

proper colony management during dearth periods is therefore essential for maintaining productive colonies. Artificial feeding is used as an alternative to migration during such periods, with the goal of maintaining colony parameters well enough to take advantage of the next floral-rich season, although no universally accepted standard commercial diet yet exists (Paray et al., 2020). Experimental studies support the value of supplementation in summer and autumn. Colonies fed liquid and protein supplements showed improved open brood area, sealed brood area, bee density, and honey area, with the strongest responses reported for super-protein supplementation (Nafi and Ghani, 2024). Commercial feeding trials likewise found that two pollen-containing diets produced the largest colonies and the heaviest bees, while some pollen-free diets still outperformed sugar-only feeding, indicating that diet formulation matters but that supplementation can remain beneficial even when pollen is absent from the recipe (Ricigliano et al., 2022).

Nutritional support in summer also has important health implications because poor forage quality can amplify pathogen pressure and weaken later recovery. Colonies under nutritional stress had lower brood and adult bee populations and higher *Nosema* infection levels than supplemented colonies, and these deficits persisted into spring, showing that inadequate nutrition can create both short- and long-term losses in colony strength. More broadly, nutritional stress and *Nosema* together had severe effects on colony strength, supporting the view that summer feeding is not only a productivity measure but also part of preventive colony health management. For colony maintenance, the key aim of summer feeding is to stabilize brood production, worker condition, and food reserves until natural forage improves. During periods of adverse weather and restricted foraging, egg laying and brood rearing decrease, but their extent depends partly on stored food availability, which is why supplementary diets are used to buffer the colony through stressful conditions (Paray et al., 2020). Optimizing diet composition remains an active area of research, because essential amino acid balance, rather than crude macronutrient content alone, appears to predict bee weight and later colony size more reliably (Ricigliano et al., 2022).

4.3 Disease and pest management during summer

Summer disease and pest management is dominated by control of *Varroa destructor*, because mite populations can rise rapidly during brood-rearing periods and compromise the bees that must survive into autumn and winter. Seasonal field studies show that mite populations rebound faster after summer and fall treatments than after winter or spring treatments, often exceeding the economic threshold in less than three months, which makes close summer monitoring especially important. This seasonal timing matters because in temperate climates *Varroa* populations peak around August, and mites parasitizing late-summer brood damage the developing winter bees that determine colony survival in the following season (Plamondon et al., 2024). Integrated pest management is therefore more effective than relying on a single treatment. *Varroa* control efficacy varies with season, temperature, humidity, colony condition, and local context, so no single strategy works for every beekeeper, and treatment choice should be matched to the specific management situation (Jack and Ellis, 2021). In Europe, seasonal brood interruption has shown strong potential as a long-term *Varroa* strategy, and its consistent use may even reduce dependence on winter treatments while supporting more sustainable control.

Recent summer-treatment trials reinforce the value of intervening before winter bees are produced. In Canada, a Formic Pro summer treatment tended to reduce *Varroa* infestation below the fall economic threshold and significantly reduced colony mortality, even though colony-level viral loads did not decline (Plamondon et al., 2024). In mild-climate systems, combining oxalic acid vaporization with a forced summer brood break increased mite mortality fivefold and significantly reduced mite populations, offering an additional nonwinter control option when brood is otherwise continuously present. Summer pathogen management should also include attention to *Nosema ceranae*, whose seasonal dynamics overlap with colony growth and food stress. Infection, prevalence, and spore viability are highest in spring and summer, and high infection levels are associated with reduced bee populations and food stores, indicating that summer colony maintenance should include surveillance for this pathogen where it is locally important. Because *N. ceranae* shows high pathogenicity during spring and summer and is associated with poor colony growth, integrated measures such as supplemental feeding, sanitation, selective breeding, and timely treatment can support better colony condition through the hottest part of the season (Emsen et al., 2020).