

positively associated with brood development and colony performance. These relationships help explain why climate anomalies can sharply reduce production: in a Mediterranean monitoring study, drought and high temperatures shortened flowering by three weeks, reduced hive weight gain from 18.92 kg to 7.67 kg between years, and increased food stress while altering pollen spectrum and honey characteristics. Seasonal stress also carries over into winter survival, as warmer and drier conditions in the preceding year have been linked to increased winter mortality, highlighting that honey production is shaped not only by harvest-season conditions, but also by how colonies enter and endure the non-productive season.

These environmental pressures make adaptive seasonal management a primary requirement for modern beekeeping. Modeling and survey studies indicate that seasonality affects colony dynamics through changes in foraging behavior, resource access, brood production, and lifespan, while climate change is altering the timing and severity of these seasonal processes in ways that can increase losses or weaken spring colonies (Chen et al., 2025). Warmer autumns and winters can extend late-season flight, skew colony age structure toward older bees, and raise the risk of spring failure, which means overwintering strategies developed under historically colder conditions may no longer remain adequate in many regions (Rajagopalan et al., 2024). At the practical level, this has shifted attention toward interventions such as seasonal feeding, improved queen and comb management, stronger autumn preparation, and in some contexts relocation, cold storage, water supplementation, or shade management to buffer climate stress. Research from Kenya likewise suggests that management can partly mitigate climate effects, with water supplementation associated with lower livestock decrease during the dry and hot season, reinforcing the view that seasonal strategies must increasingly function as climate-adaptation tools rather than routine calendar tasks.

Against this background, the objective of research on seasonal hive management is shifting from documenting losses toward developing predictive, regionally adapted, and evidence-based strategies to improve both colony resilience and honey yield. Recent studies show that productivity is influenced by multiple interacting factors, including hive number, harvest frequency, beekeeper experience, weather, and management intensity, while machine learning and remote monitoring tools are beginning to identify winter climatic variables and in-hive indicators that can forecast production outcomes and guide timely interventions. Parallel work using environmental and machine-learning models finds that winter temperature, humidity, wind, pressure, and vegetation signals can predict honey production classes and support targeted responses such as adjusted feeding or supplementary heating (Ramirez-Diaz et al., 2025). Even so, the literature remains uneven: reviews highlight regional gaps, strong dependence on local environmental context, and the need for broader integration of floral diversity, pest pressure, and management variables into decision-support frameworks (Gratzer et al., 2025). Accordingly, this paper positions seasonal management as an integrative concept linking colony biology, environmental variability, and applied beekeeping practice, with the aim of clarifying how season-specific interventions can be used to improve honey production under increasingly variable ecological conditions.

2 Seasonal Dynamics of Honeybee Colonies and Honey Production

2.1 Seasonal changes in colony population development

Honeybee colony population development follows a pronounced seasonal cycle driven by brood rearing, food availability, and queen laying dynamics. Modeling and empirical studies agree that colony populations fluctuate periodically across the year, with brood and adult populations typically increasing through spring and early summer when pollen and nectar are abundant, then declining after mid-summer as environmental conditions and forage become less favorable (Chen et al., 2025). Field observations in southwestern Saudi Arabia similarly showed that adult bee populations were highest from early March to late June, while brood populations peaked from February to June, confirming that seasonal colony expansion is closely synchronized with the main flowering period.

Seasonal transitions also shape colony physiology and overwintering capacity, not just colony size. Colonies shift from short-lived summer workers to long-lived winter bees, and this transition is strongly associated with reduced brood rearing in autumn and declining pollen supply, which helps colonies survive winter and resume brood