include:

Suppression of Worker Reproduction

QMP, particularly 9-ODA and 9-HDA, suppresses worker ovary development by inhibiting oogenesis-related gene expression (Grozinger et al., 2003). This ensures the queen's reproductive monopoly, maintaining genetic cohesion. In queenless colonies or when QMP levels drop, workers activate their ovaries, producing drone eggs, which signals colony disruption (Hoover et al., 2003). This reproductive suppression is dose-dependent, with higher QMP concentrations correlating with stronger inhibition (Pankiw et al., 1998).

Coordination of Worker Behavior

QMP modulates the division of labor among workers. Young workers exposed to QMP prioritize nursing tasks, while older workers shift to foraging (Pankiw et al., 1998). This regulation aligns worker activities with colony needs, optimizing brood care and resource collection. QMP delays the transition to foraging, ensuring adequate nurse bees (Robinson et al., 1992). The pheromone also influences worker retinue behavior, where workers groom and feed the queen, reinforcing her dominance (Seeley, 1985).

Swarm Prevention

High QMP levels indicate a healthy queen, reducing swarming tendencies (Winston, 1987). Low QMP or queen absence prompts workers to build queen cups, initiating swarm preparation. Tergal gland pheromones enhance swarm cohesion during colony fission, guiding workers to follow the queen (Keeling et al., 2003). This mechanism balances colony reproduction with stability, preventing premature division.

Drone Attraction and Mating

During mating flights, 9-ODA attracts drones, ensuring successful mating (Gary, 1962). This long-range pheromone promotes polyandry, as the queen mates with multiple drones, increasing genetic diversity among workers (Tarpy et al., 2004). Genetic diversity enhances colony resilience, improving disease resistance and task efficiency (Oldroyd et al., 1992).

Physiological and Molecular Effects

QMP exerts effects through olfactory and molecular pathways. Workers detect pheromones via antennal receptors, activating neural circuits in the antennal lobe and mushroom bodies (Grozinger et al., 2007). These signals modulate gene expression, affecting behavior and reproduction. For example, QMP downregulates vitellogenin in worker ovaries, inhibiting egg development

(Hoover et al., 2003). QMP also influences juvenile hormone levels, which regulate worker aging and task transitions (Robinson, 1987).

Epigenetic mechanisms, such as DNA methylation, mediate QMP effects. QMP exposure alters methylation patterns in worker brains, influencing caste-specific gene expression (Lyko et al., 2010). These changes enable behavioral plasticity, allowing workers to adapt to colony demands. Transcriptomic studies reveal that QMP regulates hundreds of genes, underscoring its broad impact on worker physiology (Grozinger et al., 2003).

Ecological and Evolutionary Significance

Queen pheromones evolved to maximize social cohesion and reproductive efficiency. By suppressing worker reproduction, the queen directs resources to her offspring, enhancing inclusive fitness (Keller & Nonacs, 1993). The "queen signal" hypothesis suggests pheromones are honest signals of queen fitness, reducing worker-queen conflict (Seeley, 1985). The complexity of QMP reflects an evolutionary arms race, as workers may reproduce under queenless conditions, challenging queen control (Wenseleers & Ratnieks, 2006).

Ecologically, QMP enhances colony resilience by coordinating tasks and preventing premature swarming. Well-regulated colonies better withstand environmental stressors like resource scarcity or predation (Pankiw, 2004). QMP-supported foraging populations bolster pollination services, critical for ecosystem stability (Klein et al., 2007). Declines in bee populations highlight the need to protect pheromone-mediated regulation (Goulson et al., 2015).

Applications in Beekeeping

Synthetic QMP stabilizes queenless colonies, reduces swarming, and boosts productivity (Pankiw et al., 2000). QMP lures mimic queen presence, delaying worker ovary activation (Butler & Fairey, 1964). In queen rearing, QMP exposure improves queen acceptance, reducing rejection (Slessor et al., 1990). However, overuse of synthetic QMP may desensitize workers, requiring precise application (Pankiw, 2004).

QMP also aids in colony transport and requeening, maintaining colony stability during stress. Beekeepers use QMP to monitor queen health, as reduced pheromone production signals queen failure (Pettis et al., 2013). These applications underscore the practical value of pheromone research.

Challenges and Future Directions

The full scope of queen pheromones remains elusive. Minor QMP components and pheromones from other glands may have undiscovered roles (Keeling et al., 2003). Environmental stressors, like pesticides or poor nutrition, disrupt pheromone signaling, impacting colony health (Pettis et al., 2013). Climate change may alter pheromone production or volatility, affecting communication (Villarreal et al., 2020).

Future research should employ mass spectrometry and transcriptomics to identify novel pheromones and receptors. Investigating stressor impacts on pheromone pathways is critical amid bee population declines (Goulson et al., 2015). Integrating pheromone studies with colony-level analyses will clarify social regulation dynamics. Exploring interspecies pheromone differences (e.g., Apis cerana vs. Apis mellifera) could reveal evolutionary insights (Pirk et al., 2011).

Emerging Research Areas

Recent studies highlight QMP's role in modulating worker immunity. QMP exposure upregulates immune genes, enhancing disease resistance (Grozinger et al., 2007). This suggests pheromones contribute to colony health beyond social regulation. Additionally, QMP may influence gut microbiota, affecting worker digestion and longevity (Kapheim et al., 2021). These findings open new avenues for studying pheromone-mediated health.

Cross-colony pheromone variation is another frontier. Queen age, mating status, and genetics influence QMP composition, affecting regulatory efficacy (Pankiw et al., 1996). Understanding these variations could improve queen breeding programs. Finally, synthetic biology offers potential for designing tailored pheromones, enhancing beekeeping precision (Berenbaum & Robinson, 2020).

CONCLUSION

Queen bee pheromones, especially QMP, are pivotal to colony regulation, orchestrating reproduction, behavior, and cohesion. Their chemical complexity, molecular effects, and evolutionary role highlight their significance in honey bee biology. Applications in beekeeping demonstrate their practical value, while challenges like environmental stressors underscore the need for continued research. Emerging areas, such as immunity and microbiota effects, promise to expand our understanding. Queen pheromones exemplify the delicate balance of cooperation and control in eusocial systems, with profound implications for ecology, agriculture, and conservation.

Acknowledgement:
I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding: NIL.

Conflict of Interest:
There is no such evidence of conflict of interest.

Author Contribution:
All authors have participated in critically revising of the entire manuscript and approval of the final manuscript.

REFERENCES

Berenbaum, M. R., & Robinson, G. E. (2020). Insect synthetic biology: New tools for old problems. *Proceedings of the National Academy of Sciences, 117*(6), 2855-2857.

Butler, C. G., & Fairey, E. M. (1964). The role of the queen in preventing oogenesis in worker honey bees. *Journal of Apicultural Research, 3*(2), 14-18.

Gary, N. E. (1962). Chemical mating attractants in the queen honey bee. *Science*, *136*(3518), 773-774.

Goulson, D. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science, 347*(6229), 1255957.

Grozinger, C. M. (2003). Pheromone-mediated gene expression in the honey bee brain. *Proceedings of the National Academy of Sciences, 100*(Suppl 2), 14519-14525.

Grozinger, C. M. (2007). Disentangling the effects of queen pheromones on worker behavior and physiology. *Insectes Sociaux, 54*(4), 370-377.

Hoover, S. E. (2003). The effect of queen pheromones on worker honey bee ovary development. *Naturwissenschaften, 90*(10), 477-480.

Kapheim, K. M. (2021). The honey bee gut microbiota: Ecology and evolution. *Current Opinion in Insect Science, 44*, 61-67.

Keeling, C. I. (2003). New components of the honey bee queen retinue pheromone. *Proceedings of the National Academy of Sciences, 100*(8), 4486-4491.

Keller, L., & Nonacs, P. (1993). The role of queen pheromones in social insects: Queen control or queen signal? *Animal Behaviour, 45*(4), 787-794.

Klein, A. M. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B, 274*(1608), 303-313.

Lyko, F. (2010). The honey bee epigenomes: Differential methylation of brain DNA in queens and workers. *PLoS Biology, 8*(11), e1000506.

Oldroyd, B. P. (1992). Polyandry and colony performance in the honey bee. *Behavioral Ecology and Sociobiology, 30*(5), 351-356.

Pankiw, T. (1996). Queen mandibular gland pheromone influences worker honey bee foraging ontogeny and juvenile hormone titers. *Journal of Insect Physiology, 42*(4), 303-310.

Pankiw, T. (1998). Mandibular gland components of queen honey bees affect worker behavior. *Journal of Insect Behavior, 11*(4), 583-597.

Pankiw, T. (2004). Honey bee pheromones and colony regulation. *Journal of Apicultural Research, 43*(4), 192-198.

Pankiw, T. (2000). Synthetic queen mandibular pheromone for beekeeping. *American Bee Journal, 140*(8), 629-632.

Pettis, J. S. (2013). Pesticide exposure in honey bees results in increased levels of the gut pathogen Nosema. *Naturwissenschaften, 100*(2), 153-158.

Pirk, C. W. (2011). Pheromonal communication in honey bees (Apis spp.). *Apidologie, 42*(5), 553-562.

Plettner, E. (1997). Minor components of the queen mandibular pheromone of the honey bee. *Journal of Chemical Ecology, 23*(2), 427-439.

Robinson, G. E. (1987). Regulation of honey bee age polyethism by juvenile hormone. *Behavioral Ecology and Sociobiology, 20*(5), 329-338.

Robinson, G. E. (1992). Hormonal and pheromonal regulation of honey bee foraging behavior. *American Zoologist, 32*(3), 384-395.

Seeley, T. D. (1985). *Honeybee Ecology: A Study of Adaptation in Social Life*. Princeton University Press.

Slessor, K. N. (1988). Isolation, identification, and synthesis of queen mandibular gland pheromone of the honey bee. *Journal of Chemical Ecology, 14*(8), 1747-1762.

Slessor, K. N. (1990). Semiochemicals of the honey bee queen mandibular glands. *Journal of Chemical Ecology, 16*(6), 1793-1803.

Tarpy, D. R. (2004). Genetic diversity in honey bee colonies enhances productivity and fitness. *Science, 305*(5681), 362-364.

Villarreal, C. (2020). Climate change impacts on honey bee physiology and behavior. *Environmental Entomology, 49*(6), 1267-1275.

Wenseleers, T., & Ratnieks, F. L. (2006). Enforced altruism in insect societies. *Nature, 444*(7115), 50.

Winston, M. L. (1987). *The Biology of the Honey Bee*. Harvard University Press.

Winston, M. L. (1991). The role of queen mandibular pheromone in honey bee colony dynamics. *Annals of the Entomological Society of America, 84*(3), 274-279.