



Feeding and nutrition strategies in beekeeping: Impact on colony health and honey quality

Estrategias de manejo nutricional en la producción apícola: impacto en la salud de las colonias y calidad de la miel

Authors

***Leonor Esther Cedeño Quiñonez**

✉ leonor.cedenio@institutoquininde.edu.ec



Carlos Alberto Montaña Caicedo

✉ Carlos.montania@institutoquininde.edu.ec



Instituto Superior Tecnológico Quinindé,
Quinindé, Esmeraldas, Ecuador.

*Corresponding author.

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Abstract

Beekeeping in Quinindé canton, Esmeraldas Province, is a fundamental economic activity for rural communities; however, honey productivity and quality are affected by inadequate colony feeding and nutrition strategies. This study analyzed the impact of different nutritional protocols on the health of *Apis mellifera* colonies and the physicochemical quality of the honey produced through a systematic review of studies conducted under similar agroecological conditions in Latin America. A qualitative descriptive analysis was performed on research published between 2005 and 2023, including studies of conventional feeding, supplementation with pollen and propolis, and protein substitutes under tropical conditions. The selection criteria covered research from Ecuador, Colombia, Mexico, Argentina, Uruguay, and other countries in the region with tropical and subtropical climates. The reviewed studies showed that supplemental feeding increased colony populations by 25-45% and reduced mortality by 30-50% compared with conventional management. Honey quality also improved significantly, with antioxidant content increasing by 25-40% and antimicrobial activity by 30-45%. Mean production reported in the literature rose from 20-30 to 35-45 kg·hive⁻¹·year⁻¹. These findings demonstrate that targeted nutritional strategies optimize colony health and product quality, contributing to the sustainable development of local beekeeping and generating added value for producers operating under conditions similar to those of Quinindé.

Keywords: beekeeping, bee nutrition, *Apis mellifera*, honey quality, colony development.

Resumen

La apicultura en el cantón Quinindé, provincia de Esmeraldas, representa una actividad económica fundamental para las comunidades rurales; sin embargo, la productividad se ve limitada por deficiencias en el manejo nutricional de las colonias. Esta investigación analizó el impacto de diferentes protocolos nutricionales sobre la salud de las colonias de *Apis mellifera* y la calidad fisicoquímica de la miel, mediante revisión bibliográfica sistemática de estudios en condiciones agroecológicas similares en Latinoamérica. Se evaluaron investigaciones sobre suplementación proteica y energética en climas tropicales y subtropicales de países como Ecuador, Colombia y México, Argentina y Uruguay. Los resultados evidenciaron que la suplementación adecuada incrementa la población entre 25-45% y reduce la mortalidad en 30-50% comparado con manejo tradicional. Asimismo, la calidad de la miel mejora de forma evidente en contenido de antioxidantes (25-40% superior) y actividad antimicrobiana (30-45%) mientras que la producción promedio reportada aumenta de 20-30 a 35-45 kg·colmena⁻¹·año⁻¹. Se concluye, que las estrategias nutricionales específicas optimizan la salud colonial y la calidad del producto, contribuyendo al desarrollo sostenible y al valor agregado en la región.

Palabras clave: apicultura, manejo nutricional, *Apis mellifera*, calidad de miel, productividad colonial.



Introduction

Beekeeping is an agricultural activity of growing importance in Ecuador, particularly in Esmeraldas Province, where the tropical climate and floristic diversity favor the development of *Apis mellifera*. Within this context, Quinindé canton stands out for its agricultural vocation and strategic location on the Ecuadorian coast; beekeeping is therefore regarded as an alternative productive activity for small and medium-sized rural producers, according to the Ministry of Agriculture and Livestock (MAG, 2015).

According to the Food and Agriculture Organization of the United Nations (FAO, 2015), beekeeping is a strategic tool for rural development in Latin America because pollination strengthens food security and biodiversity. National honey production is approximately 856 metric tons per year, with an average yield ranging from 20 to 30 kg·hive⁻¹, a figure that reflects the sector's growth potential (Salvador, 2019).

The Latin American Society for Bee Research (SOLATINA) reports annual colony losses of 50-60% in the region, attributed mainly to nutritional and sanitary factors and inadequate management practices (Maggi et al., 2016). Although Quinindé has favorable agroecological conditions for beekeeping, local practices therefore require urgent review to mitigate these losses and strengthen the sector's productive sustainability (MAG, 2015).

Poor nutritional management not only compromises colony population development and survival but also directly affects the physicochemical and organoleptic quality of the honey produced, reducing its commercial value and competitiveness in specialized markets (Branchiccela et al., 2021). To maintain metabolic homeostasis and the quality of the final product, colonies must receive a balanced diet of carbohydrates, proteins, lipids, and micronutrients, especially during periods of floral scarcity (Alvares, 2015).

Studies conducted in Uruguay and Argentina have shown that differentiated nutritional protocols can significantly improve both colony survival and product quality (Invernizzi et al., 2011; Antúnez et al., 2016).

In Quinindé, conventional methods based on simple sugar syrups still predominate, without accounting for colonies' specific nutritional requirements or local environmental conditions. This practice has resulted in yields below the area's productive potential and honey with limited organoleptic and functional characteristics (MAG, 2015).

The scientific literature supports specialized nutritional strategies in beekeeping. In Mexico, for example, protein supplementation increases colonies' resistance to environmental stressors and substantially improves their performance indicators (Contreras-Escareño et al., 2013). In Ecuador, recent research on the quality of commercial honey has highlighted the need to optimize production systems in order to obtain premium products (Vit et al., 2015).

Developing nutritional protocols adapted to Quinindé's agroecological conditions offers a strategic opportunity to increase the competitiveness of the local beekeeping sector, generate added value for producers, and contribute to the sustainable development of rural communities. Implementing these strategies requires a thorough understanding of the interactions among nutrition, colony health, and product quality, grounded in critical analysis of prior research conducted under similar conditions (Vit et al., 2015).

The importance of *A. mellifera* in agricultural ecosystems extends far beyond honey production: it is the principal crop pollinator worldwide. Klein et al. (2007) estimated that honey bees contribute to the pollination of approximately 87 of the world's principal food crops, representing an economic value of more than US\$153 billion annually. Garibaldi et al. (2013) later demonstrated that the abundance of wild pollinators complements, and sometimes exceeds, the pollination efficiency of managed colonies, underscoring the need to integrate pollinator-conservation strategies into tropical agricultural production systems. In the Latin American context, Imperatriz-Fonseca et al. (2012) emphasized that pollinator diversity in the Neotropical region is a natural heritage of incalculable value to sustainable agriculture; *A. mellifera* functions as a key species in disturbed ecosystems and agroforestry systems such as those found in Quinindé canton.

The phenomenon known as Colony Collapse Disorder (CCD) has generated unprecedented global concern in the beekeeping sector since it was officially identified in 2006. Oldroyd (2007) described the syndrome as the massive and sudden disappearance of adult worker bees, leaving the queen with little brood and few food reserves, without a single identifiable cause. Van Engelsdorp and Meixner (2010) documented sustained declines in managed colony populations in Europe and the United States over recent decades, with winter losses reaching 20-30% per year in some countries. Within the German bee-monitoring

project, Genersch et al. (2010) identified the interaction of multiple stressors-including pathogens, pesticides, and nutritional deficits-as the principal explanatory mechanism for the colony collapses observed worldwide, a pattern also evident under tropical Latin American conditions (Maggi et al., 2016).

The relationship between colony nutritional status and immune capacity has been the subject of extensive research over the past decade. In a comprehensive review, Brodschneider and Crailsheim (2010) showed that adequate availability of proteins, lipids, and micronutrients is fundamental to the development of the hypopharyngeal glands in nurse bees, the structures responsible for producing royal jelly and antimicrobial factors. Di Pasquale et al. (2013) experimentally demonstrated that bees fed diets with high pollen diversity had lower viral loads and greater longevity than colonies with access to floral monocultures, confirming that nutritional diversity is as important as the amount of available food. In addition, DeGrandi-Hoffman et al. (2010) showed that protein concentration in the hemolymph of young bees was directly correlated with hypopharyngeal-gland development and royal-jelly production, explaining the mechanism by which protein supplementation increases queen oviposition and brood development, as observed in Latin American studies (Pino et al., 2017; Martínez-Espinoza et al., 2018).

Tropical ecosystems such as Quinindé canton offer exceptional floristic diversity, which underpins the region's beekeeping potential. Moo-Valle et al. (2001) established that the pollen richness available to colonies directly determines their development rate and reproductive capacity, and that access to diverse pollen sources is especially critical during periods of colony growth. However, Couvillon et al. (2014), using waggle-dance analysis as an indicator of foraging conditions, showed that even environments apparently rich in floral resources contain periods of scarcity that compromise colony development, particularly during intense rains or seasonal droughts. Decourtye et al. (2010) proposed enhancing agricultural landscapes by introducing flower strips and native-vegetation corridors to ensure a continuous supply of nectar and pollen. This strategy is particularly relevant in agricultural areas of coastal Ecuador, where African oil-palm production and other monocultures limit the floral diversity available to *A. mellifera* colonies.

Secondary hive products, especially propolis, have become increasingly important both to colony health and in natural-product markets. Bogdanov et al. (2008) documented honey's nutritional and medicinal properties and showed that their expression is directly linked to the diet and health of the producing colonies, establishing a fundamental relationship between nutritional management and final-product quality. Propolis has been widely studied

for its antimicrobial, anti-inflammatory, and antioxidant properties; Ghosh et al. (2021) reported that propolis extracts contain more than 300 bioactive compounds, including flavonoids, phenolic acids, and terpenes whose concentrations vary according to colony diet and the botanical diversity of the environment. In Ecuadorian beekeeping, propolis production represents a diversification opportunity for producers in Quinindé because the area's high tropical plant diversity favors the collection of high-quality resins by forager bees (Antúnez et al., 2008).

Placing Ecuadorian honey in high-value international markets requires compliance with strict quality standards established by international bodies. The Codex Alimentarius (Sánchez et al., 2019) establishes minimum physicochemical parameters for the international marketing of honey, including limits for moisture, sugar content, enzymatic activity, and adulterants; these standards present a challenge for small producers without access to adequate processing technology. Calderone (2012) estimated that insect-pollination services in United States agriculture exceed US\$14 billion annually, demonstrating the strategic value of maintaining healthy, productive colonies beyond direct honey production. Ramírez et al. (2017) and Zapata-Vahos et al. (2023) evaluated the microbiological and physicochemical quality of honey produced in northern Colombia, a region with climatic conditions similar to those of Quinindé, and found that appropriate colony nutrition was the principal predictor of final-product quality: well-nourished colonies consistently produced honey that met Codex Alimentarius parameters.

Climate change is an emerging threat to tropical beekeeping systems, with direct implications for floral-resource availability and flowering phenology. Le Conte and Navajas (2008) found that climate-related changes in temperature and precipitation patterns alter the flowering cycles of melliferous plants, creating unpredictable periods of nutritional scarcity that may seriously compromise colony survival. Giannini et al. (2012) projected that under moderate climate-change scenarios, the potential ranges of many South American bee species could contract significantly, with negative implications for pollination services and tropical-ecosystem biodiversity. Naug (2009) proposed that nutritional stress caused by habitat loss and degradation is the principal underlying factor in modern colony collapses; consequently, supplemental-nutrition strategies are not merely a means of improving production but an adaptive necessity in the face of progressively declining natural floral resources. This perspective is especially relevant in regions such as Quinindé, where expansion of oil-palm monocultures has reduced the diversity of the agricultural landscape available to managed bee colonies (Steffan-Dewenter and Kuhn, 2003).

Technological advances in bee nutrition have enabled the



development of increasingly specific and efficient feed substitutes and supplements that meet colony requirements under different environmental conditions. Paoli et al. (2014) determined that the optimal nutritional balance for adult bees varies with age and functional role within the colony, including specific essential-amino-acid requirements that are not always met by a single pollen source. Rossman et al. (2018) compared various protein sources as supplements for managed colonies and found that soybean meal combined with brewer's yeast extracts produced the best results for population development and honey production, consistent with the findings of Pino et al. (2017) under Ecuadorian conditions. Crailsheim (1998) established that trophallactic interactions between nurse bees and larvae are fundamental to nutrient exchange within the colony, emphasizing that improved individual nutritional status in adult bees has multiplier effects on development of the entire colony. This principle underpins the effectiveness of nutritional supplementation as a management tool for optimizing the health and productivity of bee colonies in tropical systems (Martínez and Balboa, 2014).

The objective of this study was to analyze the impact of different feeding and nutrition strategies on the health of *Apis mellifera* colonies and the physicochemical quality of honey under tropical conditions. Specifically, the effects of protein supplementation on population development were evaluated, the influence of feeding protocols on honey bioactive compounds was determined, and the technical feasibility of these practices for small- and medium-scale beekeeping was established.

Materials and methods

This study followed a qualitative, descriptive-analytical approach. A systematic literature review was used as the principal method, complemented by documentary analysis and synthesis of technical information. This design enabled the coherent integration of prior data to generate conclusions applicable to the current production context.

The review focused on specialized scientific literature concerning bee nutrition, the health of *A. mellifera* colonies, and honey quality. The analysis centered on studies conducted in Latin American countries with agroecological conditions similar to those of Quinindé canton, Esmeraldas Province. This focus ensured that the nutritional strategies discussed were technically feasible under the humid tropical conditions characteristic of the study area.

Systematic searches were conducted in SciELO, Redalyc, Google Scholar, and ScienceDirect using descriptors such as “bee nutrition,” “protein supplementation,” and “honey quality.” Studies published between 2005 and 2023 that provided empirical evidence on the use of protein and energy substitutes were included. The collected information was processed in analysis matrices to compare the effects of nutritional protocols on colony health-population and mortality-and on the bioactive properties of honey.

Results and discussion

Effects of nutritional management on population dynamics

The scientific literature review yielded consistent evidence of the positive impact of nutritional management on the population dynamics of *A. mellifera* colonies under tropical Latin American conditions.

The technical literature revealed a direct correlation between strategic supplementation and stronger hive populations. As shown in Table 1, protein sources such as soybean meal and natural pollen generated increases ranging from 28% to 45%. This effect was particularly evident in the Ecuadorian study by Pino et al. (2017), in which colony populations exceeded 30,000 bees, establishing a higher productivity benchmark for the region.

Table 1. Effects of nutritional supplementation on population development reported in the reviewed studies.

Study	Country	Year	Type of supplementation	Population increase (%)	Final population (bees)
Pino et al.	Ecuador	2017	Soybean meal	45	30,000-32,000
Martínez-Espinoza et al.	Mexico	2018	Protein supplement + JMAF	35-40	28,000-30,000
Alvares	Nicaragua	2015	Soybean meal	28	25,000-28,000
Contreras-Escareño et al.	Mexico	2013	Natural pollen	30	26,000-29,000
Regional average	-	-	-	-	-

Research conducted in Mexico by Martínez-Espinoza et al. (2018) documented that colonies fed protein supplements

maintained monthly growth rates of 12-15% during periods of greater floral availability, compared with 6-8% in colonies receiving conventional feed. These findings are consistent with studies from Nicaragua, where Alvares (2015) reported that soybean-meal supplementation increased average queen oviposition from 3,347 eggs in control colonies to 4,310 eggs in supplemented colonies.

The consistent results reported across Latin American countries confirm the effectiveness of nutritional supplementation for optimizing population development under tropical conditions. Branchiccela et al. (2021) explained that pollen supplementation effectively mitigated nutritional stress, particularly during periods of floral scarcity common in seasonal tropical ecosystems such as Quindé. The availability of adequate protein allowed nurse bees to maintain the royal-jelly production required for larval development, explaining the documented increases in queen oviposition.

Impact of supplemental feeding on colony survival

The reviewed studies demonstrated significant reductions in colony mortality when specialized nutritional strategies were implemented.

Antúñez et al. (2016) reported that annual colony losses in Uruguay reached 50-60% under conventional management, whereas later research by Branchiccela et al. (2021) showed that pollen supplementation could reduce these losses significantly.

Table 2. Colony mortality reported in studies with and without nutritional supplementation.

Study	Country	Year	Conventional management (% mortality)	Supplementation (% mortality)	Reduction (%)
Antúñez et al.	Uruguay	2016	50-60	25-35	40-50
Maggi et al.	Argentina	2016	35-45	15-20	45-55
Contreras-Escareño et al.	Mexico	2013	40-50	20-30	35-45
Branchiccela et al.	Uruguay	2021	45-55	18-25	45-60
Regional average	-	-	42-55		

Research by Maggi et al. (2016) in Argentina documented mortality of 15-20% in colonies managed with specialized nutritional protocols, compared with 35-45% in conventionally managed colonies. Studies conducted in Mexico by Contreras-Escareño et al. (2013) reported

similar results, with mortality reductions of 30-40% in supplemented colonies during tropical dry seasons.

The literature indicates that the highest mortality periods coincide with floral scarcity, demonstrating the protective effect of nutritional supplementation during critical periods. The reduction in mortality reported in multiple Latin American studies confirms the effectiveness of nutritional strategies as a preventive management tool. Antúñez et al. (2008) showed that propolis acts as a natural pathogen-control agent, which may partly explain the lower mortality observed in supplemented colonies.

Adequate nutrition strengthens colony immunity, enabling bees to better resist environmental stressors and pathogens and reducing the incidence of documented colony collapses (Antúñez et al., 2008).

Productive performance and seasonal stability of honey harvests

Implementing specialized nutritional protocols substantially increases honey yield per hive.

Martínez-Espinoza et al. (2018) reported that Mexican colonies fed protein supplements produced 27% more honey than control colonies, reaching 38-42 kg·hive⁻¹·year⁻¹ compared with 25-30 kg·hive⁻¹·year⁻¹ under conventional management.

Table 3. Honey production reported in studies using different nutritional strategies.

Study	Country	Year	Conventional production (kg·hive ⁻¹ ·year ⁻¹)	Supplemented production (kg·hive ⁻¹ ·year ⁻¹)	Increase (%)
Martínez-Espinoza et al.	Mexico	2018	25-30	38-42	27-40
Pino et al.	Ecuador	2017	20-25	35-42	60-68
Alvares	Nicaragua	2015	18-22	28-35	35-45
Invernizzi et al.	Uruguay	2011	22-28	32-38	35-45
Regional average	-	-	20-30		

In Ecuador, Pino et al. (2017) documented increases of up to 65% in honey production from colonies supplemented with soybean meal, with yields exceeding 40 kg·hive⁻¹·year⁻¹ under tropical climatic conditions. In Nicaragua, Alvares (2015) reported more moderate but consistent increases of 35-45% in colonies receiving protein supplementation.

The studies analyzed agree that supplemented colonies showed greater seasonal stability in production, with



smaller fluctuations between periods of high and low flowering, suggesting better adaptation to the environmental variability characteristic of tropical ecosystems.

Reported production increases of 27-68% significantly exceeded conventional-management yields, confirming the economic effectiveness of nutritional supplementation. Invernizzi et al. (2011) explained that well-nourished colonies maintained their productive parameters more effectively during adverse periods, reflected in the greater seasonal stability documented. By sustaining active worker populations during floral scarcity, supplemented colonies were better able to exploit available resources when environmental conditions improved.

Influence of colony nutrition on the physicochemical quality of honey

The reviewed scientific literature documents significant improvements in multiple quality variables when colonies receive adequate nutritional supplementation.

Table 4. Physicochemical quality variables of honey reported in Latin American studies.

Variable	Conventional management	Supplementation	Increase (%)	Reference study
Phenolic compounds (mg GAE·kg ⁻¹)	180-220	250-300	25-40	Vit et al. (2022)
DPPH antioxidant activity (%)	45-60	65-85	30-42	Salvador (2019)
Antimicrobial activity (mm inhibition zone)	12-15	18-22	30-45	Antúñez et al. (2008)
Diastase (Schade units*)	18-22	25-32	25-35	Invernizzi et al. (2011)
pH	4.1-4.3	3.8-4.0	-	Salvador (2019)
Moisture (%)	17-19	16-18		

Note: *Schade units are the standard measure of diastase (α -amylase) activity in honey. This bee-produced enzyme indicates freshness and quality. International standards require at least 8 Schade units for tropical honey and 3 units for temperate honey. Higher diastase activity indicates fresher honey subjected to less heat processing.

Studies conducted in Venezuela and Colombia by Vit et al. (2022) reported phenolic-compound contents of 250-300 mg gallic acid equivalents·kg⁻¹ in honey from well-nourished colonies, compared with 180-220 mg·kg⁻¹ under conventional management, representing increases of 25-40%.

Research on encenillo (*Weinmannia tomentosa*) honey in Colombia documented flavonoid contents of 129.4 ± 1.20 mg·kg⁻¹ and phenolic contents of $1,570 \pm 14$ mg·kg⁻¹ in honey from supplemented colonies, indicating high antioxidant capacity (Vit et al., 2022). Studies conducted in Ecuador by Salvador (2019), meanwhile, found that honey from colonies under optimized nutritional management showed 30-45% greater antimicrobial activity against common pathogens.

Physicochemical analyses in the literature showed that honey from supplemented colonies remained within international standards, with moisture of 16-18% and a slightly lower pH (3.8-4.0 versus 4.1-4.3), indicating greater acidity and better preservative capacity. Diastase activity was consistently higher (25-30 Schade units versus 18-22 units in controls).

The documented increases in antioxidant content and antimicrobial activity confirm the direct relationship between colony nutrition and final-product quality established by Vit et al. (2004). Propolis incorporated into colony diets may contribute to improved antimicrobial properties, as documented by Antúñez et al. (2008). Higher diastase values indicate greater enzymatic activity and exceed the international minimum of 8 Schade units for tropical honey, positioning these products in premium market segments.

Economic feasibility of specialized nutritional strategies

The economic studies reviewed consistently demonstrate the financial viability of implementing specialized nutritional protocols in tropical beekeeping.

Table 5. Economic analysis of nutritional strategies reported in Latin American studies.

Study	Country	Year	Additional cost (USD·hive ⁻¹ ·year ⁻¹)	Profitability increase (%)	Payback period (months)
Martínez-Espinoza et al.	Mexico	2018	35-50	45-65	8-10
Pino et al.	Ecuador	2017	40-55	60-78	6-8
Alvares	Nicaragua	2015	30-45	40-55	9-12
Invernizzi et al.	Uruguay	2011	38-48	50-70	7-9
Regional average	-	-	35-50	40-78	6-12

Research conducted in Mexico by Martínez-Espinoza et al. (2018) reported that, after accounting for additional supplement costs of US\$35-50 per hive per year and the resulting production gains, net profitability increased by 45-65% compared with conventional management.

Studies conducted in Ecuador by Pino et al. (2017) documented investment payback periods of 6-10 months for different supplementation protocols, with soybean meal providing the best cost-benefit ratio. Research in Nicaragua (Alvares, 2015) reported profitability increases of 40-55% in small-scale systems, confirming feasibility for producers with limited resources.

The economic viability consistently reported across Latin American countries—a 45-78% increase in profitability—confirms that nutritional strategies constitute a productive investment for beekeepers at different scales. Short payback periods of 6-10 months were especially attractive to small-scale producers, who make up most of the beekeeping sector in Quindé. Simultaneously improving product quantity and quality allowed beekeepers to diversify their markets and obtain differentiated prices, strengthening the activity's economic sustainability.

Conclusion

The systematic review of scientific literature from the Latin American context confirms that nutritional-management strategies are a determining factor in the sustainability of beekeeping in tropical ecosystems comparable to Quindé canton. Population increases of 25-45% and mortality reductions of 30-50% in supplemented colonies demonstrate that adequate protein availability makes it possible to maintain stable populations during the periods of floral scarcity characteristic of tropical ecosystems.

Comparative analysis of the studies shows that different supplemental-feeding protocols improve honey's physicochemical variables and bioactive-compound content. Increases of 25-40% in antioxidant content and improvements of 30-45% in antimicrobial activity were observed.

The reviewed documents confirm the economic viability of specialized nutritional strategies in small- and medium-scale beekeeping systems, with profitability increases of 40-78% and investment payback periods of 6-10 months. These results demonstrate that such strategies are a productive and sustainable investment for producers with different resource levels, including those characteristic of the Quindé beekeeping sector.

Conflict of Interest

The authors declare that they had no conflicts of interest at any stage of this publication.

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CRedit author contribution statement

Leonor Esther Cedeño-Quíñonez: Conceptualization, Data curation, Formal analysis, Supervision, Validation, Visualization, Methodology, and Writing - review & editing. **Carlos Alberto Montaña-Caicedo:** Funding acquisition, Investigation, Project administration, Resources, Software, Writing - original draft, and Writing.