

production in the next cycle (Knoll et al., 2020). At the same time, simulation studies indicate that seasonality in queen egg-laying rate can either support or suppress colony survival, and brood-based indicators can reveal stress from spring and autumn forage gaps earlier than adult bee abundance or honey reserves alone.

2.2 Influence of seasonal floral resources on honey yield

Seasonal variation in floral resources directly affects honey production because nectar and pollen availability determine both foraging opportunity and colony nutritional status. Large-scale floral resource datasets show that flowering phenology, nectar output, pollen production, and sugar availability vary through the year and can be quantified on a daily basis, making seasonal resource continuity a central determinant of potential honey yield. In farmed landscapes, nectar supply shows strong seasonal fluctuations, with major peaks in May and July but clear deficit periods in March, June, and late summer, indicating that the timing of forage availability can constrain honey production even where total annual floral resources appear adequate.

Seasonal honey yield also depends on the diversity and composition of flowering plants available to colonies. In semi-arid Tanzania, the number of foraging bees varied significantly among months in parallel with flower abundance, and foraging increased with plant diversity, supporting the view that diverse plant communities sustain more continuous honey production across the year (Mramba, 2025). More region-specific studies reach the same conclusion: linden species can substantially improve nectar and pollen supply in June and July, but their short flowering periods and year-to-year shifts in flowering onset mean that complementary plant species are needed to stabilize seasonal resource availability and reduce fluctuations in honey flow.

2.3 Seasonal environmental factors affecting foraging behavior

Seasonal environmental conditions strongly regulate honeybee foraging behavior, and weather effects are often immediate enough to alter daily nectar and pollen intake. Honeybee activity is more sensitive to weather variation than bumblebee activity, and predictive modeling shows that most observed variation in bee egress rate can be explained by temperature and solar radiation, highlighting how closely foraging depends on short-term atmospheric conditions. Review evidence further indicates that temperature and light intensity are generally positively associated with nectar collection, whereas rainfall, humidity, and wind reduce collection efficiency, so seasonal weather patterns influence honey production through both bee behavior and floral nectar secretion (Vincze et al., 2024).

The effects of environmental conditions on foraging also vary by season and time of day. In Egypt, honeybees showed a bimodal daily foraging rhythm, significant temperature dependence, and the highest seasonal abundance of foragers in spring, with effective flight occurring within a microclimatic window of about 20 °C-28 °C. Autumn observations in Chandigarh likewise found that pollen foraging peaked around midday under moderate temperatures and then declined later in the afternoon, while the main pollen source near the colonies strongly shaped the daily pattern of activity, illustrating how local forage and season-specific weather interact to determine field performance.

3 Spring Management Strategies for Enhancing Honey Production

3.1 Early spring colony recovery and population expansion

Early spring colony recovery depends first on rebuilding brood production before the main nectar flow begins. Spring pollen supplementation consistently advances brood rearing and increases early worker production, with supplemented colonies starting brood rearing earlier and producing more workers by late April or early May than pollen-limited colonies. This nutritional effect is especially important when natural pollen is scarce, because unsupplemented colonies in pollen-poor environments rear less brood and later enter the season with smaller adult populations (Figure 1) (Hoover et al., 2022; Ulgezen et al., 2025).

Targeted feeding before or at the start of spring also improves colony build-up at the whole-colony level. Late-winter supplemental feeding increased net hive weight, bee numbers, and brood cell numbers by April, showing that early nutritional support can accelerate spring development under commercial conditions. More recent field evidence similarly found that a pollen substitute diet can improve early-spring population growth,