

capped brood area, colony weight, and vitellogenin-linked nutritional status, although natural pollen still remains nutritionally superior to any artificial replacement.

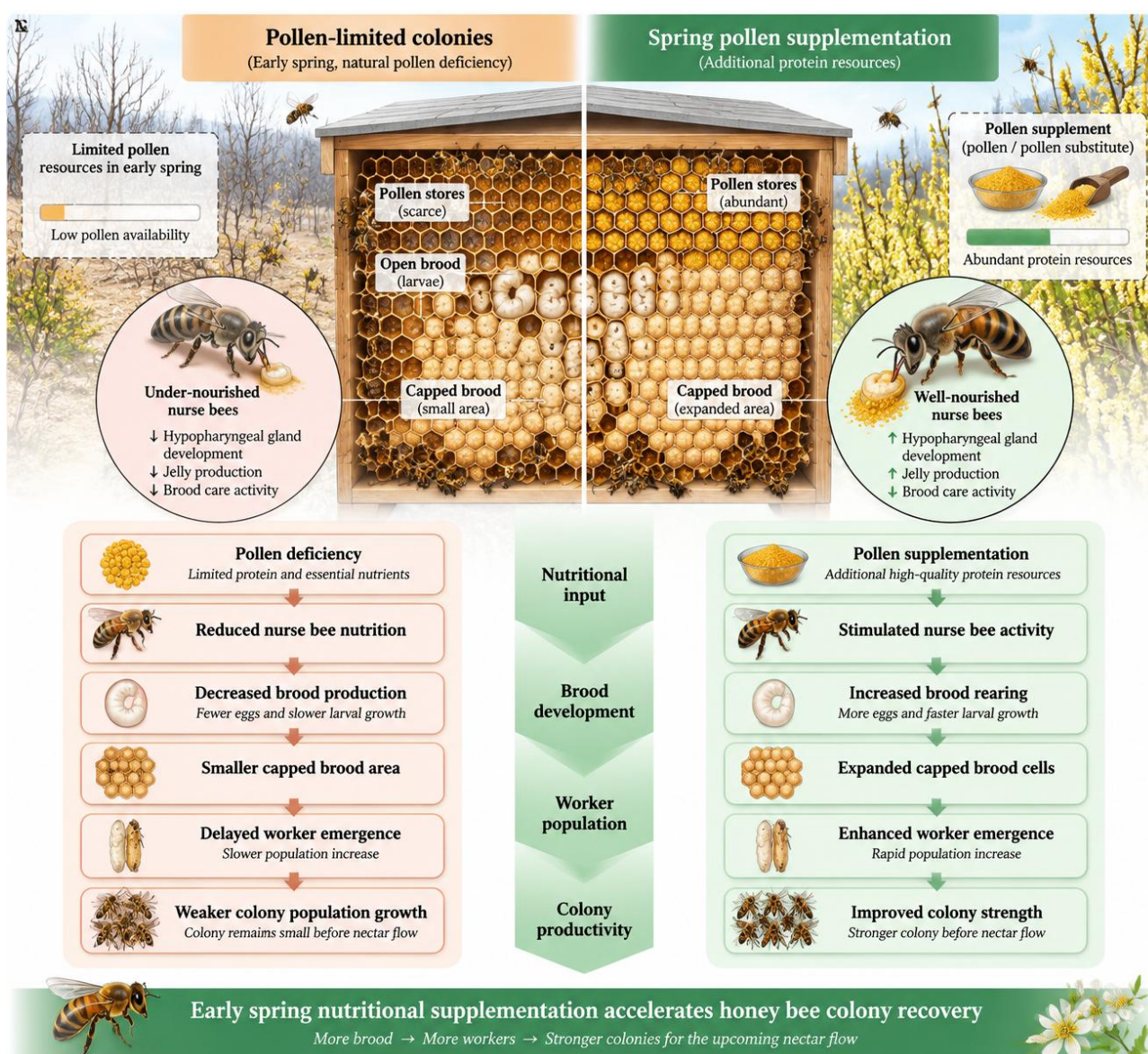


Figure 1 summarizes the nutritional mechanism underlying early spring colony recovery. When pollen availability is limited, nurse bees experience insufficient protein intake, resulting in reduced brood production and delayed worker population expansion

3.2 Swarm prevention and colony strength optimization

Swarm prevention is a core spring management objective because swarming reflects strong colony growth but usually diverts bees away from harvestable honey production. In managed systems, swarming is generally undesirable because it reduces colony productive capacity and can directly lower honey yield if the departing swarm is lost (Puškadija et al., 2023). Proactive swarm-season management therefore aims to maintain large but controlled colonies, allowing beekeepers to preserve strong field populations while retaining the option to make splits and increase profitability.

Colony strength optimization in spring also requires controlling biological stressors that weaken expanding populations. Evidence syntheses show that swarm control, methods of starting new colonies, and regular Varroa management all contribute to lower colony losses, and no single intervention is sufficient without integration into broader colony management (Gratzer et al., 2025). Experimental work supports this integrated view: colonies managed under best-management-practice systems had lower Varroa infestation, lower viral infection, and lower