The 11th Asian-Australasian Conference on Precision Agriculture (ACPA 11)
October 14-16, 2025, Chiayi, Taiwan

MODELING AND CHARACTERIZATION OF UNIMODAL AND BIMODAL DIURNAL POLLEN FORAGING PATTERNS IN HONEYBEE COLONIES

Jhih-Cing Huang, Ta-Te Lin*

Department of Biomechatronics Engineering, National Taiwan University, Taipei, Taiwan, ROC

*Corresponding Author: m456@ntu.edu.tw

ABSTRACT

Pollen foraging patterns in honeybee colonies provide essential information on their ecological adaptation strategies. This study proposes a statistical modeling framework to characterize diurnal pollen foraging patterns in honeybee colonies. To support this, data were collected from healthy honeybee colonies during controlled experimental period. The raw pollen harvest data were then segmented into daily time series and converted into hourly histograms to capture foraging rhythms more effectively. Gaussian curve fitting combined with nonlinear least-squares optimization was employed to model activity distributions. Each observation day was classified as either unimodal or bimodal based on detected peak frequencies. Key parameters including peak timing, amplitude, and spread were estimated for each distribution type. Model performance was evaluated using multiple statistical criteria, including Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and the coefficient of determination (R^2). Cross-validation procedures with fallback mechanisms were implemented to handle fitting failures. Results revealed significant distinctions between unimodal and bimodal foraging strategies. Unimodal distributions exhibited average peak activity at midday, while bimodal distributions demonstrated two distinct activity peaks occurring in morning and early afternoon periods. These observations highlight varying foraging strategies across observation days, indicating flexible adaptive mechanisms in honeybee colonies. The proposed framework provides a robust approach for classifying and characterizing diurnal pollen foraging patterns. By distinguishing unimodal and bimodal distributions, this methodology contributes to enhanced understanding of honeybee foraging behavior.

Keywords: honeybee, foraging behavior, diurnal activity pattern, pollen harvest, modality.

INTRODUCTION

Understanding the diurnal pattern of honeybee foraging is essential for evaluating colony health with pollination efficiency. Honeybee foraging patterns are typically assumed to follow unimodal rhythms with single midday peaks (Li et al., 2025). However, observations reveal both unimodal and bimodal patterns, with distinct morning and afternoon peaks under certain conditions (Abdel-Galel et al., 2021). This study employs Gaussian mixture modeling to systematically identify and characterize these rhythms.

MATERIALS AND METHODS

Data were collected from healthy honeybee colonies using continuous webcam recording. Hourly bee traffic counts were extracted, excluding nighttime records for reducing noise. Pollen harvest rate was defined as the ratio of pollen-carrying bees to total incoming bees per hour. Daily data were organized into 24-hour histograms and fitted with Gaussian mixture models (GMMs) using nonlinear least-squares optimization. The number of detected peaks determined daily modality classification. Key parameters were estimated, including peak time (μ), amplitude (A), and spread (σ). Model performance was evaluated using multiple statistical criteria: AIC, BIC, MAE, RMSE, and R^2. Lower information criteria and error values indicated better model fits.

RESULTS & DISCUSSION

Across 173 observation days, unimodal distributions occurred on 116 days (67%) and bimodal distributions on 57 days (33%). Unimodal patterns showed single midday peaks with higher amplitude and broader temporal spread, while bimodal patterns exhibited distinct morning and afternoon peaks with lower individual amplitudes and narrower spread (Table 1).

Table 1 Gaussian Fitting Parameters for Unimodal and Bimodal Foraging Patterns

Modality	Days	Peak Time μ (h)	Amplitude A	Spread σ (h)
Unimodal	116	10.8 ± 0.4	0.41 ± 0.14	2.1 ± 0.6
Bimodal (Peak 1)	57	9.1 ± 1.4	0.25 ± 0.13	1.2 ± 0.7
Bimodal (Peak 2)	-	13.5 ± 1.7	0.20 ± 0.11	1.6 ± 0.9

Bimodal fits achieved good model performance (MAE=0.014, RMSE=0.021, R^2=0.93) compared to unimodal fits (MAE=0.025, RMSE=0.037, R^2=0.91), with AIC and BIC values following the same trend. These results demonstrate that honeybee colonies employ flexible foraging strategies, alternating between concentrated midday activity and split morning and afternoon patterns.

CONCLUSIONS

Gaussian mixture modeling effectively distinguished unimodal and bimodal diurnal pollen foraging patterns in honeybee colonies. Unimodal days, which occurred in 67% of observations, showed concentrated midday peaks around 10.8 h (≈11:00 AM). In contrast, bimodal days (33% of observations) exhibited two distinct activity peaks: a morning peak around 9.1 h (≈9:00 AM) and an early afternoon peak around 13.5 h (≈1:30 PM). Such findings provide a robust foundation for exploring how seasonal or environmental dynamics shape colony foraging behavior.

REFERENCES

Xu, X., Z.-X. Ren, J. Trunschke, J. Kuppler, Y.-H. Zhao, E. Knop, and H. Wang. 2021. Bimodal activity of diurnal flower visitation at high elevation. *Ecol. Evol.* 11(20): 13487-13500.

Baum, K. A., W. L. Rubink, R. N. Coulson, and V. M. Bryant Jr. 2011. Diurnal patterns of pollen collection by feral honey bee colonies in southern Texas, USA. *Palynology* 35(1): 85-93.

Li, D.-F., J. Tang, X.-D. Fan, Y.-D. Chen, Z. Liu, A.-T. Liang, Y.-T. He, and X.-C. Yan. 2025. Diurnal temperature and time affect visitation patterns of honey bees. *Sociobiology* 72(1): e11384.

Abdel-Galel, R. M., S. M. Elbanna, and F. M. Semida. 2021. Foraging rhythm of honeybees Apis mellifera in Ismailia, Egypt. *CATRINA Int. J. Environ. Sci.* 23(1): 27-33.