

Article

Mapping Apiculture in Lebanon: A National Survey of Practices, Challenges, and Management Strategies

Dany Yammouni ^{1,2,*}, Abdo Tannouri ^{3,4}, Ziad Rizk ^{1,3}, Selma P. Snini ², Florence Mathieu ², Sofi G. Julien ⁵ and Youssef El Rayess ^{3,4,*}

¹ Lebanese Agricultural Research Institute (LARI), Fanar Station, Jdeidet El-Metn, Fanar P.O. Box 90-1965, Lebanon; ziadrizk@usek.edu.lb

² Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INPT, UPS, 31326 Toulouse, France; selma.snini@toulouse-inp.fr (S.P.S.); florence.mathieu@toulouse-inp.fr (F.M.)

³ Department of Agriculture and Food Engineering, School of Engineering, Holy Spirit University of Kaslik, Jounieh P.O. Box 446, Lebanon; abdotannoury@usek.edu.lb

⁴ Processing and Biosystems (ProBio) Multidisciplinary Research Group, Holy Spirit University of Kaslik, Jounieh P.O. Box 446, Lebanon

⁵ Department of Nutrition and Food Sciences, Faculty of Arts and Sciences, Holy Spirit University of Kaslik, Jounieh P.O. Box 446, Lebanon; sophiejulien@usek.edu.lb

* Correspondence: danyammouni@hotmail.com (D.Y.); youssefrayess@usek.edu.lb (Y.E.R.)

Abstract

This study provides the first nationwide assessment of the apiculture sector in Lebanon. It integrates socio-economic characteristics, technical practices, and disease and pest prevalence and management. A structured questionnaire was administered to 5775 beekeepers representing 91.1% of the registered population across all Lebanese governorates. The sector is predominantly small-scale, male-dominated, with low cooperative participation, limited product diversification and heterogeneous management practices. Honey is the main product, while other hive products remain marginal. Queen replacement practices are inconsistent, and most beekeepers reported limited awareness of pests and diseases. The most recognized threat is Varroa; however, multiple stressors such as pesticides, poor nutrition, and climate variability contribute to colony health constraints. Chi-square analyses revealed statistically significant associations between disease occurrence and geographic and socio-economic variables ($\chi^2 = 129.99\text{--}2251.78$, df 12–30, $p < 0.001$), with small to moderate effect sizes (Cramer's $V = 0.08\text{--}0.37$), reflecting the multifactorial nature of colony health determinants. Overall, Lebanese apiculture demonstrates strong ecological potential but limited technical and organizational optimization. Strengthening extension services, improving disease diagnostics, and promoting diversification are critical to enhance sector sustainability.

Keywords: apiculture; Lebanon; queen replacement; pests and diseases prevalence; nationwide survey; beekeeping management

Received: 22 April 2026

Revised: 25 May 2026

Accepted: 2 June 2026

Published: 13 July 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Beekeeping is a significant component of global agricultural systems, contributing significantly to biodiversity conservation, ecosystem functioning, and rural livelihoods [1]. Pollinators, particularly honeybees, provide an annual economic value ranging widely from US\$267 billion to ~US\$657 billion [2]. Their role is critical, with about 87 out

of 124 major food crops and nearly 84% of cultivated crop species in Europe directly depending on insect pollination [3]. Among pollinators, *Apis mellifera* remains the most economically valuable species, particularly in intensive agricultural systems where wild pollinators are scarce, offering a scalable and cost-effective solution for crop pollination.

Despite their importance, pollinator populations are under increasing threats, which have been reviewed in detail [4,5]. These pressures include climate change, extensive use of pesticides, pests and pathogens, pollution, habitat loss, and the expansion of monocultures [4,5]. All these stressors have led to alarming declines in bee populations worldwide, posing significant risks to food security, ecosystem stability, and dietary diversity.

Being located on the eastern coast of the Mediterranean, Lebanon covers 10,452 km² and has a mosaic of ecosystems that support apiculture. Although agriculture represents only 3% of national GDP, beekeeping continues to be indispensable to rural populations, providing economic and ecological benefits [6]. Bees in Lebanon aid in the pollination of natural plants as well as agricultural crops, which strengthens biodiversity and food security [7].

The Mediterranean basin is recognized as a biodiversity hotspot of pollinators, where different subspecies of *Apis mellifera* and wild bees are found [8]. However, there is increasing pressure on beekeeping in the Middle East and North Africa (MENA) region: drought, shortage of flowers, epidemics of diseases (e.g., *Varroa destructor*, *Nosema* spp., and viruses), and limited access to veterinary and extension services [9,10]. Climate stress and unsustainable land use also pose an additional threat to the survival of the colony [5].

At the national level, efforts to support the beekeeping sector have been initiated, notably through the establishment of a specialized beekeeping unit at the Lebanese Agricultural Research Institute (LARI) in 2017. Nevertheless, the first observations showed signs of inconsistencies within the sector, including the number of hives, bees' subspecies, queen genetics, beehive management, and the form of cooperation. These issues contribute to low honey yields, disease outbreaks, and unsustainable colony management despite Lebanon's favorable ecological potential.

Despite several national reports on honey production and beekeeping practices in Lebanon, there remains a critical knowledge gap regarding the integration of socio-economic, epidemiological, and management data within a single national framework. There is little information on the beekeeping sector in Lebanon and its volume, honey production and type, beekeeping practices, spatial distribution of major pathogens such as *Varroa destructor*, *Nosema* spp., and fowlbrood diseases [11]. In this context, there is an urgent need for a comprehensive assessment of the Lebanese beekeeping sector. Therefore, the present study aims to provide a comprehensive nationwide analysis of Lebanese beekeeping, combining socio-economic characteristics, management practices, and disease prevalence. Its specific objectives aim to (i) characterize the socio-economic profiles and beekeeping practices across all Lebanese governorates, (ii) evaluate the prevalence and management of key honeybee diseases and pests, and (iii) generate policy-oriented insights to support sustainable, disease-resilient apiculture in Lebanon. To address these objectives, we conducted a nationwide structured survey of 5775 beekeepers representing 91.1% of registered beekeepers.

2. Methodology

2.1. Study Area

Lebanon is a small country with a surface area of 10,452 km² located on the eastern Mediterranean coast. It is divided into 8 governorates as shown in Figure 1: Akkar, North, Baalbeck-Hermel, Beirut, Mount Lebanon, Bekaa, South, and Nabatiyeh. In this study, all the governorates were included except Beirut due to the absence of beekeepers. It has a moderate Mediterranean climate with a relatively large amount of rainfall, except in some north-eastern areas. Lebanon's particular geography, topography, and demography make it an important biodiversity hotspot. The floristic richness of Lebanon is estimated at 2612 vascular plant taxa, of which 108 are endemic [12]. Approximately 33.33% of Lebanon's territory ($\approx 348,440$ ha) is covered by wildland vegetation, predominantly composed of forests and shrublands (87.8%), with grasslands representing a smaller proportion (12.18%) [13].

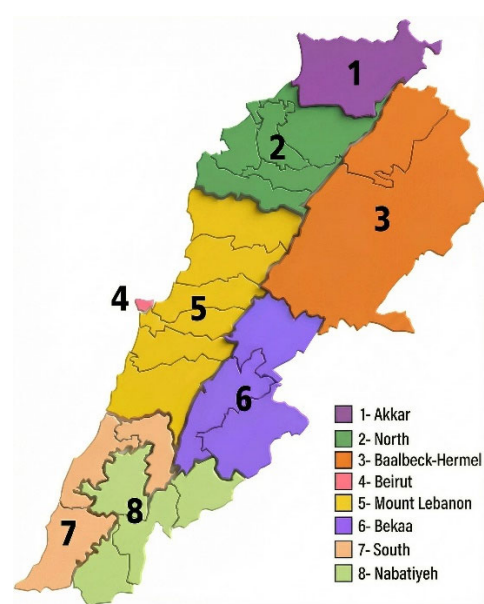


Figure 1. Lebanon map with governorates.

2.2. Study Population

The study targeted the entire population of registered beekeepers in Lebanon, estimated at 6340 individuals according to official records from the Ministry of Agriculture for the year 2019. A nationwide survey was conducted across all governorates (Mount Lebanon, North, Akkar, Bekaa, Baalbeck–Hermel, South, and Nabatieh). Data were collected exclusively on beekeeping practices and colony health observations from professional beekeepers. A geographically distributed convenience sampling approach was adopted to ensure adequate representation across the different Lebanese regions. Beekeepers were selected using a convenience sampling method, based on accessibility and willingness to participate. A total of 5775 beekeepers responded to the questionnaire, representing approximately 91.1% of the national beekeeper population. This exceptionally high participation rate provides a robust and representative dataset for national-level analysis. Records with missing data for any variable of interest were excluded using listwise deletion (complete-case analysis). Specifically, data were excluded when incomplete for governorate ($n = 284$), age ($n = 404$), marital status ($n = 55$), academic level ($n = 99$), or when the reported number of beehives was less than 1 ($n = 17$). No data imputation procedures were applied. A total of 4916 beekeepers were included in the final analysis.

2.3. Survey Data

A draft survey questionnaire was designed in 2019 in collaboration with several researchers and beekeepers from Lebanon. The survey was made available in two languages: Arabic and English. Due to the COVID-19 pandemic, the survey data collection experienced delays and was ultimately completed in 2023. Because this exploratory, observational, and minimal-risk study focused strictly on apiculture practices and bee colony health in Lebanon without disclosing any personal identifying information, formal ethical committee approval was not required. Voluntary informed consent was obtained from participants prior to their participation. The initial questionnaire was pilot tested with 20 beekeepers in various regions in order to evaluate clarity, cultural appropriateness, and language accessibility. Minor adjustments were made based on feedback to improve question wording and response options. The final version of the questionnaire was administered through direct interviews and field surveys. To collect the data, a team of 19 personnel from LARI was assembled, including two survey coordinators, one information technology specialist, and 16 field surveyors distributed across all of Lebanon. The entire staff was thoroughly trained, depending on their job descriptions. Surveyors were also taught some beekeeping practices and the use of questionnaires in a training-of-trainers (TOT) program. All surveyors were provided with a standardized kit consisting of a 10-inch tablet on which they would enter data, a GPS log, and document photos.

The questionnaire contains three principal theme domains. The first domain focused on socio-economic characteristics, including demographic information such as age, gender, marital status, educational attainment, primary occupation, and cooperative affiliation. These criteria were included because socio-economic elements significantly influence the adoption of contemporary beekeeping techniques, educational access, and the ability to engage in formal marketing channels. The demographic characteristics of beekeepers in Lebanon are essential for identifying populations who may require targeted support, capacity enhancement, or governmental intervention. The second domain addressed the practical procedures of apiculture. The questions targeted the quantity and types of hives, the frequency of queen replacement, the volume of honey production, diversification into other apicultural products (royal jelly, pollen, propolis, and honeycomb), and market channels. These variables were included to assess the level of technical adoption, management capacity, and economic orientation of beekeeping activities. The third domain addressed the pest and disease prevalence and management. Beekeepers were asked about the presence of pests and diseases such as Varroa, American foulbrood (AFB), European foulbrood (EFB), *Nosema*, and the types of treatments adopted. The purpose of these questions was to assess the perceived epidemiological status of apiculture in Lebanon and to understand beekeepers' responses to health hazards. It provides an indirect assessment of diagnostic awareness and the effectiveness of disease management strategies at the national level. Data on disease prevalence reflect beekeepers' reported perceptions rather than laboratory-confirmed diagnoses, which may introduce reporting bias. All questions were primarily closed-ended (multiple choice and categorical variables) to facilitate statistical analysis, particularly contingency analysis and association testing.

2.4. Statistical Analysis

Statistical analyses were performed using JASP Team (2025), version 0.95.4 [Intel]. Graphical illustrations were created using Numiqo (<https://numiqo.com>). Demographic and management variables were described using absolute frequencies and relative proportions.

Associations between categorical variables, specifically, the occurrence of five honeybee diseases and pests (*Varroa destructor*, American foulbrood, European foulbrood, *Nosema* spp., and sacbrood) and two demographic characteristics (region and educational

level), were assessed using the Pearson Chi-square (χ^2) test of independence. Prior to analysis, expected cell frequencies were verified to meet the minimum threshold of five across all cells, confirming the appropriateness of the test. The threshold for statistical significance was set at $p < 0.05$. Effect size was quantified using Cramér's V as the primary measure (small, $V \cong 0.1$; moderate, $V \cong 0.3$; strong, $V \geq 0.5$). The contingency coefficient C is additionally reported for completeness.

To control for type I error inflation arising from 10 simultaneous comparisons (5 core diseases $\times$ 2 sociodemographic variables), a Bonferroni correction was applied, yielding an adjusted significance threshold of α -corrected = 0.005. In the context of our exploratory descriptive survey, its application further attests to the strength and robustness of the observed patterns, as all five primary disease associations reported in this study remained statistically significant after correction.

3. Results and Discussion

3.1. Sociodemographic Structure and Cooperative Integration of Beekeepers

Figure 2a illustrates the sociodemographic structure of beekeepers across Lebanon ($n = 4916$). The spatial distribution reveals a heterogeneous regional concentration, with Nabatiyeh accounting for the largest share (29%), followed by the South (18%), Akkar (18%), and Mount Lebanon (15%), while Baalbeck-Hermel (13%), Bekaa (5%), and the North (1%) contribute less substantially. This uneven distribution reflects the strong ecological dependency of apiculture, particularly on floral diversity, climate, and land-use patterns. Demographic data show a strong 97% dominance of men among beekeepers, confirming that the sector is predominantly male-dominated. This imbalance aligns with observations in similar agro-rural systems, where labor-intensive activities and land ownership patterns limit female participation [14,15]. However, the near absence of women highlights a significant opportunity for inclusive development, particularly in downstream value-chain activities. The age structure indicates a mature workforce, especially within the 41–60-year range (60%), followed by those over 60 years (18%). In contrast, only 20% of beekeepers are aged 26–40, and a mere 3% are under 25 years old, showing a significant underrepresentation of younger age groups in the sector. This pattern suggests that beekeeping is primarily an experience-based and inherited activity, raising concerns about generational renewal and the long-term sustainability of the sector. Marital status data show that 89% of beekeepers are married. When linked to the second job results of Figure 2b, the observation reinforces the interpretation of beekeeping as a household-integrated activity, contributing to diversified family income rather than functioning as a standalone profession. The majority of beekeepers are high school graduates (44%), followed by elementary (22%) and secondary (19%) schooling, while university graduates represent only 14%. This mix reflects a moderate level of human capital with limited penetration of higher education, highlighting the difficulties of the beekeeping community to embrace cutting-edge technologies and drive innovative practices. Nevertheless, it also highlights an opportunity for targeting technical training programs and skills-building interventions that could enhance the beekeepers' ability to adopt new technologies and improve their practices. A key finding from Figure 2a related to cooperative adhesion shows that only 9% of beekeepers are affiliated with cooperatives, while 91% operating independently. This situation underscores a fragmented sector that lacks collective organization. Such fragmentation is known to hinder access to shared resources, diminish market efficiency, and limit participation in higher-value markets, including export channels.

Figure 2b suggests that beekeeping is predominantly a supplementary activity rather than a primary profession, which is consistent with findings reported in other studies [16,17]. Indeed, the largest proportion of beekeepers reported having a household and social-related function (40%), agricultural work (28%), and service/manual labor (17%).

Business/entrepreneurship (5%), public administration (3%), professional services (3%), and engineering/technical fields (3%) represented smaller representations of secondary labor markets among beekeepers. This distribution underscores the multi-activity nature of rural livelihoods, where beekeeping is integrated into broader income diversification strategies. The strong linkage with agriculture confirms that apiculture remains embedded within agroecosystems, benefiting from synergies such as pollination services and shared resource use. However, the relatively low representation of professional and entrepreneurial categories suggests limited sectoral professionalization and innovation capacity. The minimal proportion of individuals solely dedicated to beekeeping further indicates that the sector operates below its economic potential, likely due to income instability, market constraints, and structural inefficiencies. The high proportion of “household/social status” responses may also reflect elements of informality within the rural economy, pointing to challenges in formal employment classification and economic structuring.

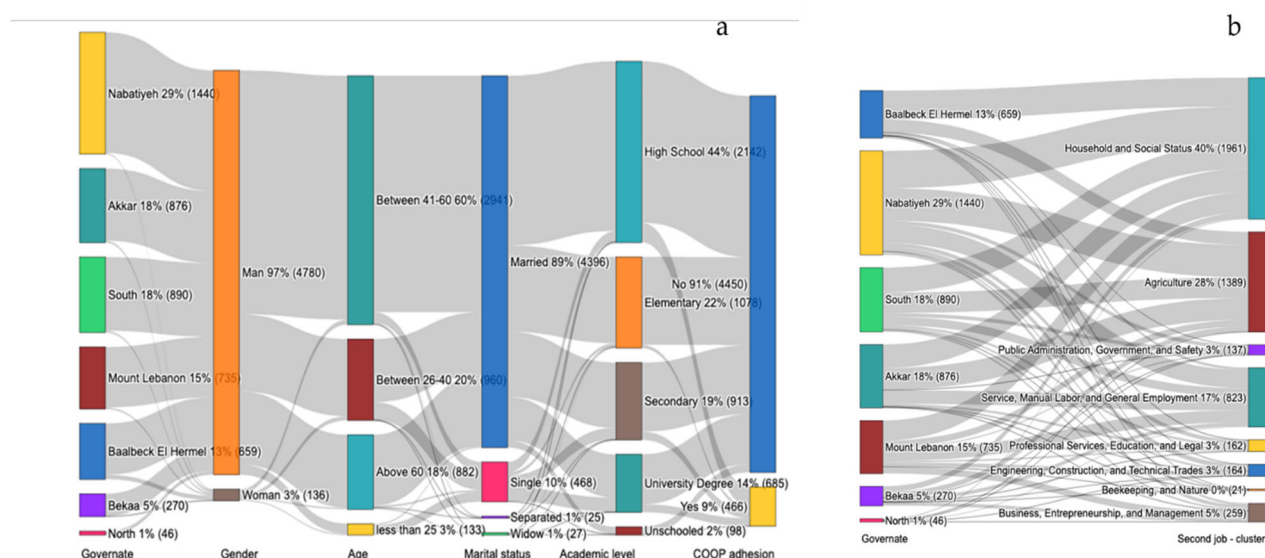


Figure 2. Socio-demographic characteristics of beekeepers in Lebanon ($n = 4916$). Sankey diagrams illustrating the distribution and frequency of beekeepers across governate, gender, age, marital status, and academic level of beekeepers, and their cooperative (COOP) adhesion (a); and the distribution and frequency of beekeepers across governates and second job-clusters (b). The width of the bars for each column category (governate, gender, age, marital status, academic level, and COOP adhesion) represents the proportion (%) and count (n) of beekeepers. The grey connecting lines illustrate how individuals within one variable category transition to another one.

3.2. Structural Organization of Beekeeping Systems: Hive Number Distribution

Figure 3 shows a heterogeneous distribution of beekeeping operation size, known as the number of beehives per beekeeper, across Lebanese governorates. This indicates a sector dominated by small-scale producers with a limited number of large-scale operations. Across all regions, most beekeepers manage relatively small numbers of hives, confirming that apiculture in Lebanon is primarily a smallholder-based activity, often integrated within diversified rural livelihoods. This observation is consistent with previous findings indicating that beekeeping is largely practiced as a secondary income-generating activity rather than a fully commercial enterprise [18]. However, the presence of extreme values, particularly in Nabatiyeh (up to ~1000 hives), Mount Lebanon (~850 hives), and the North (~700 hives), highlights the existence of a subset of semi-commercial or commercial-scale

beekeepers. The mentioned beekeepers likely benefit from better access to resources, technical expertise, and market opportunities, positioning them as potential drivers of sectoral modernization.

The substantial intra-regional variability observed across all governorates suggests that production systems are highly heterogeneous, even within similar ecological contexts. This variability reflects differences in management practices, investment capacity, and technical knowledge, rather than purely environmental factors. Regions such as Baalbeck-Hermel and Akkar, characterized by lower upper ranges and reduced dispersion, appear to be dominated by traditional, small-scale systems, whereas Nabatiyeh and Mount Lebanon demonstrate more diversified and potentially intensive production structures.

From a structural perspective of the beekeeping sector in Lebanon, this dual system, comprising a large base of smallholders and a limited number of large-scale producers, indicates that the sector is fragmented and unevenly developed. Such fragmentation may limit the diffusion of best practices and constrain the development of efficient apiculture value chains.

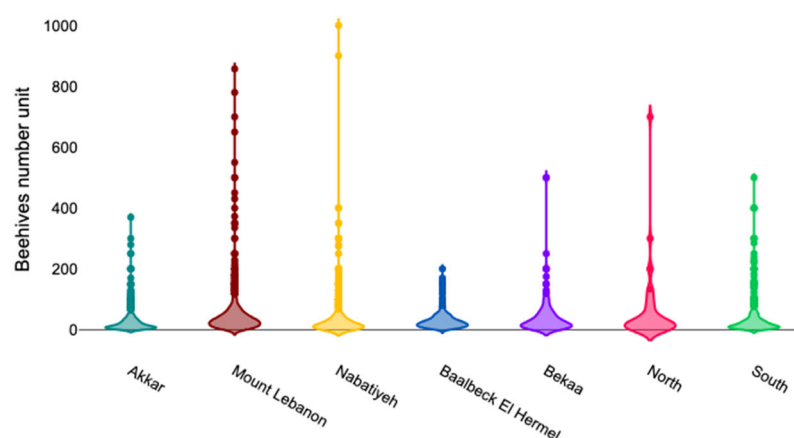


Figure 3. Regional distribution and variability of beekeeping operation size (number of beehives per beekeeper) across Lebanese governorates.

3.3. Queen Replacement Practices and Colony Management

The analysis of queen replacement practices (Figure 4) reveals a moderate but suboptimal adoption of this critical management strategy. Only 45% of beekeepers ($n = 2202$) reported practicing queen replacement, while a majority of 55% ($n = 2714$) do not replace queens at all. Neglecting the regular rejuvenation of queen populations can have significant consequences, including reduced colony productivity, weakened colony strength and disease resistance, increased swarming, overwintering failures, and higher colony losses, ultimately leading to greater labor demands and reduced management efficiency. Therefore, the timely replacement of aging, less fertile queens with high-quality individuals should be considered a fundamental practice in modern beekeeping management [19,20]. The high proportion of non-adopters suggests that a large segment of the sector relies on natural queen supersedence, which may result in reduced colony performance, increased variability, and, in the short term, lower resilience to environmental and pathological stressors. However, Lin et al. [21] discussed that routine queen replacement results in reducing genetic diversity within and between colonies, leading to higher relatedness and lower heterozygosity. While this genetic uniformity offers short-term benefits, it can weaken the colony's ability to respond to environmental stressors, diseases, and emerging threats. Consequently, although artificial queen replacement enhances immediate perfor-

mance, it may compromise the long-term resilience and adaptability of honeybee populations.

Among beekeepers who practice queen replacement, the dominant frequency is every two years (27%), followed by 1.5 years (8%) and annual replacement (6%), while longer intervals (three years: 3%) and shorter cycles are marginal. Although the prevalence of a two-year replacement cycle partially aligns with recommended practices, the relatively low proportion of annual replacement indicates suboptimal management intensity.

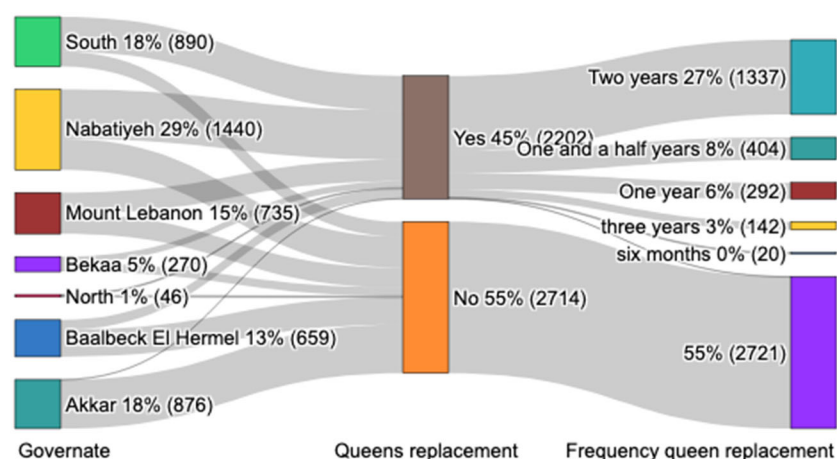


Figure 4. Sankey diagram of queen replacement practices and frequency across Lebanese governorates ($n = 4916$).

3.4. Hive Product Diversification and Value Chain Development

The analysis of hive product diversification (Figure 5a) indicates a significantly unbalanced production structure, dominated by honey. In fact, 95% of beekeepers ($n = 4670$) are engaged in honey production, showing that the apiculture sector in Lebanon is mostly focused on a single-product system. In contrast, the production of other hive-derived products is still very limited. Only 28% of Lebanese beekeepers produced honeycomb, indicating a modest level of diversification into value-added products. However, the production of higher-value products such as pollen ($\approx 1\%$), royal jelly ($\approx 2\%$), and propolis ($\approx 0\%$) is almost negligible. This pattern shows that beekeeping systems are not being used to their full biological and economic potential. While honey production remains relatively easy and does not require specialized technical skills, the production of other hive products typically requires advanced knowledge, specialized tools, and access to a niche market. The fact that these products are almost nonexistent suggests that the industry is still technologically limited and not well-connected to high-value markets. This lack of diversification has significant effects from a value chain perspective. Over-reliance on honey reduces the opportunities for beekeepers for income diversification and economic resilience. It also makes beekeepers more vulnerable to price fluctuations, climate changes, and colony losses. On the other hand, products like royal jelly, pollen, and propolis are linked to high market value, useful properties, and strong demand in the pharmaceutical and nutraceutical industries. The absence of regional differentiation in diversification patterns serves as further evidence that this limitation is systemic rather than geographically driven, indicating national-level constraints in technical capacity, extension services, and market structuring. These results are in line with the industry's more general description as under-optimized and semi-traditional, with production methods that focus more on volume than on adding value.

Simultaneously, the analysis of honey yield distribution (Figure 5b) shows that production performance is uneven across governorates. The most variable and upper production ranges are found in areas like Akkar and Mount Lebanon, where some hives achieve extraordinarily high yields (>50 kg/bee hive). In contrast, Bekaa, Baalbeck-Hermel, and North exhibit relatively low to medium productivity levels. The Baalbek–Hermel Governorate, located approximately 86 km inland from the coastline, covers 3444 km²—accounting for nearly 33% of Lebanon’s total territory—and is characterized by an average elevation of around 1000 m above sea level, with altitudes ranging from 800 to 3060 m [22]. Despite this extensive geographic area, honey productivity remains relatively low. This apparent paradox is primarily explained by the region’s semi-arid climatic conditions, where rising temperatures, recurrent drought episodes, and harsh winter cold collectively constrain floral diversity and shorten flowering periods [22]. As a result, nectar availability is limited both spatially and temporally, preventing optimal exploitation of the large land area and ultimately leading to lower median honey yields per colony. Median annual honey production ranged between 4 and 5 kg/bee hive across governorates. Interquartile ranges (IQRs) varied between approximately 2 and 3 kg/bee hive, indicating moderate regional variability in production.

The relatively large variability in honey production across governorates indicates that intra-regional variations are just as important as inter-regional ones, highlighting the importance of beekeeper-level factors in addition to geographical influences. This is in line with a previous study showing that management practices, colony health, and beekeeper expertise are the most important factors influencing productivity, frequently outweighing environmental conditions [23]. The presence of both high-performing and low-performing systems in the same areas indicates a significant productivity gap and untapped opportunities for enhancement.

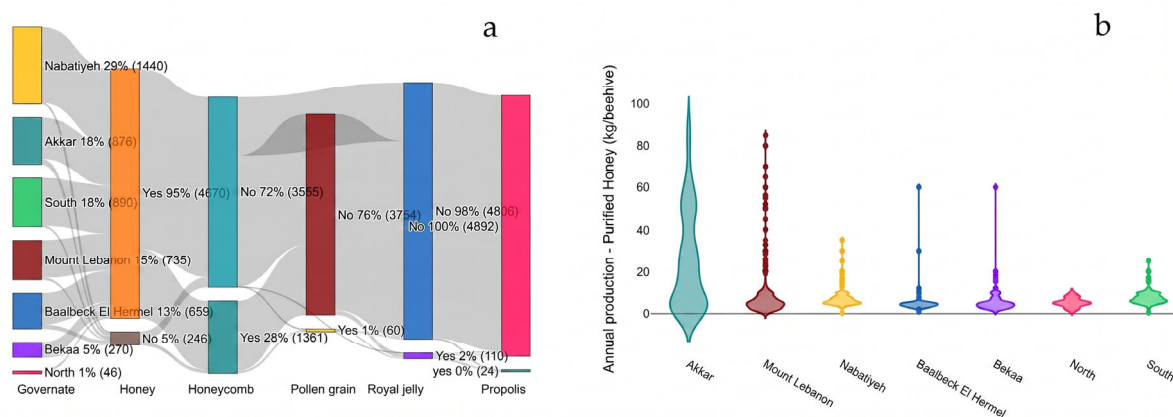


Figure 5. (a) Distribution of hive product diversification across Lebanese governorates; (b) Regional variability in annual honey yield per hive (kg/bee hive) among beekeepers ($n = 4916$).

The analysis of hive product output in relation to sociodemographic characteristics (Figure 6) reveals that productivity in Lebanese apiculture is strongly influenced by human and territorial factors, while diversification remains uniformly constrained across all groups. There are clear differences in production between regions (Figure 6a). Mount Lebanon and Akkar have the highest honey and honeycomb production. This is probably because of better management practices and favorable climatic conditions. On the other hand, the North and South governorates have lower productivity, which could be due to limitations in technical skills, resources, or environmental conditions. Even with these differences, the production of high-value hive products like pollen, royal jelly, and propolis

is still very low in all areas. This shows that the problems with diversification are not limited to one area.

One important factor influencing productivity is the educational level (Figure 6b). Beekeepers with higher education produce much more honey, with university graduates achieving the highest production levels. This result underscores the importance of crucial human capital, which leads to an increase in productivity, probably due to better decision-making, better disease management, and increased adoption of best practices. On the other hand, lower productivity among beekeepers with less education reflects their limited access to information and technical expertise.

Additionally, productivity patterns are significantly influenced by age (Figure 6c). The age group between 26 and 40 exhibits the highest output, indicating that a balance between experience, physical capability, and openness to innovation leads to optimal performance. Younger beekeepers (<25 years) show lower productivity, probably due to limited experience. Older beekeepers, on the other hand, have moderate productivity levels, which could be due to their accumulated knowledge but also because they may not be working as hard.

The impact of secondary occupation (Figure 6d) underscores the significance of socio-economic context. Beekeepers, who are engaged in agricultural activity, show more productivity, probably because they use ecological integration and complementary practices like managing pollination. Beekeepers with technical or professional backgrounds tend to show relatively high productivity, which suggests that knowledge from other fields can help beekeeping. Beekeepers who work in the home or do manual labor, on the other hand, tend to be less productive due to less time, money, or technical skills.

These findings collectively illustrate that productivity is significantly influenced by sociodemographic factors; however, the absence of diversification into high-value products remains consistent across all groups, suggesting structural barriers that extend beyond individual characteristics. This underscores the necessity for comprehensive interventions across the sector aimed at enhancing technical training, adopting innovative ideas, and advancing value chain development.

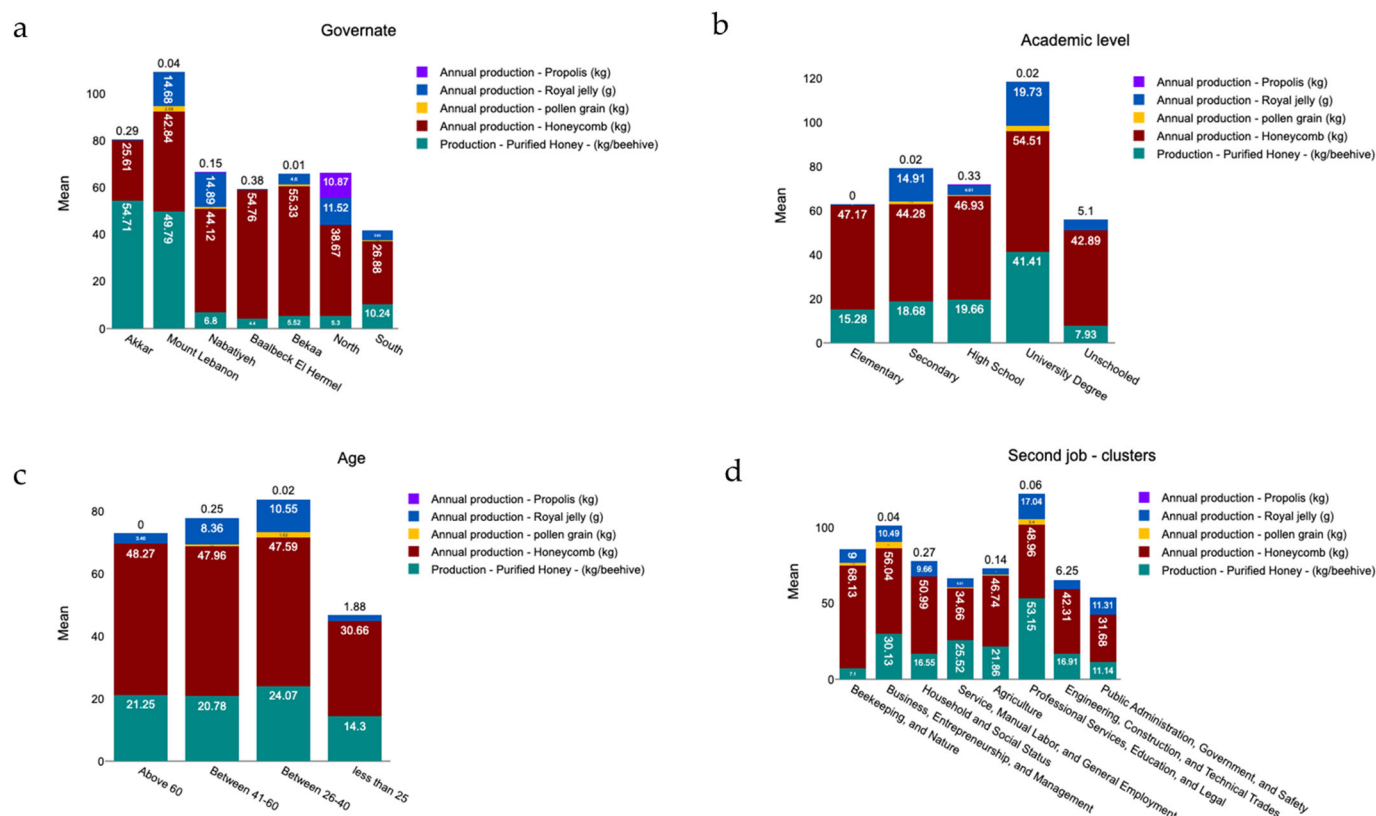


Figure 6. Influence of sociodemographic factors on hive product output in Lebanese apiculture: (a) Governorate, (b) Academic level, (c) Age, and (d) Secondary occupation clusters ($n = 4916$).

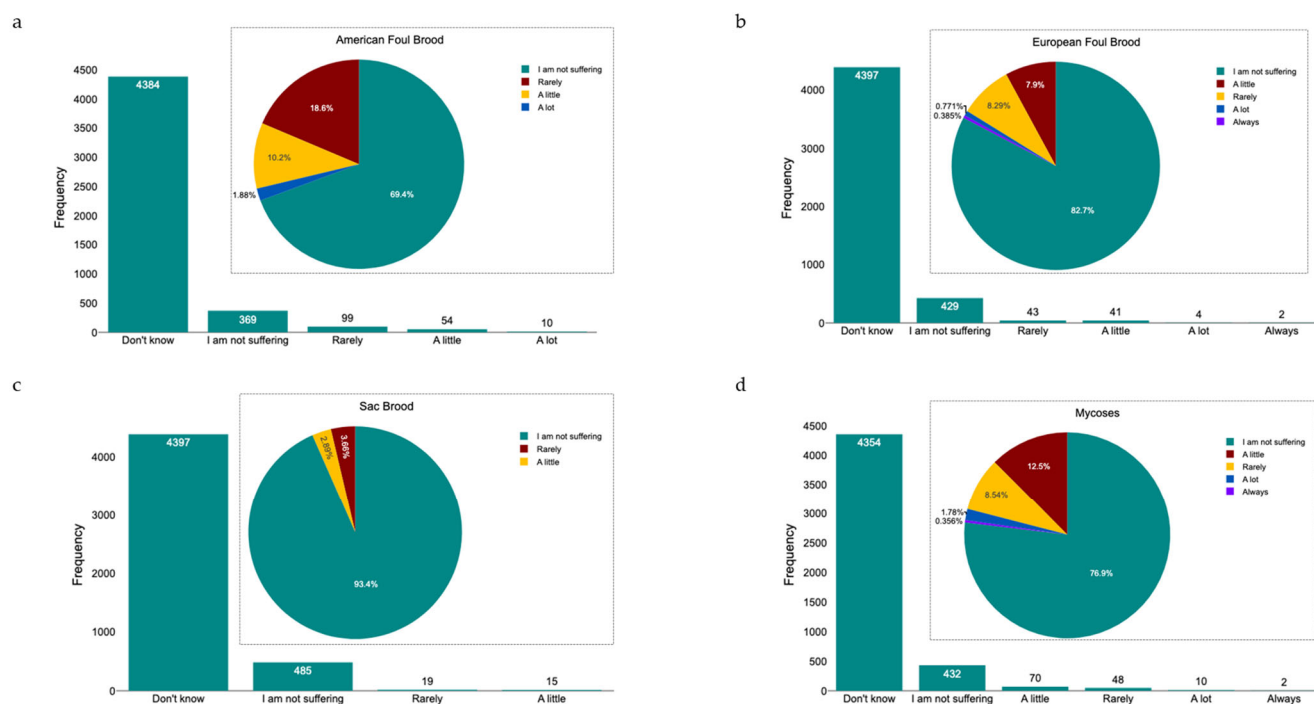
3.5. Disease Awareness, Prevalence, and Health Management Constraints

Given the scale of the survey, this study provides one of the most comprehensive assessments of beekeeper-reported colony health and management constraints in Lebanon. The evaluation of common bee diseases (Figure 7) reveals a significant deficiency in disease knowledge and diagnostic capacity among Lebanese beekeepers. Across all investigated diseases, including American foulbrood (AFB), European foulbrood (EFB), sacbrood, mycoses, nose mosis, bee paralysis, and dysentery, most respondents selected “Don’t know”, with frequencies exceeding 85% in most cases. This finding indicates a systemic deficiency in disease recognition and monitoring. This suggests that beekeepers lack adequate knowledge, training, or access to diagnostic tools. Consequently, the claimed prevalence of diseases must be interpreted with caution, as it likely represents perceived rather than real disease occurrence. Sociocultural and economic factors may also affect disease reporting, where beekeepers are reluctant to admit infections in their hives. In many smallholder systems, the presence of diseases is perceived as poor management, which can hurt the reputation of beekeepers in their community or with customers. Consequently, beekeepers have a tendency to under-report diseases, further contributing to discrepancies between announced and actual disease prevalence [24,25]. This limitation is accentuated by the lack of sufficiently equipped governmental diagnostic laboratories and integrated surveillance systems in Lebanon. In many developing countries, limited institutional capacity hinders prompt disease identification, confirmation, and reporting, consequently undermining overall biosecurity frameworks and underestimating the disease's prevalence.

Among respondents who reported disease status, the majority indicated no infection, particularly for sacbrood, nose mosis, and bee paralysis (>90%). However, AFB had the highest reported prevalence, followed by mycoses and dysentery. This could mean that

these disorders are either more common or easier for beekeepers to recognize. AFB stands out as the most impactful disease, with a notable proportion of respondents reporting occurrences ranging from “a little” to “a lot”. This finding shows how important it is to monitor and treat this disease because it spreads easily and has a big effect on colony survival.

Bacterial brood diseases remain a significant concern for disease awareness and biosecurity. AFB caused by *Paenibacillus larvae* is highly infectious because spores remain viable for decades. Infection occurs when bee larvae ingest *P. larvae* spores, resulting in brownish, semi-fluid, glue-like larvae that subsequently dry into hard scales attached to the lower cell wall. EFB caused by *Melissococcus plutonius* is frequently associated with colony stress. It primarily affects honeybee larvae, and it is characterized by dead, twisted brood within their cells [26]. In Australia, recent DNA screening of honey found a 21% prevalence of AFB and 18% prevalence of EFB [27]. Epidemiological data from the USA indicate that EFB may be more prevalent than AFB in some regions, with national averages reaching 19.2% compared to 8.6% for AFB, and infection rates varying widely (0–63.6% for EFB and 0–54.8% for AFB) depending on geographic and environmental conditions [28]. This highlights that these diseases are common even in well-monitored systems. These infections have a direct impact on brood viability, leading to weakened colony structure, reduced worker populations, and ultimately decreased productivity. Despite their importance, the absence of clear reporting in the present dataset suggests that AFB and EFB are probably missing due to limited diagnostic awareness, particularly since early-stage symptoms can be subtle and easily confused with other brood disorders.



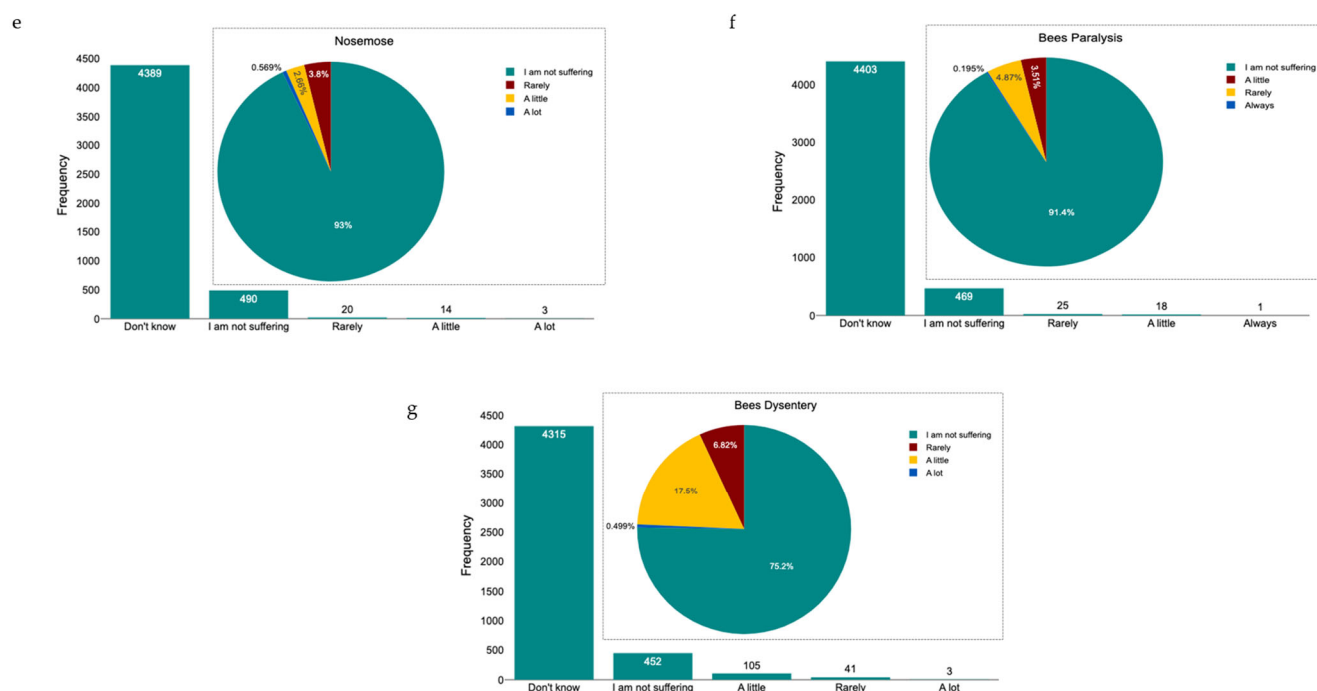


Figure 7. Prevalence and perceived severity of major bee diseases among Lebanese beekeepers. Frequency distribution and self-reported impact across pathologies ($n = 4916$) (a) American foulbrood; (b) European foulbrood; (c) Sacbrood; (d) Mycoses; (e) Nosemose; (f) Bee paralysis; (g) Dysentery. The inset pie charts illustrate the proportional distribution of responses as burden level (“Always”, “A lot”, “A little”, “Rarely”, “Not suffering”).

The evaluation of additional parasitic and colony-level disorders (Figure 8) further reinforces the limited diagnostic capacity and heterogeneous perception of colony health among Lebanese beekeepers. Acariose is largely unrecognized, with most respondents (>90%) reporting no symptoms among those who provided an answer, while a substantial proportion again selected “Don’t know”. This pattern confirms that parasitic diseases are not obvious and remain largely undetected, likely due to their subclinical or less easily identifiable symptoms.

Colony collapse disorder (CCD), on the other hand, exhibits a different pattern, with a more balanced distribution across response categories. While a considerable number of beekeepers still report uncertainty, a significant share indicates experiencing CCD at different levels, including “a little” (17%), “a lot” (~15.6%), and “always” (~16%). This implies that CCD is more perceptible at the colony level, probably because of its severe and evident effects (sudden colony loss), even without a clear diagnostic comprehension. Colony Collapse Disorder (CCD) represents one of the most critical threats to global apiculture. It is characterized by the sudden disappearance of adult worker bees from other viable colonies, leaving behind the queen, brood, and food reserves with minimal evidence of dead individuals [29]. The relatively high reporting of CCD may thus indicate symptom-based recognition rather than mechanistic understanding, potentially involving various underlying stressors such as pathogens, pesticides, nutritional deficiencies, and environmental pressures [29,30]. Since its formal recognition in 2006 in the United States, CCD has become a global phenomenon, with reports of colony losses exceeding 30% in several regions, including Europe and North America [29]. A comprehensive epidemiological investigation in South Korea revealed a significant reduction in colony numbers after 2021, which was associated with extensive pathogen exposure and environmental stressors [30].

Varroa infestation emerges as the most reported and harmful condition. A large number of beekeepers reported high levels of infestation (“a lot”: ~33.5%; “always”: ~6.8%), while only a small fraction reported being unaffected. Even though a significant number of respondents still selected “Don’t know”, the distribution clearly indicates that Varroa is both widely present and relatively well recognized compared to other diseases. This is consistent with the global literature that identifies *Varroa destructor* as a principal factor contributing to colony losses and productivity decline in apiculture systems worldwide. Multiple large-scale surveys confirm that honeybee colonies are rarely free from pathogens. For example, *Varroa destructor* infestation affects 75.7% of colonies in Uruguay. About 33% of those colonies are at risk of viral infections like deformed wing virus (DWV) because they are more than 4% infected [31]. Similarly, in Mexico, *Varroa* was also found in 83.5% of apiaries, with infestation levels exceeding 4.5% in high-risk regions [32].

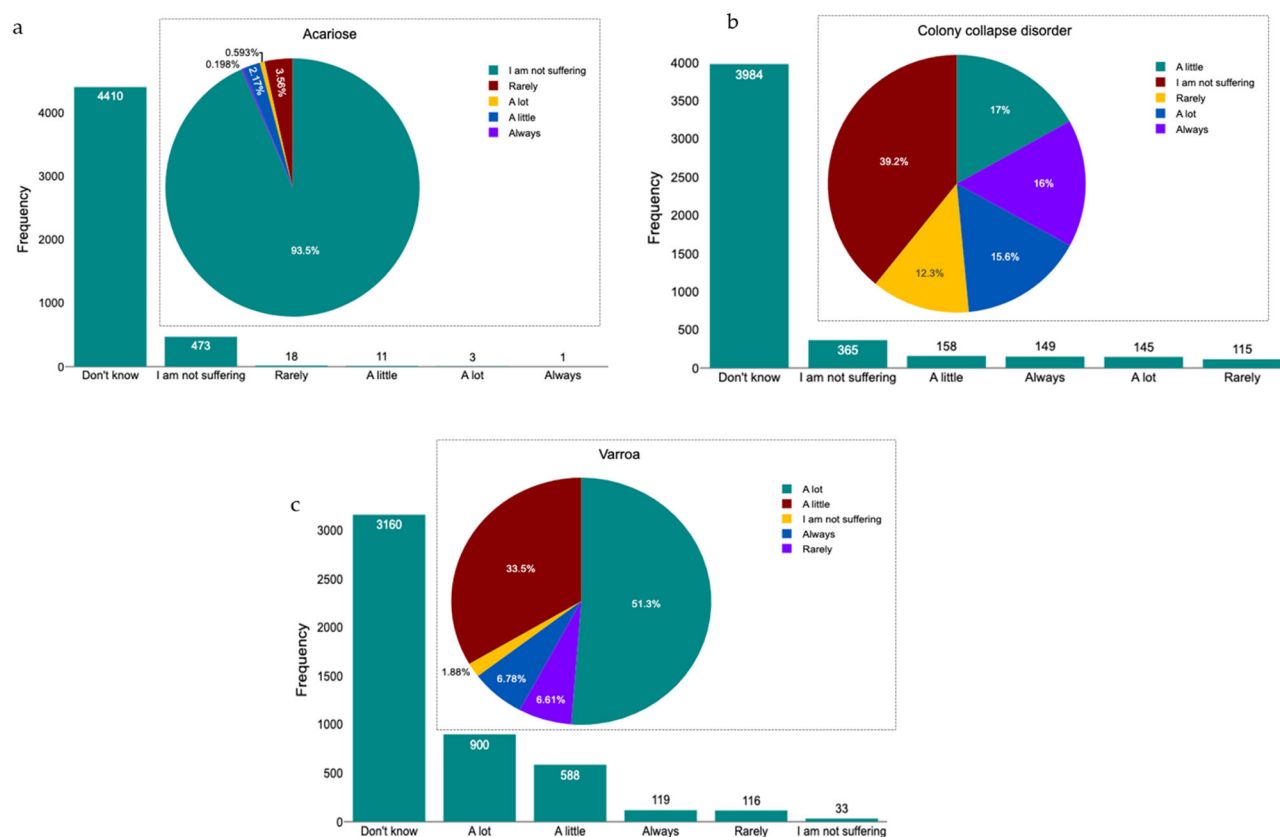


Figure 8. Beekeeper-reported prevalence and severity of key parasitic and colony-level disorders: Acarirose (a), Colony Collapse Disorder (b), and Varroa Infestation (c) in Lebanese Apiculture ($n = 4916$).

The evaluation of predator and pest pressures (Figure 9) underscores the insufficient awareness and heterogeneous perception of biotic stressors affecting Lebanese apiculture systems. Similar to disease-related findings, the majority of respondents chose “Don’t know” for all pest categories, highlighting a significant gap in pest identification and monitoring capabilities. Among the pests investigated, wasps and hornets are the most serious and dangerous pests that were studied. A large number of beekeepers reported moderate to high levels of infestation (“a little” to “a lot”). This contrasts with other pests, such as beetles and wax moths, for which most respondents claimed no impact on them. However, given the high level of uncertainty, these results are likely to reflect differences in perceptibility rather than actual prevalence. Beekeepers can easily spot wasps because

they are very visible and directly attack bee colonies. Their impact on colony strength and honey production is obvious, explaining the higher reporting rates. On the other hand, pests like wax moths and beetles, which may be less obvious or live in hive structures, are probably not diagnosed as often, especially in systems with little technical monitoring. The case of birds and animals presents an intermediate pattern, with moderate levels of reported impact. This suggests that interactions depend on the environment and location.

These findings support the broader observation that biotic stressors are not always recognized. Beekeepers mostly respond to threats that are clear and immediate, while pests that are less obvious but could be important are often ignored. This selective perception may lead to imbalanced management strategies, where certain threats are exaggerated, and others are neglected. From a systems point of view, pest pressures, especially from wasps, represent an additional layer of stress that interacts with previously identified challenges, such as disease burden, limited queen management, and productivity variability. The combined effects of these factors may contribute to colony weakening and reduced economic performance.

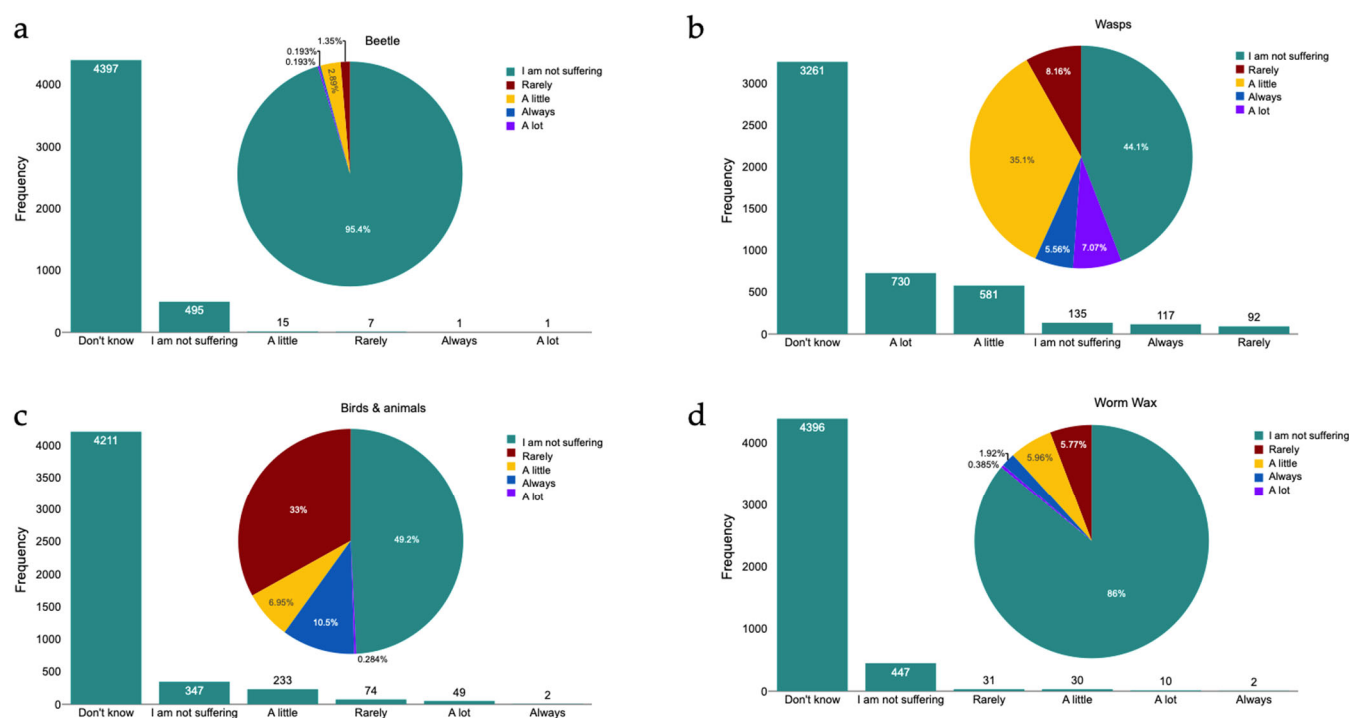


Figure 9. Beekeeper-reported prevalence and impact of predators and pests in Lebanese apiculture: Beetles (a), Wasps and Polistines (b), Birds and Animals (c), and Wax Moths (d) ($n = 4916$).

Table 1 represents the regional variability in honeybee pest and disease distribution across Lebanese governorates. After applying the conservative Bonferroni correction ($\alpha_{\text{corrected}} = 0.005$), only five conditions maintained statistically significant associations with the governorates, providing strong quantitative support for the epidemiological trends observed in the disease section. In particular, the moderate-to-strong effect sizes recorded for AFB ($\chi^2 (24) = 2060.92$, $p < 0.001$, Cramer's $V = 0.32$), EFB ($\chi^2 (30) = 1958.71$, $p = 0.002$, Cramer's $V = 0.28$), and nosemosis ($\chi^2 (24) = 1953.91$, $p = 0.004$, Cramer's $V = 0.32$) confirm that these diseases are not evenly distributed across Lebanon but rather display distinct spatial structuring, likely influenced by environmental and management-related factors. This aligns with the biological characteristics of AFB and EFB, where transmission is influenced by colony density, hygiene practices, and climatic conditions affecting the pathogen survival [33]. The strong association between sacbrood (Cramer's $V = 0.37$) and lo-

calized stressors like nutritional deficiencies and seasonal brood dynamics shows that it has a role as an indicator of colony stress rather than a primary pathogen-driven collapse [34]. Varroa infestation (Cramer's $V = 0.30$) showed statistically significant spatial variability, indicating its central role in disease dynamics, as highlighted in the disease section. Given that *Varroa destructor* acts as both a parasite and a vector for viral pathogens (e.g., DWV) (Warner et al., 2024) [35], its uneven distribution across governorates is probably a factor in the study's findings of different rates of viral and secondary infections. This correlation between Varroa pressure and disease expression supports the hypothesis of synergistic pathogen interactions, a key mechanism underlying colony weakening and collapse [35]. The notable correlation between colony collapse disorder (CCD) and governorates (Cramer's $V = 0.30$) offers evidence connecting the disease burden to more extensive colony failure results. This backs up the idea that disease pressure, especially brood diseases and infections linked to Varroa, is a major cause of colony instability, which in turn leads to lower productivity and a higher risk of collapse [36]. The geographic clustering of CCD indicates that collapse events are the result of localized combinations of stressors rather than a singular predominant cause.

Table 1. Association between Lebanese governorates and the prevalence of honeybee pests and diseases.

	Chi ²	df	<i>p</i>	Cramer's V	C
American Foul Brood	2060.92	24	<0.001	0.32	0.61
European Foul Brood	1958.71	30	0.002	0.28	0.58
Varroa	2251.78	30	0.003	0.3	0.61
Nosemosis	1953.91	24	0.004	0.32	0.6
Sac Brood	1995.5	18	0.005	0.37	0.62
Mycoses	1934.25	30	0.006	0.28	0.58
Bees Paralysis	1962.59	24	0.007	0.32	0.6
Bees Dysentery	1986.01	24	0.008	0.32	0.6
Worm Wax	1984.9	30	0.009	0.28	0.59
Acariose	1961.56	30	0.01	0.28	0.59
Birds and animals	1964.52	30	0.011	0.28	0.59
Beetle	1878.59	30	0.012	0.28	0.58
Wasps and hornets	1824.48	30	0.013	0.27	0.57
Colony collapse disorder	2186.61	30	0.014	0.3	0.61

C: Pearson's contingency coefficient.

The chi-square analysis (Table 2) aims to assess the association between beekeepers' education level and the occurrence of honeybee pests and diseases in Lebanon. It demonstrated statistically significant correlations between beekeepers' education level and all investigated honeybee pests and diseases ($p < 0.001$). This observation suggests that educational background plays a measurable role in colony health outcomes. However, the effect sizes (Cramer's $V = 0.08$ – 0.10) consistently fall within the weak association range, suggesting that while education is a relevant factor, it is not the primary determinant of disease occurrence. Among the variables, Varroa infestation ($\chi^2 = 197.54$, Cramer's $V = 0.10$) and sacbrood ($\chi^2 = 138.84$, Cramer's $V = 0.10$) had the highest effect sizes but remained weak. This means that these conditions are slightly more sensitive to differences in beekeepers' knowledge, management practices, and technical capacity [37]. This is not surprising, particularly for Varroa, as its control requires regular monitoring, appropriate timing of treatment, and integrated pest management (IPM) strategies [38], which are typically associated with higher levels of technical awareness and training. In contrast, brood diseases such as AFB and EFB also showed significant associations ($p < 0.001$), but weak

effect sizes (Cramer's $V = 0.08$). This indicates that although education contributes to disease awareness and detection, the spread of these highly infectious diseases is more strongly influenced by external factors, such as colony density, equipment contamination, and biosecurity practices at the community level (Forsgren et al., 2018) [33], rather than individual beekeeper characteristics alone. Colony collapse disorder (CCD) showed a weak but significant association with education level ($\chi^2(20) = 161.24, p < 0.001$, Cramer's $V = 0.09$). This supports the idea that CCD is a multifactorial phenomenon including beekeeper knowledge, environmental stressors, pathogen pressure, and management practices, but no single factor can be identified as the principal cause [29,30]. From an epidemiological perspective, the relatively low Cramer's V values (≤ 0.10) and moderate contingency coefficients ($C \approx 0.18$ – 0.22) indicate that education level accounts for only a small fraction of the variability in disease incidence. This differs from the earlier findings that showed stronger geographic effects, suggesting that environmental and regional factors have a bigger impact on disease distribution than the characteristics of individual beekeepers.

Table 2. Association between beekeepers' education level and the prevalence of honeybee pests and diseases in Lebanon.

	Chi ²	df	<i>p</i>	Cramer's <i>V</i>	<i>C</i>
American Foulbrood	139.13	16	<0.001	0.08	0.19
European Foulbrood	129.99	20	<0.001	0.08	0.18
Varroa	197.54	20	<0.001	0.1	0.22
Nosemosis	152.9	16	<0.001	0.09	0.19
Sac Brood	138.84	12	<0.001	0.1	0.19
Mycoses	170.19	20	<0.001	0.09	0.2
Bees Paralysis	139.86	16	<0.001	0.08	0.19
Bees Dysentery	143.37	16	<0.001	0.09	0.19
Worm Wax	149.39	20	<0.001	0.09	0.19
Acariose	139	20	<0.001	0.08	0.19
Birds and animals	164.52	20	<0.001	0.09	0.2
Beetle	141.67	20	<0.001	0.08	0.19
Wasps and hornets	164.45	20	<0.001	0.08	0.2
Colony collapse disorder	161.24	20	<0.001	0.09	0.2

3.6. Disease Management Practices and Treatment Strategies in Lebanese Apiculture

The treatment strategies reported by beekeepers for major honeybee pests and diseases in Lebanon are summarized in Table 3. This provides an insight into current management practices and their alignment with recommended apicultural standards. Overall, the results indicate a predominant reliance on chemical treatments, especially for parasitic and microbial diseases, combined with limited adoption of alternative and management-based practices. For *Varroa destructor*, diversified control strategies are adopted, including amitraz-based products (Apivar®, Apistan®), organic acids (formic acid), and essential oils. This indicates that beekeepers recognize Varroa as a significant threat and are proactively employing control strategies; however, the simultaneous application of multiple acaricides raises concerns regarding potential emergence of resistance and improper treatment rotation, which are widely documented challenges in apiculture [39]. For AFB, the use of antibiotics like tetracycline and oxytetracycline, along with practices like destruction and isolation, indicates partial adherence to recommended control strategies. There is a gap between best practices (burning infected colonies) and field-level implementation, likely influenced by economic constraints. However, the excessive or inappropriate use of antibiotics should be avoided, as it can promote the development of antimicrobial re-

sistance and negatively affect colony health. Moreover, the detection of antibiotic residues in honey raises significant concerns regarding food safety and potential risks to human health [28]. For EFB and sacbrood virus, the reported practices (e.g., queen replacement, sanitation, nutritional support) emphasize management-based and preventive approaches, which are consistent with current recommendations [34,40]. This suggests that beekeepers recognize the role of colony strength and nutrition in mitigating non-obligate or stress-induced diseases. The treatment of *Nosema* spp. relies primarily on fumagillin-based products (Fumidil-B®) and sterilization, indicating dependence on chemical interventions. Numerous recent articles reviewed the use of fumagillin; however, uncertainty persists regarding its efficacy in controlling *Nosema* spp. infections, its overall benefit to honeybee colony health, and whether its effectiveness has declined over time [41,42]. However, the use of fumagillin is restricted globally because of fumagillin's potential toxic effect on humans and the risk of residues in honey and wax [43]. This suggests the lack of awareness or access to alternative strategies, such as improved hive hygiene and nutritional management. For secondary disorders like bee paralysis, dysentery, and mycoses, the reported interventions are largely environmental and managerial (e.g., ventilation, sanitation, humidity control, hive replacement), reflecting their multifactorial and opportunistic nature. Pest management practices, including those targeting wax moths, wasps, beetles, and birds, are predominantly based on mechanical and preventive measures (e.g., traps, hive protection, environmental control), which are aligned with integrated pest management (IPM) principles. However, these approaches appear reactive rather than systematic, suggesting limited implementation of structured monitoring strategies.

These findings show that the disease management system in Lebanese beekeeping is not uniform and is only partially optimized. The coexistence of chemical, biological, and management-based interventions highlights the necessity for standardized national guidelines, enhanced training programs, and integrated surveillance systems. Strengthening these areas would make it easier to move toward sustainable, evidence-based beekeeping, which would lower the number of diseases while also lowering the risks of antimicrobial resistance, chemical residues, and colony stress.

Table 3. Reported treatment practices for major honeybee pests and diseases among beekeepers in Lebanon.

Disease	Common Treatments Reported
<i>Varroa destructor</i>	Amitraz®, Apivar®, Apistan®, Apiguard®, ApilifeVar®, Perizin, formic acid, fluvalinates, essential oils
AFB	Tetracycline, Oxytetracycline, Sulfatiazol, isolation, destruction
EFB	Queen replacement, isolation, sterilization, cleaning, pollen feeding
<i>Nosema</i> spp.	Fumagillin, Fumidil-B®, sterilization
Sacbrood virus	Queen replacement, nutritional support, protein feeding, hive sanitation
Bee Paralysis	Queen change, forage change, hive ventilation, apiary condition improvement
Dysentery	Fumagillin, Oak honey removal, clean water feeding, vitamin supplements, humidity control
Mycoses	Frame removal, wax recycling, hive replacement, resistant races
Acariose	Apivar®, Byvarol®, Maverick, essential oils, Amitraz®
Wax Moth (Worm Wax)	Certan, Mellonex®, wax replacement, sulfur traps, aeration, polished wood hives

Wasps	Trap setting, nest destruction, hive protection, hive door reinforcement
Beetles	Sandy area avoidance, honey frame elevation, Faster honey extraction, humidity control
Harmful Birds	Scaring, physical removal

3.7. SWOT Analysis of the Beekeeping Sector in Lebanon

The SWOT analysis (Figure 10) provides a systemic assessment of the Lebanese apiculture sector, integrating structural, technical, economic, and environmental dimensions. The results highlight a sector characterized by strong intrinsic potential yet constrained by significant operational and institutional limitations.

From a strengths perspective, Lebanese beekeeping benefits from a high-value product positioning, particularly for niche honey types such as mountain, oak, and citrus honey. This is reinforced by the relatively low capital investment and rapid return on investment, making beekeeping accessible to small-scale producers. Furthermore, the country's agroecological diversity supports a wide range of floral sources, enabling product differentiation. The sector also demonstrates strong rural engagement, indicating its importance as a livelihood strategy in several regions.

However, these advantages are counterbalanced by critical weaknesses. The data presented in previous sections clearly demonstrate low and highly variable productivity across regions and sociodemographic groups, reflecting inconsistencies in management practices and technical capacity. A major structural limitation is the extremely low level of disease awareness, with more than 70% of beekeepers reporting a lack of knowledge regarding key pathogens and pests. This finding aligns with the observed underutilization of high-value bee products such as pollen, propolis, and royal jelly, where non-production rates exceed 70–98%, indicating limited diversification and technical expertise. Additionally, weak cooperative structures, limited aggregation capacity, and lack of quality standardization constrain market expansion, particularly for export-oriented value chains. Furthermore, beekeepers reported inconsistencies in marketing strategies and market access during the survey, which may limit their ability to commercialize products effectively and reduce overall sector competitiveness.

Despite these constraints, several opportunities emerge for sector development. The increasing global demand for premium and traceable honey products presents a significant opportunity for Lebanese producers to penetrate international markets. The development of value-added products offers an important pathway for income diversification and resilience. Moreover, targeted capacity-building programs and technical training could directly address productivity gaps identified in this study. The integration of marginalized populations, including rural and refugee communities, further enhances the socio-economic relevance of the sector. The adoption of modern apicultural practices, such as integrated pest management (IPM) and digital monitoring systems, alongside improved institutional support, could substantially enhance both productivity and sustainability.

Conversely, the sector faces several external threats that may compromise its long-term viability. The high burden of bee diseases, including *Varroa destructor*, *Nosema* spp., AFB, and EFB, represents a major risk, particularly in the context of low diagnostic awareness among beekeepers. In addition, the potential introduction and unnoticed spread of invasive or emerging pathogens and pests may constitute an additional biological stressor for the Lebanese apiculture sector, especially given the limited capacity of many beekeepers to accurately recognize and differentiate established bee health disorders. These biological stressors, combined with environmental pressures such as a reduction in forage resources and climate variability, increase the likelihood of colony losses and reduced

productivity. In addition, honey adulteration and fraud, as well as competition from unregulated imports, threaten market integrity and consumer trust. The absence of robust surveillance systems and regulatory enforcement further exacerbates these risks.

Overall, the SWOT analysis confirms that the Lebanese apiculture sector operates within a high-potential yet vulnerable system, where productivity and sustainability are tightly linked to improvements in colony health management, technical capacity, and institutional governance.

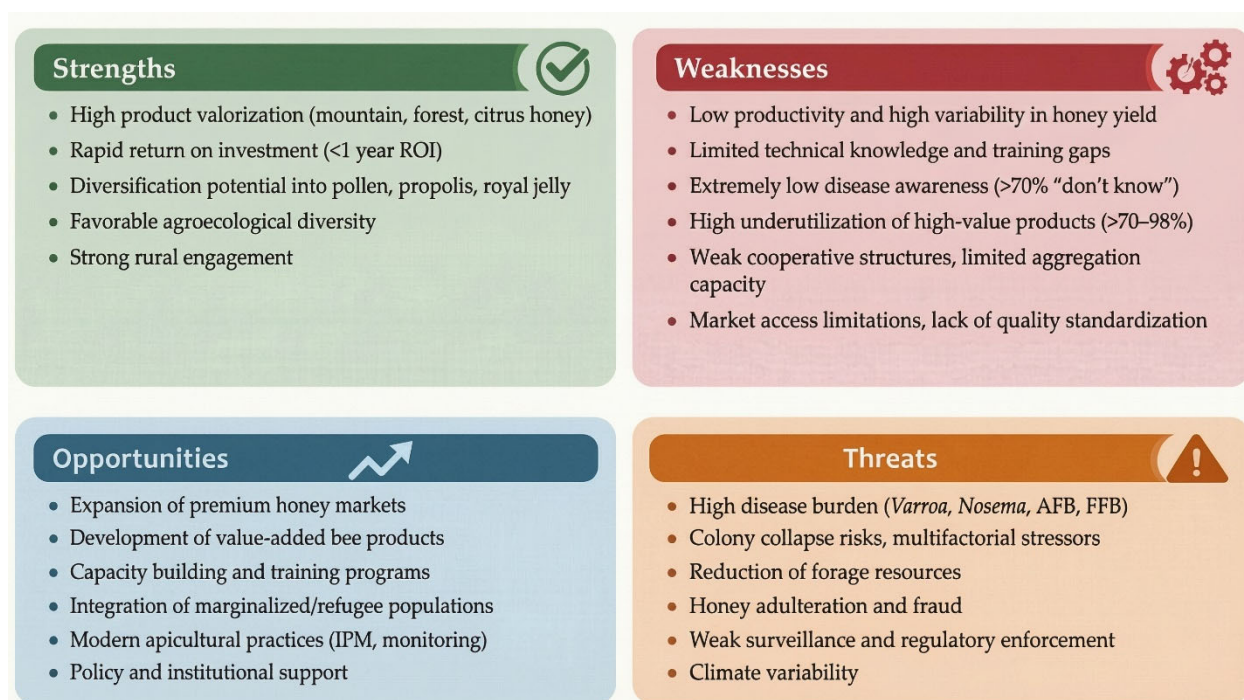


Figure 10. SWOT analysis of the beekeeping sector in Lebanon.

4. Conclusions and Recommendations

This study provides the first comprehensive, data-driven assessment of the Lebanese beekeeping sector, integrating sociodemographic structure, production systems, disease dynamics, and management practices. It highlights the interconnections between colony health, productivity, and long-term sustainability. The findings demonstrate that apiculture in Lebanon is predominantly a smallholder, semi-traditional system, characterized by low cooperative integration, limited professionalization, and strong dependence on diversified rural livelihoods. Production systems are largely mono-product oriented, with honey dominating overwhelmingly, while high-value products such as pollen, propolis, and royal jelly remain underdeveloped. Colony health emerges as a central limiting factor. The study identifies a critical deficiency in disease awareness and diagnostic capacity, with most beekeepers unable to recognize key pathologies. Management practices are heterogeneous and only partially aligned with recommended standards, with a strong reliance on chemical treatments and limited implementation of preventive and integrated approaches.

To support the transition toward a sustainable and resilient apiculture sector in Lebanon, a comprehensive and integrated approach is required. Priority should be given to establishing a national bee health surveillance system that combines field diagnostics with laboratory confirmation, enabling early detection and region-specific management of major threats. As an initial implementation step, a pilot surveillance program could be launched within the next 12–24 months in selected governorates representing different ecological and production systems. The establishment of mobile diagnostic hubs could

enhance accessibility to technical support, particularly in remote and underserved areas, through periodic field visits conducted by trained veterinary and apicultural teams equipped with rapid diagnostic tools, sampling materials, and treatment guidance protocols. These mobile units could support on-site colony inspections, early screening for diseases and pests, sample collection for laboratory confirmation, beekeeper training on disease recognition and biosecurity practices, and dissemination of standardized management guidelines. Concurrently, strengthening capacity building through structured training programs and extension services is essential to improve disease recognition, biosecurity, and the adoption of integrated pest management strategies. Efforts should also focus on promoting sustainable management practices by reducing the misuse of antibiotics and chemical treatments, while encouraging environmentally friendly alternatives and improved hive hygiene. From an economic perspective, enhancing value chain diversification through the development of high-value hive products, alongside the implementation of quality standards and traceability systems, would significantly improve market competitiveness and resilience. In parallel, reinforcing cooperative structures and fostering collaboration among beekeepers can enhance resource sharing, innovation diffusion, and access to markets. From an economic perspective, enhancing value chain diversification through the development of high-value hive products, alongside the implementation of quality standards and traceability systems, would significantly improve market competitiveness and resilience. In parallel, reinforcing cooperative structures and fostering collaboration among beekeepers can enhance resource sharing, innovation diffusion, and access to markets.

Author Contributions: Conceptualization: D.Y., A.T., Z.R. and Y.E.R.; Methodology: D.Y., A.T., Z.R., S.G.J. and Y.E.R.; Software: D.Y. and S.G.J.; Validation: A.T., S.P.S., F.M., S.G.J. and Y.E.R.; Investigation: D.Y., A.T. and Z.R.; writing—original draft preparation: D.Y. and Y.E.R.; writing—review and editing, A.T., Z.R., S.P.S., F.M., S.G.J. and Y.E.R.; Visualization: S.G.J. and Y.E.R.; Supervision: S.P.S., F.M. and Y.E.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study is waived for ethical review as the study involved an anonymous survey related to apiculture practices and bee colony health and did not include medical interventions, collection of sensitive personal information, identifiable human data, vulnerable populations, or experimental procedures involving human participants by Institution Committee.

Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: All authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Gebretsadik, T.; Alemu, T. Linking bees, biodiversity, and breadwinners: Ecological and economic values of beekeeping for agricultural productivity and livelihood sustainability in Southern Ethiopia. *Environ. Sustain. Indic.* **2026**, *30*, 101157. <https://doi.org/10.1016/j.indic.2026.101157>.
2. Porto, R.G.; De Almeida, R.F.; Cruz-Neto, O.; Tabarelli, M.; Viana, B.F.; Peres, C.A.; Lopes, A.V. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Secur.* **2020**, *12*, 1425–1442. <https://doi.org/10.1007/s12571-020-01043-w>.

3. Klein, A.M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tschamntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B* **2007**, *274*, 303–313. <https://doi.org/10.1098/rspb.2006.3721>.
4. Nath, R.; Singh, H.; Mukherjee, S. Insect pollinators decline: An emerging concern of Anthropocene epoch. *J. Apic. Res.* **2023**, *62*, 23–38. <https://doi.org/10.1080/00218839.2022.2088931>.
5. Brunet, J.; Fragoso, F.P. What are the main reasons for the worldwide decline in pollinator populations? *CABI Rev.* **2024**, *19*. <https://doi.org/10.1079/cabireviews.2024.0016>.
6. Available online: <https://faolex.fao.org/docs/pdf/leb202167.pdf> (accessed on 22 March 2026).
7. Boustani, M.; Rasmont, P.; Dathe, H.H.; Ghisbain, G.; Kasperek, M.; Michez, D.; Nemer, N. The bees of Lebanon (Hymenoptera: Apoidea: Anthophila). *Zootaxa* **2021**, *4976*, 1–146. <https://doi.org/10.11646/zootaxa.4976.1.1>.
8. Herrera, C.M. Gradual replacement of wild bees by honeybees in flowers of the Mediterranean Basin over the last 50 years. *Proc. R. Soc. B* **2020**, *287*, 20192657. <https://doi.org/10.1098/rspb.2019.2657>.
9. Awad, A.M.; Owayss, A.A.; Alqarni, A.S. Performance of two honey bee subspecies during harsh weather and *Acacia gerrardii* nectar-rich flow. *Sci. Agric.* **2017**, *74*, 474–480. <https://doi.org/10.1590/1678-992X-2016-0101>.
10. Jmal, S.; Ben Ismail, H.; Hamzaoui, M.; Ben Salem, H.; Debbabi, H. Analysis of Tunisian beekeepers' perceptions in honey bee diseases and pests management. *Egypt. J. Agric. Sci.* **2024**, *75*, 48–59. <https://doi.org/10.21608/ejarc.2024.345965>.
11. El Hajj, R.; Nemer, N.; Skaff, W.; Estephan, N. Multivariate approach to analyzing survey data: A case study of beekeeping in Lebanon. *J. Apic. Res.* **2023**, *62*, 459–467. <https://doi.org/10.1080/00218839.2021.1987739>.
12. Tohmé, G.; Tohmé, H. *Illustrated Flora of Lebanon*; National Council for Scientific Research: Beirut, Lebanon, 2014.
13. CNRS-L. Land Cover/Land Use Map of Lebanon, Scale 1:20,000. 2019. Available online: <http://rsensing.cnrs.edu.lb> (accessed on 15 February 2026).
14. Mburu, P.D.M.; Affognon, H.; Irungu, P.; Mburu, J.; Raina, S. Gender roles and constraints in beekeeping: A case from Kitui county, Kenya. *Bee World* **2017**, *94*, 54–59. <https://doi.org/10.1080/0005772X.2016.1275490>.
15. Guiné, R.P.F.; Mesquita, S.; Oliveira, J.; Coelho, C.; Costa, D.T.; Correia, P.; Correia, H.E.; Dahle, B.; Odiie, M.; Raimets, R.; et al. Characterization of beekeepers and their activities in seven European countries. *Agronomy* **2021**, *11*, 2398. <https://doi.org/10.3390/agronomy11122398>.
16. Abro, Z.; Kassie, M.; Tiku, H.A.; Taye, B.; Ayele, Z.A.; Ayalew, W. The impact of beekeeping on household income: Evidence from north-western Ethiopia. *Heliyon* **2022**, *8*, e09492. <https://doi.org/10.1016/j.heliyon.2022.e09492>.
17. Etxegarai-Legarreta, O.; Sanchez-Famoso, V. The role of beekeeping in the generation of goods and services: The interrelation between environmental, socioeconomic, and sociocultural utilities. *Agriculture* **2022**, *12*, 551. <https://doi.org/10.3390/agriculture12040551>.
18. ACTED. Lebanon Honey Value Chain Analysis Report. Final Report of the EU Project “Support to Olive and Beekeeping Cooperatives in Lebanon”. 2018. Available online: <https://www.acted.org/wp-content/uploads/2018/01/final-value-chain-report---aggregate--acted-lebanon.pdf> (accessed on 23 March 2026).
19. Bienkowska, M.; Łoś, A.; Węgrzynowicz, P. Honey bee queen replacement: An analysis of changes in the preferences of Polish beekeepers through decades. *Insects* **2020**, *11*, 544. <https://doi.org/10.3390/insects11080544>.
20. Gratzer, K.; Musalkova, V.; Brodschneider, R. How science supports honey bees: Identification of research on best practices in beekeeping. *Insects* **2025**, *16*, 1025. <https://doi.org/10.3390/insects16101025>.
21. Lin, Z.; Zhang, Y.; Wang, K.; Jiang, X.; Ji, T. Genetic bottlenecks in modern beekeeping: Implications for conservation and sustainable pollination. *Conserv. Lett.* **2025**, *18*, e13156. <https://doi.org/10.1111/conl.13156>.
22. Der Sarkissian, R.; Zaninetti, J.M.; Abdallah, C. The use of geospatial information as support for disaster risk reduction: Contextualization to Baalbek-Hermel Governorate/Lebanon. *Appl. Geogr.* **2019**, *111*, 102075. <https://doi.org/10.1016/j.apgeog.2019.102075>.
23. Schouten, C.N. Factors influencing beekeepers income, productivity and welfare in developing countries: A scoping review. *J. Apic. Res.* **2020**, *60*, 204–219. <https://doi.org/10.1080/00218839.2020.1844464>.
24. Chauzat, M.P.; Cauquil, L.; Roy, L.; Franco, S.; Hendriks, P.; Ribiere-Chabert, M. Demographics of the European apicultural industry. *PLoS ONE* **2013**, *8*, e79018. <https://doi.org/10.1371/journal.pone.0079018>.
25. Silva de Oliveira, V.H.; Nilsson, A.; Kim, H.; Hallgren, G.; Frössling, J.; Kristiansen, L.F.; Forsgren, E. Honey bee pathogens and parasites in Swedish apiaries: A baseline study. *J. Apic. Res.* **2021**, *60*, 697–706. <https://doi.org/10.1080/00218839.2021.1902679>.
26. Chantawannakul, P.; de Guzman, L.I.; Li, J.; Williams, G.R. Parasites, pathogens, and pests of honeybees in Asia. *Apidologie* **2016**, *47*, 301–324. <https://doi.org/10.1007/s13592-015-0407-5>.
27. Bhasi, G.; Zerna, G.; Beddoe, T. Nationwide screening for arthropod, fungal, and bacterial pests and pathogens of honey bees: Utilizing environmental DNA from honey samples in Australia. *Insects* **2025**, *16*, 764. <https://doi.org/10.3390/insects16080764>.

28. Alburaki, M.; Abban, S.K.; Evans, J.D.; Chen, Y.P. Occurrence and distribution of two bacterial brood diseases (American and European foulbrood) in US honey bee colonies and resistance to antibiotics from 2015 to 2022. *J. Apic. Res.* **2024**, *63*, 701–710. <https://doi.org/10.1080/00218839.2024.2329854>.
29. Singh, G.; Rana, A. Honeybees and colony collapse disorder: Understanding key drivers and economic implications. *Proc. Indian Natl. Sci. Acad.* **2025**, *91*, 750–766. <https://doi.org/10.1007/s43538-025-00399-x>.
30. Heo, J.; Yoo, D.S.; Cheon, D.S.; Kim, Y.; Kim, D.Y. Prevalence of pathogens in abnormal honey bees in South Korea, 2020–2023. *J. Vet. Diagn. Investig.* **2025**, *37*, 104–113. <https://doi.org/10.1177/10406387241299868>.
31. Anido, M.; Branchiccela, B.; Castelli, L.; Harriet, J.; Campá, J.; Zunino, P.; Antúnez, K. Prevalence and distribution of honey bee pests and pathogens in Uruguay. *J. Apic. Res.* **2015**, *54*, 532–540. <https://doi.org/10.1080/00218839.2016.1175731>.
32. Correa-Benítez, A.; Anguiano-Baez, R.; Heneidi-Zeckua, A.; Dávalos-Flores, J.L.; Peña-Haaz, N.T.; Pérez-Martínez, E.E.; Carbal-Rodríguez, M.; Vasquez-Valencia, I.; Alamazan-Maldonado, N.; Petukhova, M.; et al. Prevalence of adult honey bee (*Apis mellifera* L.) pests and pathogens in the five beekeeping regions of Mexico. *Animals* **2023**, *13*, 1734. <https://doi.org/10.3390/ani13111734>.
33. Forsgren, E.; Locke, B.; Sircoulomb, F.; Schäfer, M.O. Bacterial diseases in honeybees. *Curr. Clin. Microbiol. Rep.* **2018**, *5*, 18–25. <https://doi.org/10.1007/s40588-018-0083-0>.
34. Wei, R.; Cao, L.; Feng, Y.; Chen, Y.; Chen, G.; Zheng, H. Sacbrood virus: A growing threat to honeybees and wild pollinators. *Viruses* **2022**, *14*, 1871. <https://doi.org/10.3390/v14091871>.
35. Warner, S.; Pokhrel, L.R.; Akula, S.M.; Ubah, C.S.; Richards, S.L.; Jensen, H.; Kearney, G.D. A scoping review on the effects of *Varroa destructor* on global honey bee decline. *Sci. Total Environ.* **2024**, *906*, 167492. <https://doi.org/10.1016/j.scitotenv.2023.167492>.
36. Morfin, N.; Goodwin, P.H.; Guzman-Novoa, E. *Varroa destructor* and its impacts on honey bee biology. *Front. Bee Sci.* **2023**, *1*, 1272937. <https://doi.org/10.3389/frbee.2023.1272937>.
37. De Carolis, A.; Newmark, A.J.; Kim, J.; Song, J.; Pietropaoli, M.; Manara, V.; Formato, G. A comprehensive analysis of beekeeping risks and validation of biosecurity measures against major infectious diseases in *Apis mellifera* in Europe. *Agriculture* **2024**, *14*, 393. <https://doi.org/10.3390/agriculture14030393>.
38. Jeyapriya, G.; Sumathi, E.; Saminathan, V.R.; Renukadevi, P.; Sasikala, R.; Priya, S.S.; Pradeep, S. Parasitic mites of honey bees (*Apis* spp.): A detailed review of *Varroa destructor*. *Acta Parasitol.* **2025**, *70*, 184. <https://doi.org/10.1007/s11686-025-01124-w>.
39. Mitton, G.A.; Meroi Arcerito, F.; Cooley, H.; Fernandez de Landa, G.; Eguaras, M.J.; Ruffinengo, S.R.; Maggi, M.D. More than sixty years living with *Varroa destructor*: A review of acaricide resistance. *Int. J. Pest Manag.* **2026**, *72*, 1–18. <https://doi.org/10.1080/09670874.2022.2094489>.
40. Mosca, M.; Gyorffy, A.; Pietropaoli, M.; Giannetti, L.; Cersini, A.; Fortugno, L.; Formato, G. IPM strategy to control EFB in *Apis mellifera*: Oxytetracycline treatment combined with partial shook swarm and queen caging. *Vet. Sci.* **2024**, *11*, 28. <https://doi.org/10.3390/vetsci11010028>.
41. Marín-García, P.J.; Peyre, Y.; Ahuir-Baraja, A.E.; Garijo, M.M.; Llobat, L. The role of *Nosema ceranae* in honey bee colony losses and current insights on treatment. *Vet. Sci.* **2022**, *9*, 130. <https://doi.org/10.3390/vetsci9030130>.
42. Peirson, M.; Pernal, S.F. A systematic review of fumagillin field trials for *Nosema* disease. *Insects* **2024**, *15*, 29. <https://doi.org/10.3390/insects15010029>.
43. Bahreini, R.; Nasr, M.; Docherty, C.; de Herdt, O.; Feindel, D.; Muirhead, S. In vivo inhibitory assessment of potential antifungal agents on *Nosema ceranae* proliferation in honey bees. *Pathogens* **2022**, *11*, 1375. <https://doi.org/10.3390/pathogens11111375>.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.