Environmental determinants of honey bee productivity and the bioeconomics of apiculture in Armenia

Tatevik Shahinyan[1,2*] and *Manush* Minasyan [1,3]

[1] The Institute of Economics after M. Kotanyan of the National Academy of Sciences of the Republic of Armenia, 15 Grigor Lusavorich Str., Yerevan 0015, Armenia
[2] Yerevan Branch of Plekhanov Russian University of Economics, 0038 Yerevan, Armenia
[3] Armenian State University of Economics, 128 Nalbandyan Str., Yerevan 0025, Armenia

Abstract. This study investigates the interplay between environmental conditions, honey bee colony biology, and economic performance of apiculture in Armenia. During 2024-2025, 120 colonies were monitored across varying elevations to assess climatic and pathological influences on productivity. Temperature was identified as a primary biological driver of foraging activity, with maximum daily honey yields of 10.6 kg per hive achieved within +18°C to +25°C. Varroosis, present in 47% of colonies, reduced honey production by 30-40%, representing a major challenge to agricultural productivity. Economic analysis of adaptive management strategies revealed that annual queen replacement increased commercial honey yields by 32.3%, while sixteen-frame hives boosted production efficiency by 24.1%, offering rapid returns on investment. Beyond direct honey production, pollination services to Armenian agriculture were valued at 10-15 times the market value of harvested honey. This integrated bioeconomic approach demonstrates that management practices adapted to local environmental conditions are essential for economically viable and sustainable apiculture.

1 Introduction

Armenian beekeeping faces declining economic viability despite favorable natural conditions. Historical records from Xenophon's Anabasis document abundant honey production in the Armenian Highlands during ancient times, indicating long-standing suitability of the region for apiculture [1]. However, contemporary colony populations have declined from approximately 260,000–300,000 units during the Soviet period to around 200,000 colonies in recent years, while average honey yields have decreased from 30–40 kg to 5–10 kg per colony annually, reflecting structural and environmental challenges facing the sector [2,3].

* Corresponding author: tatev1510@gmail.com

This decline represents substantial economic losses not only in direct honey production but also in pollination-dependent agricultural output. Global assessments estimate that insect pollination contributes between USD 235 and 577 billion annually to world agriculture, with approximately 35% of crop production relying directly on animal pollination [4,5]. In Armenia's predominantly small-scale and diversified agricultural system, honey bees play a critical role in sustaining fruit orchards, vegetable production, and forage crops, thereby generating ecosystem services that significantly exceed the market value of honey itself [6,7].

Environmental degradation further intensifies these economic pressures. Industrial emissions, agricultural pollution, and habitat fragmentation negatively affect colony health and foraging efficiency, while growing evidence suggests that electromagnetic radiation from telecommunications infrastructure may impair orientation and stress responses in honey bees [8,9]. In parallel, climate variability alters flowering phenology and nectar secretion patterns, increasing uncertainty in nectar flows and elevating production risks for beekeepers operating in continental and mountainous climates [10,11].

Given these challenges, understanding the quantitative relationships between environmental factors and economic performance is essential for developing sustainable apicultural systems. Previous studies emphasize that adaptive management practices—including optimized hive design, disease control strategies, and queen replacement—can partially offset environmental constraints and improve profitability under variable climatic conditions [12,13].

This study evaluates the economic returns of different management interventions under the specific environmental conditions of Armenia. Costs and benefits associated with hive design, wintering strategies, and queen replacement schedules are assessed alongside the economic impacts of disease pressure and environmental stressors. The objective is to provide evidence-based recommendations aimed at improving profitability and long-term sustainability of Armenian apiculture within a changing environmental context.

2 Literature review

The economic performance of apiculture is strongly influenced by environmental conditions that shape honey bee foraging activity, colony health, and resource availability. Temperature and weather conditions are consistently identified as key drivers of honey production. Climatic stress reduces foraging activity and increases energetic costs, resulting in lower nectar intake and reduced daily honey yields, particularly in regions characterized by high climatic variability [10,11].

Landscape composition and floral resource diversity play a decisive role in sustaining colony productivity. Heterogeneous landscapes containing forests, semi-natural habitats, and diversified agricultural systems support higher honey yields and greater colony resilience than simplified monoculture systems [6,7]. In mountainous environments, altitudinal differentiation of flowering periods allows temporal extension of nectar flows, improving production stability and economic returns for migratory beekeeping systems.

Disease pressure remains one of the most economically damaging factors in apiculture. Varroosis significantly weakens colonies, reduces honey yields, and increases overwintering losses. Empirical evidence indicates that unmanaged infestations can reduce productivity by more than 30%, leading to substantial revenue losses that exceed the costs of preventive treatment [3,12].

Anthropogenic environmental stressors further exacerbate these losses. Exposure to pesticides and industrial pollution impairs foraging efficiency and colony health, while electromagnetic radiation associated with telecommunications infrastructure has been linked to altered orientation and stress responses in honey bees [8,9]. These factors impose indirect economic costs through reduced productivity and increased vulnerability to disease.

Management practices play a crucial role in mitigating environmental constraints. Annual queen replacement improves brood development and colony cohesion, resulting in higher honey yields and improved economic performance [12,13]. Hive design also influences productivity, as expanded-capacity hives allow stronger colony development and reduce swarming losses. Wintering strategies affect both costs and productivity, with outdoor wintering under suitable climatic conditions reducing infrastructure expenditures and improving spring colony strength.

Beyond honey production, honey bees provide economically significant pollination services. Pollination increases crop yields, improves quality, and stabilizes agricultural income, with estimated economic values far exceeding direct honey revenues [4,5]. However, these benefits are largely externalized, resulting in under compensation of beekeepers and underinvestment in apiculture.

Despite extensive international research, integrated economic analyses that combine environmental conditions, disease pressure, management practices, and pollination service valuation remain limited for the South Caucasus region. This gap underscores the importance of region-specific studies capable of translating environmental variability into economic outcomes under local ecological and market conditions.

3 Materials and Methods

Field observations occurred across elevation zones from 600-2000 meters during 2024-2025 seasons. We monitored 120 colonies in six apiaries, comparing experimental and control groups. Daily temperature, precipitation, and hive weight measurements documented environmental influences on nectar collection rates.

Economic analysis incorporated direct costs including equipment, labor, and disease treatments, against revenue from honey sales at market prices of 3,500-4,500 Armenian drams per kilogram. We calculated return on investment for different management interventions including hive type selection, wintering strategies, and requeening schedules. Disease prevalence was quantified through monthly colony inspections and laboratory diagnostics.

Botanical surveys within 3-kilometer foraging radii documented nectar resources. Forest composition data from regional inventories showed oak forests dominating southern regions while mixed beech stands characterized northern provinces. Agricultural crop surveys provided estimates of cultivated nectar sources including alfalfa and sweet clover.

Statistical comparisons employed analysis of variance with significance thresholds at $p<0.05$. Economic indicators included gross margin per colony, return on invested capital, and breakeven production volumes under different cost structures.

4 Results

4.1 Environmental factors and production economics

Temperature directly influenced economic productivity through effects on foraging activity. Control hive measurements showed maximum weight gains of 10.6 kg occurred at mean temperatures of +18°C to +25°C. Conversely, temperatures below +13°C or precipitation events resulted in weight losses up to 1 kg, representing direct income reduction from missed foraging opportunities.

Extended rainy periods reduced nectar sugar concentrations from 70% to 22% in sweet clover, substantially lowering honey quality and market value. However, adequate winter snow accumulation followed by gradual spring warming created optimal soil moisture conditions that enhanced subsequent nectar production, demonstrating inter-seasonal economic linkages.

Elevation-dependent phenology created opportunities for economically beneficial transhumance. Lowland sites provided honey flows from late May through mid-June, foothill zones from mid-June through mid-July, and mountain locations from late July through mid-August. Beekeepers practicing strategic colony migration accessed sequential resource pulses, potentially tripling seasonal revenues compared to stationary management.

4.2 Disease impacts on economic performance

Disease pressure imposed substantial economic costs through reduced productivity and treatment expenses. Varroosis affected 47.0% of surveyed colonies, with ascosphaerosis present in 77.5%. Colonies with active varroa infestations produced 30-40% less honey than healthy units, translating to significant revenue losses.

Treatment costs for varroosis ranged from 2,000-5,000 drams per colony annually depending on method selection. Organic acid treatments provided more economical solutions than synthetic acaricides while avoiding residue concerns affecting honey marketability. However, treatment timing during evening hours reduced labor efficiency, increasing operational costs.

Environmental pollution compounded disease-related losses. Colonies positioned near highways or industrial facilities showed 35% lower productivity than those in pristine locations. Proximity to high-voltage transmission lines reduced yields by approximately 40%, representing substantial opportunity costs in site selection decisions.

Prophylactic management using botanical preparations increased colony resistance while improving productivity by 30% relative to untreated controls. The economic return from these interventions exceeded costs by factors of 3-5, justifying systematic implementation across commercial operations.

4.3 Economic returns from management interventions

Queen replacement schedules significantly affected profitability. Colonies with one-year-old queens produced 32.3% more commercial honey than those with aged queens. Given queen costs of 8,000-12,000 drams and honey prices of 3,500-4,500 drams per kilogram, annual requeening generated positive returns when productivity gains exceeded 3-4 kg per colony.

Calculations showed that colonies producing 25 kg annually with old queens could achieve 33 kg with young queens. At 4,000 drams per kilogram, this 8 kg increase generated 32,000 drams additional revenue against 10,000 drams queen cost, yielding 22,000 drams net benefit per colony annually.

Winter management strategy selection influenced both costs and productivity. Outdoor wintering eliminated infrastructure expenses for storage facilities estimated at 500,000-1,000,000 drams for small operations. Additionally, outdoor colonies produced 19.7% more honey than those in storage facilities. Combined capital savings and productivity gains made outdoor wintering economically superior in most Armenian locations.

Hive design choices affected long-term profitability. Sixteen-frame horizontal hives cost approximately 15,000-20,000 drams more than standard twelve-frame units but generated 24.1% higher commercial honey yields. Assuming 25 kg baseline production, the 6 kg increase worth 24,000 drams provided payback within one season while delivering ongoing returns throughout equipment lifespan.

4.4 Pollination service valuation

Beyond direct honey sales, bee colonies provided valuable pollination services to agricultural crops. Conservative estimates suggest pollination increases crop yields by 15-30% for insect-dependent species. In Armenia, major beneficiaries include fruit orchards, vegetable production, and forage legumes.

Applying yield improvement factors to agricultural production data, we estimated pollination services worth 150,000-200,000 drams per colony annually, substantially exceeding typical honey revenues of 80,000-120,000 drams. However, these ecosystem service benefits accrued primarily to crop producers rather than beekeepers, creating economic externalities.

Recognition of pollination values justifies policy interventions supporting apiculture. Subsidies for equipment purchases, technical training programs, and pesticide regulations protecting pollinators generate societal benefits exceeding direct costs. Economic analysis incorporating these broader values demonstrates higher social returns from apicultural development investments.

5 Discussion

This research establishes quantitative relationships between environmental conditions and economic outcomes in Armenian beekeeping. Temperature emerged as the primary factor determining daily productivity, with optimal ranges generating maximum revenue potential. Disease pressure imposed substantial costs through both reduced yields and treatment expenses, highlighting importance of integrated pest management.

Management intervention analysis revealed clear profitability advantages from annual queen replacement, outdoor wintering, and expanded hive designs. These practices generated positive returns on investment within single production seasons while delivering ongoing benefits. Economic modeling demonstrated that adopting recommended practices could increase net income by 40-60% relative to traditional methods.

However, environmental constraints increasingly threaten economic sustainability. Pollution impacts from industrial development and electromagnetic radiation from telecommunications infrastructure reduce productivity in affected areas by 30-40%. Climate change projections indicate shifting phenological patterns that may disrupt traditional management schedules. Adaptation strategies including transhumance, genetic selection for stress tolerance, and landscape-scale habitat conservation will require coordinated investments.

The substantial economic value of pollination services relative to direct honey production argues for policy frameworks that compensate beekeepers for ecosystem service provision. Payment schemes linking crop producers with pollination service providers could internalize currently externalized benefits, improving economic sustainability of apiculture. Such mechanisms operate successfully in several international contexts and merit consideration for Armenian conditions.

Limitations of this analysis include relatively short observation period and restricted geographic sampling. Multi-year studies across broader regions would strengthen economic projections. Additionally, market price volatility for honey creates revenue uncertainty not fully captured in static calculations. Future research should incorporate risk analysis and sensitivity testing under different price scenarios.

6 Conclusions

Environmental conditions directly influence economic performance of Armenian apiculture through effects on colony productivity and management costs. Temperature optimization, disease management, and appropriate technology selection represent critical determinants of profitability. Recommended practices including annual queen replacement, outdoor wintering, and sixteen-frame hives demonstrate strong positive returns on investment.
Economic analysis should incorporate pollination service values alongside direct honey revenues to properly evaluate sector contributions. Policy interventions supporting beekeeper adoption of environmentally-adapted management practices generate societal benefits exceeding implementation costs. Sustainable development of Armenian apiculture requires integrated approaches addressing both economic optimization and environmental conservation objectives.

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