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Honey bees production – parameters influencing its productivity

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Declaration

Me, Teodor Husarčík, hereby declare that I have done this thesis entitled Honey bees production – parameters influencing its productivity independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague ………….

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Teodor Husarčík

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Abstract

Honey and wax production serve as vital components of the rural economies, particularly in Northern Algeria. This thesis aims to explore and assess several factors influencing honeybee colony development, weather-influenced daily dynamics, and forage sources availability. This study intends to establish efficient procedures for proper colony monitoring and beekeeper interventions through extensive data collection from various bioclimatic regions in Northern Algeria, including questionnaires, hive observations, pollen load analyses, palynological and honey sample analyses.

The development of the questionnaire survey was necessary for problem detection and monitoring as beekeeping has become more popular in Africa in recent years and more beekeepers are adopting inappropriate management practices. The questionnaire survey was administered to a homogeneous population of beekeepers (17 beekeepers from 22 sampled locations participated in the survey) and provided invaluable insights into a wide spectrum of management practices.

Hive observations provided crucial information on actual colony strength level and were reinforced by the Liebefelder method which was pivotal in assessing colony dynamics during internal hive inspections. Palynological analysis of pollen loads and honey sample analysis, provided in the Bouchegouf district, clarified the diversity of local floral sources and seasonal foraging patterns and detected the origin of local honey.

Understanding of the interactions between various beekeeping techniques, colony health, and environmental factors affecting honeybee productivity in Northern Algeria is provided by the integration of these methodologies. The identification of the key parameters influencing colony production revealed that the parameters affect individual factors in different ways.

Key words: Bees, Liebefelder method, production parameters, questionnaire, seasonal dynamics

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BEP = break even point

GLMM = generalized linear mixed models

1. Introduction

Algeria, characterized by diverse climatic conditions, nurture two primary subspecies of bees, namely *Apis mellifera intermissa* and *A. m. sahariensis* (Hepburn & Radloff 1998; Barour & Baylac 2016; Tamali & Özkırım 2019; Khedim et al. 2023). This study focuses on *Apis mellifera intermissa*, also known as Tellian bees, as the research is geographically centered in the northern part of Algeria.

Apis mellifera intermissa and *A. m. sahariensis* exhibit distinct behavioral and physiological characteristics (De la Rúa et al. 2009; Dietemann et al. 2009; Loucif-Ayad et al. 2015; Adjlane et al. 2016; Abed et al. 2020; Aglagane et al. 2022).

Apis mellifera intermissa, are known for their adaptability to the diverse bioclimatic conditions prevalent in the northern regions of Algeria (Ruttner 1988; Dietemann et al. 2009; Salvatore et al. 2023). Their ability to adapt to diverse and challenging environmental conditions is attributed to their distinctive foraging patterns, colony dynamics, and disease resistance mechanisms (Hepburn & Radloff 1997; Shaibi & Moritz 2010; Adjlane et al. 2016).

On the other hand, *A. m. sahariensis*, also known as the Saharan honey bee, is mostly found in the arid and desert areas of southeast Morocco and Algeria (Aglagane et al. 2022; Khedidji et al. 2022). This subspecies is endemic to the south-eastern Moroccan oases (Hepburn & Radloff 1997; Loucif-Ayad et al. 2015; Aglagane et al. 2022) separated from the other African subspecies geographically by the Sahara Desert and from the *Apis mellifera intermissa* by the High Atlas Mountain (Ruttner 1988; Chahbar et al. 2013; Adjlane et al. 2016; Aglagane et al. 2023). According to Shaibi and Moritz (2010) and Salvatore et al. (2023), *Apis mellifera sahariensis* exhibits adaptations suitable for harsh desert environments, such as effective water utilization and thermoregulation strategies. These differences in behaviour and physiological traits reflect the ecological niches occupied by each subspecies, highlighting their adaptations to their habitats (De la Rúa et al. 2009; Meixner et al. 2015; Khedidji et al. 2022).

The factors influencing honeybee productivity spans a broad range of parameters that contribute to the prosperity of honeybee colonies (Vaudo et al. 2012; Adjlane & Haddad 2014). These parameters cover both biological and climatological fields. Evaluating these factors and parameters enables us to comprehend the intricate interplay between various beekeeping practices, the health and well-being of colonies, and all influences that may play a crucial role (Bendifallah et al. 2012; Adjlane & Haddad 2014; Khedim et al. 2023).

I was particularly curious about the possibility of working with different bee species, as well as fascinated by their diverse behaviors in the examined localities. In today's world, where ecological sustainability and biodiversity are key issues, it is important to understand the factors that affect the health and vitality of beehives. This study can contribute to a better understanding of the factors influencing brood development in beehives and how beekeepers can optimize conditions to increase brood production not only in Northern Algeria.

2. Literature review

Consideration of various climatic and environmental factors that affect bee populations and their prosperity (Schneider & McNally 1992; Šotolová 2017), such as temperature range, precipitation patterns, habitat diversity, flowering season, altitude, seasonal changes, microclimate, pesticide use and native plant availability is the key to optimised production (Přidal 2014).

Humidity regulation is essential for optimizing air circulation within the hive, as it facilitates the necessary oxidation processes for energy circulation. Energy released within beehives serves various functions, including supporting movement, thermoregulating the brood, maintaining proper function of wax glands, and facilitating metabolic activities crucial for bee well-being (Linhart 2019). Adequate hive ventilation is element for effective metabolite removal. Accumulation of metabolites in high concentrations within hives can induce narcotic effects on the colony (Meikle et al. 2022). Beekeepers prioritize ensuring optimal ventilation year-round, minimizing heat loss from bees used for brood heating, preventing metabolite condensation to mitigate mold growth in colder periods, and shielding honeybees from drafts (Humphrey & Dykes 2008). Water regulation also plays a critical role in influencing honeybee behaviour (Ostwald et al. 2016). During periods of heightened brood activity, beekeepers implement management strategies to prevent water scarcity near apiaries, often by establishing small sun-exposed ponds (Landaverde et al. 2023). Regular visits to these ponds by bees can indicate strong forage sources in the vicinity. Additionally, wind circulation, particularly its strength and direction, can affect colonies in windy areas (Hennessy et al. 2020). Improper heat variance due to strong winds can influence colony dynamics and negatively affect honey yields in subsequent periods (Sudarsan et al. 2012).

Production is also affected by quality of the colonies. This study will delve into the behavior of *Apis mellifera intermissa*, emphasizing the role of queen quality, swarming activity, and hive dynamics in shaping overall colony health and productivity.

The queen bee, who is responsible for reproduction and genetic propagation, is a key figure in the colony's hierarchy, shaping its dynamics and resilience (Abou-Shaara et al. 2021). This genetic heterogeneity provides resilience, allowing the colony to thrive despite changing environmental conditions and biological challenges (Büchler et al. 2014). Aside from reproduction, the queen's pheromones act as powerful regulators of colony behaviour and physiology (Kocher & Grozinger 2011; Přidal 2017). She maintains order and cohesion among her subjects by using subtle chemical cues that instil a sense of collective purpose. Her absence can lead to social unrest and decreased productivity, emphasizing the importance of her role in colony dynamics (Rangel et al. 2013). Furthermore, the queen's influence extends to foraging and resource allocation. Her reproductive status determines the allocation of resources within the hive, influencing worker behaviour and resource acquisition strategies (Mitesser et al. 2007).

Queen cells are specialized structures within the hive that play an important role in the reproduction and maintenance of bee colonies (Mattiello et al. 2022). These cells, which are classified into three types: swarm cells, supersedure cells, and emergency cells, represent distinct stages in the colony's reproductive cycle and are influenced by a

Figure 2 Capped queen cells (Husarčík 2023)

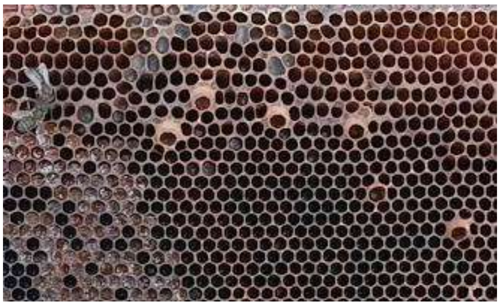

Figure 1 Cups (Husarčík 2023)

variety of environmental and internal factors (Meduna 2022).

Swarm cells are the most common type of queen cell. Worker bees construct them in preparation for the colony's swarm, natural reproductive behaviour in honeybee colonies (Kopecký 2013; Lattorff & Moritz 2016). When the colony becomes overcrowded or conditions are otherwise unfavourable, the bees will form swarm cells to raise new queens. These new queens will lead separate swarms, forming new colonies. Swarm cells are often larger and more numerous than other types of queen cells (Ledoux et al. 2001).

Bees construct supersedure cells to replace an existing queen within the colonies. This can happen for various reasons, including the current queen's deteriorating health or productivity, or the colony's desire for a younger or more vigorous queen. Supersedure cells are typically found in smaller numbers than swarm cells and are dispersed throughout the hive (Hauser & Lensky 1994; Hamdan 2015).

Worker bees form emergency cells in response to the queen's sudden loss or absence. This can occur if the queen dies unexpectedly, or if she is accidentally killed or removed from the hive during inspections. Emergency cells form quickly, and the larvae inside them are frequently older than those found in swarm or supersedure cells. The colony's survival is dependent on the successful development of a new queen from these emergency cells (Fell & Morse 1984; Schneider & DeGrandi-Hoffman 2002).

Algeria has a diverse climate in general due to its large size and assorted geographical features (Ben Abdelkader 2020; Homrani et al. 2020; Bona et al. 2021). Moreover, regions vary between each other by not only macroclimate or microclimate (Bona et al. 2021), but sources of plants suitable for nectar or pollen forage for bees are crucial for their prosperity (Makhloufi et al. 2010; Escuredo et al. 2013).

This study will pay special attention to important parameters essential to honeybee colonies' health and productivity within the complex web of factors that affect productivity. These consist of several parameters, but are not restricted to - only foraging activity, disease resistance, colony strength, and environmental adaptability. For a comprehensive assessment of honeybee colonies in the northern region of Algeria, it is crucial to comprehend how these parameters interact with the distinct bioclimatic conditions and environmental factors in each district.

In the Northern regions, where samples and datasets were collected, Mediterranean and Semi-arid climates are present (Makhloufi et al. 2010; Taibi et al.

2017; Homrani et al. 2020). Both climate types might be characterised by mild wet winters and warm dry summers, milder temperatures and moderate rainfalls. Moving southern from both climate regions, more arid and desert climates are contemporary – connected with less rainfall activity and higher seasonality of sources (Ben Abdelkader 2020; "Climat: Le Climat en Algérie, Banque de données météorologiques" 2023).

2.1. Guelma district

In the Guelma district, a hot summer Mediterranean climate is present. The average temperature area is around 17.3°C, and fluctuation of temperature during the year is present (Haffaressas et al. 2017; Meddad-Hamza et al. 2017; Mezedjri 2021). During sampling activities (May to July), temperature and weather fluctuations were at a high level – from 6th May to 18th May precipitation and temperatures hit records – cold and rainy weather negatively influenced bees and were considered as a temperature stressor for colonies. After this period, weather in general settled down for a while and heatwave hit. All these factors had a notable impact on other bioclimatic compounds.

Sampling activities were provided in the many parts of the Guelma district, tangibly: Ben Djerrah (municipality), Houari Boumédiéne, Khezaras (commune), Oued Seybouse (commune) and Meshta Bu Shrikh (commune).

Floral resources from a bio-climatological perspective involve weather conditions that influence the distribution, availability, and characteristics of resources (Wang & Li 2011). Early spring marks the start of the flowering season, which lasts the entire beekeeping year (Quézel 1978). Although endemic plant species are well adapted to temperature cues, persistent rainy weather reduced the amount of pollen and nectar available to bees. The Guelma district's plant species diversity is greater than that of other districts where sampling was done because forage sources and diversity are present not only in the early spring months when pollen and nectar resources are most needed for colony development but also during the off-season (Djaouida et al. 2021). Native plant species play a crucial role in supporting pollinator populations. Many floral resources are coordinated between late spring and summer, and bee activity is modestly boosted during this time. On the other hand, many local beekeepers are noticing the effects of climate change. According to the local beekeepers' blooming activity of rich pollen and nectar sources, climate change is changing the time of flowering in some species. In recent years, *Opuntia ficus-indicta* has diminished and grown less intense.

Water sources and precipitation - As previously said, there is a lack of appropriate precipitation. Precipitation activity is erratic, particularly during the summer, and the average monthly rainfall is a maximum of 100 millimetres (Zeroual et al. 2013; Taibi et al. 2017). There are fewer rainy days and more thunderstorms throughout the spring and summer, which frequently causes flooding and the destruction of habitat diversity. Additionally, the source and variety of plants that bees use as food are significantly impacted by excessive rains washing away the nectar of indigenous species (Econde Communication Nationale De L'algerie Sur Les Changements Climatiques A La Ccnucc 2010).

Biodiversity in the Guelma district is quite diverse; ecosystems with a variety of plant species are present. According to the local beekeepers, the main sources of forage for bees are herbs, fruit trees, wild shrubs, eucalyptus, and wildflowers. Additionally, invasive plant species including *Acacia saligna*, *Acanthus mollis*, and *Psidium guajava* have been recorded by beekeepers (Quézel 1978; "Global Invasive Species Database" 2013; Véla & Benhouhou 2007; Haffaressas et al. 2017). According to the topography, geographical features, and climate, the Guelma district includes ecosystems such as Mediterranean forests and woodlands, Mediterranean scrublands, mountain ecosystems, steppes and grasslands, rivers and streams, urban ecosystems, and agricultural lands (Mezedjri 2021). In the aforementioned environments, which contain a variety of plant species appropriate for the foraging of bees as a primary or nearby source, sampling activity was made available. The flower species that beekeepers have identified as significant or minor sources of forage are included in the following table.

Table 1 Forage sources in the Guelma district (Chelouche 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Punica granatum	higher	copious	late spring - early summer
Borago officinalis	rich	yes	late spring - early fall
Bermuda buttercup	yes	yes	early spring bloomer
Opuntia ficus-indicta	copious	copious	late spring - early fall
Phoenix dactylifera	rich	limited	spring months
Salvia officinalis	yes	rich	late spring - early summer
Melia azedarach	limited	limited	late spring - early summer
Brassica oleracea	higher	higher	late spring - early summer
Pistacia lentiscus	higher	higher	late spring - early summer
Phillyrea angustifolia	higher	rich	late spring - whole summer

Chamaeleon gummifer	yes	higher	spring - whole summer
Quercus suber	yes	yes	late spring - early summer
Datura stramonium	yes	copious	summer - early autumn
Foeniculum vulgare	yes	higher	late spring - fall
Malva sylvestris	yes	yes	late spring - early autumn

In the Guelma region, beekeepers have **close-knit community ties**. During sampling processes, cooperative beekeeping techniques and knowledge sharing were noticed. As a result of information sharing between beekeepers at nearby apiaries, conditions at the apiaries were essentially the same throughout the sampled localities.

The Guelma region is suitable for beekeeping, but many local beekeepers are concerned about **the effects of climate change**. As was already mentioned, the unusual rainfall at the very start of June postponed the production of honey by two weeks. Moreover, bee colonies from various habitat types and altitudes in the area were impacted by the season's early low temperatures. Low-altitude colonies should begin to develop at the end of March, mid-altitude colonies between mid-March and late March, and high-altitude colonies at the beginning of April during the ideal beekeeping year. Low and mid-altitude colonies experienced belation of evolution due to low temperatures and unsuitable weather for the spring starter flowers' blooming, which caused all colonies to begin development at nearly identical times. At various locations, bees were observed starving and floral resources were depleted. The results of a questionnaire study revealed that many beekeepers do not use additional feedings like sugar-honey dough or sugar syrup; as a result, bee starvation reached a critical point and caused the colonies to die in one location.

Figure 3 Apiary in the Guelma district (Husarčík 2023)

2.1.1. Ben Djeraah

Ben Djeraah is a municipality with a highly uneven and mostly hilly terrain, which has an impact on the bee colonies in the area. Numerous difficulties for beekeeping arise from the hilly terrain, including limited sources of forage (Holzschuh et al. 2007). The diverse terrain variations in this region have an impact on the availability of suitable apiary sites, with the rugged landscape potentially limiting access to certain forage plants and complicating hive management and maintenance (Roberts et al. 2017). Furthermore, the steep slopes and rugged terrain raise the possibility of weather fluctuations and extreme conditions disrupting bee flight patterns and foraging activities. Furthermore, higher predation risk, as highlighted by Hoiss et al. (2012), poses a threat to bee colonies in hilly areas, where predatory species such as birds and rodents are more prevalent. These difficulties emphasize the importance of strategic hive placement, careful management practices, and adaptation to local conditions for successful beekeeping in hilly terrain. The following table shows important forage sources for bees.

Figure 4 Apiary in the Ben Djeraah (Husarčík 2023)

Table 2 Forage sources in the Ben Djeraah location (Fitoussi 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Opuntia ficus-indicta	copious	copious	late spring - early fall
Anacyclus clavatus	medium	higher	spring - early summer
Marrubium vulgare	medium	medium	late spring - early summer
Daphne gnidium	lower	medium	spring
Vicia faba	medium	medium	spring
Silene cinerea	medium	higher	late spring - early summer
Silene kremeri	medium	higher	late spring - early summer
Morus alba	lower	lower	spring - mid spring
Moraea sisyrinchium	medium	medium	spring
Pisum sativum	excellent	excellent	spring
Medicago intertexta	medium	higher	spring - early summer
Lathyrus ochrus	medium	medium	late spring - early summer
Vicia lutea	medium	medium	late spring - early summer
Coronilla scorpioides	medium	higher	spring - early summer
Hordeum marinum	low	low	spring

2.1.2. Hourari Boumédiéne

The Guelma's district Hourari Boumédiéne, a comparatively level area, provides excellent beekeeping conditions. In contrast to hilly terrain, this region's varied terrain has little effect on bee colonies. The area's vast meadows and agricultural lands offer a plentiful supply of forage for the colonies, creating ideal conditions for beekeeping activities. Many beekeepers purposefully site their apiaries next to gardens, where high-level ecological interactions are observed, improving the health and productivity of the bee colonies. Furthermore, beekeeping has a long history in the region, and the sampled locations are close to a thriving market for beekeeping products. These favourable factors make Hourari Boumédiéne a great location for beekeeping ventures (Neggad et al. 2019).

2.1.3. Khezaras

Due to its unfavourable geographical characteristics, the Khezaras commune in the Guelma region presents one of the most challenging environments for beekeeping. This area is unsuitable for beekeeping production due to its hilly and dusty terrain and limited sources of forage for bees. Despite the strong beekeeping infrastructure observed during sampling activities, which included many beekeepers working together, the terrain's fragmentation presents significant challenges. The presence of hills and other natural features frequently impedes collaboration and worsens seasonal variations in beekeeping activities. The commune's isolation from larger cities, combined with its poor beekeeping infrastructure, exacerbates the difficulties. Accessibility is limited to a single old road, making transportation difficult, especially for older vehicles. These conditions making hive management and maintenance particularly difficult in this region.

Figure 5 Apiary in the Khezaras CNC locality (Husarčík 2023)

2.1.4. Oued Seybouse

Commune located closest to Guelma city, stands out as a highly favourable beekeeping location. This region, with its expansive meadows devoid of terrain variations and abundant water sources from the Seybouse River, is ideal for bee colonies. Meadows provide large forage for bees, both from wild plant species and cultivated crops that promote bee activity and foraging. Notably, a wide variety of floral sources is available to bees in this area, providing long-term sustenance for the duration of the beekeeping season. The low prevalence of parasitic mite *Varroa destructor* discovered during sampling operations can be attributed to appropriate treatment methods, like burning cedar tree branches (Bava et al. 2023) while conducting internal hive observations. The aromatic smoke generated from burning cedar trees via smoker acts as an effective deterrent against *Varroa destructor* infestations, contributing to the overall health of bee colonies in this area. Following table summarises possible plant sources of pollen and nectar.

Figure 6 Apiary in the Oued Seybouse forest locality (Husarčík 2023)

Table 3 Forage sources in the Oued Seybouse locality (Sidi 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Nerium oleander	higher	copious	late spring - early fall
Ziziphus jujuba	lower	higher	late summer - early fall
Pseudopodospermum undulatum	medium	medium	late spring - early summer
Ornithogalum arabicum	copious	copious	late spring - early summer
Scilla peruviana subsp. elongata	higher	copious	spring
Calicotome villosa	higher	lower	late spring - summer
Echinops bovei	medium	medium	summer
Silene gallica	lower	lower	late spring - early summer
Sherardia arvensis	medium	medium	late spring - early summer
Iris juncea	medium	medium	late spring - early summer
Centaurium erythraea	lower	higher	late spring - late summer
Bellardia trixago	lower	higher	late spring - early summer
Mentha pulegium	lower	medium	late spring - early summer
Colchicum cupanii	lower	medium	early autumn
Bellis annua	lower	medium	spring - early summer

2.2. El Kala district

The El Kala district has a Mediterranean semi-arid climate, with temperatures averaging approximately 29°C in the summer and falling below 19°C in the winter. There is a considerable seasonal difference in monthly rainfall, and the rainy season lasts from August to June. The severe seasonal change in humidity is influenced by the rainy period (from November to May, relative to June to October, when humidity is oppressively high). (Xoplaki et al. 2004; "Climate and Average Weather Year Round in El Tarf Algeria" 2018; Necer et al. 2019; Kahit et al. 2019). While sample activities were taking place in June, there was some daytime temperature and weather variation (colder mornings compared to hot and muggy afternoons), but generally conditions were constant. A light breeze from the sea was present too.

In the El Kala district, fire is the main stressor for bees. Massive forest fires decimated the forest's ecosystems (Beddiar et al. 2015; Khallef et al. 2021) and drastically reduced forage sources for bees. Destroyed forests are recovering quickly, and many floral resources are being replanted.

El Kala district has a wide variety of **floral resources**; however, they are sporadically and unevenly dispersed. Irregular and patchy floral resource areas were created due to wildfires in the past (Nair et al. 2013; Khallef et al. 2021). The El Kala National Park and Biosphere Reserve, which is home to numerous native plant species suitable for bees' foraging as well as for the development of local agriculture, sustained the most damage (Djamel et al. 2014; Boughrara & Belgacem 2016). On the other hand, many plant species are adapted and resilient to fires, and their recovery is at a high level. The main blooming season starts in the late spring and is continuous throughout the whole beekeeping year. Early spring boosters, such as fruit trees, are present in this district.

Precipitation and water sources are also various, same as floral resources. The month with the least rain activity is July (average rainfall around 2.54 mm) in comparison to January with an average of 8 days with precipitation of at least 1 mm (Djamel et al. 2014; Taibi et al. 2017; Kahit et al. 2019). The El Kala district is located in the coastal zone of - the Mediterranean Sea, rivers and streams, wetlands, marshes, estuaries, lagoons and reservoirs cross through almost the whole district and they are copious sources of water not only for bees (Youbi & Benslama 2015; Necer et al. 2019).

Biodiversity is diversified in the El Kala region since it is home to several different habitats (Quézel 1978; Boughrara & Belgacem 2016). The Mediterranean Sea, combined with rivers and streams that cut over practically the whole region, plays a major role in forming coastal, aquatic, or wetland habitats. Additionally, there are shrublands, maquis, and woodland ecosystems with evergreen oak trees and plants that can withstand drought (Nair et al. 2013).

The El Kala region also includes a mountainous ecosystem, where the El Kala National Park biodiversity hotspot belongs (Youbi & Benslama 2015; Kahit et al. 2019). The Asteraceae family is numerous - not only for bees forage but also *Matricaria chamomilla*, *Cynara cardunculus*, *Artemisia herba-alba*, *Cynara scolymus*, *Artemisia arborescens*, and *Lactuca sativa* (Djamel et al. 2014; Klech et al. 2022). The main flower sources that are present in the region are mentioned in the Table 4. Local beekeepers also identified these plants as a major source of nectar or pollen for bees.

Table 4 Forage sources in the El Kala district (Ziani 2023; Bouzid 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Sulla coronaria	higher	copious	late spring - summer
Cistus monspeliensis	medium	high	perrenial growth
Trifolium nigrescens	medium	high	late spring - summer
Cerinthe major	medium	copious	late winter - early spring
Lobularia maritima	medium	high	early spring - late fall
Scirpoides holoschoenus	low	low	summer
Cydonia oblonga	medium	higher	early spring blooms
Melissa officinalis	higher	abundant	late spring - early fall
Paraserianthes lophantha	low	higher	late winter - spring months
Verbascum sinuatum	medium	high	summer - early autumn
Solenopsis bicolor	medium	higher	late spring - early summer
Filago asterisciflora	medium	medium	late spring - whole summer
Cistus salviifolius	medium	high	late spring - early summer
Limonium echioides	medium	higher	late spring - summer
Scrophularia laevigata	higher	copious	late spring - whole summer

The **community support** among beekeepers in the El Kala district is not very visible. The presence of different habitats where beekeepers have their apiaries situated is the primary cause of lower support; thus, differences among them are creating gaps. The blooming season begins much earlier in the low elevations than it does in the mountains; the higher elevations result in a later evolution of the colonies' hierarchies and development.

In conclusion, the El Kala region is **optimal for beekeeping** because all monitored conditions and factors produce a favourable environment that encourages the colonies' health and strength.

Figure 7 Apiary in the El Kala - highway locality (Husarčík 2023)

2.3. Roknia district

The Roknia district is located in the Guelma province and has a Mediterranean climate (hot dry summers) with a coastal influence (Taibi & Souag 2011; "Climate Change Knowledge Portal" 2021). The average temperature area is around 18.87°C, fluctuation of the temperature range is present but has a mild lapse (Taibi et al. 2017). Differences in precipitation are monitored – the wettest month (March with 57.56 mm) in comparison to the driest month (July with 4.05 mm) (Xoplaki et al. 2004). Between May and June, sampling operations were provided in consistent weather and temperature conditions; their volatility was not monitored. Thus, external factors did not influence sampling activities.

The Roknia district's **floral resources** are distributed; their abundance is amplified, and their distribution spans a wide range. However, there are areas where plants suitable for bees forage are prevalent. Mostly, many native species are present and were monitored during field trips – *Lavandula stoechas, Thymus vulgaris, Rosmarinus officinalis* and *Centaurea* (Djaouida et al. 2021). In the suitable areas, many beekeepers have their apiaries localised – there is an increased risk of their overlapping. Floral resources are not enough for the bees and bees may starve during the unpleasant period of the beekeeping year - this factor was monitored during internal hive observations. Thus availability might be limited.

Precipitation and water sources are dispersed, same as floral resources. Streams and rivers are present in the several apiary suitable areas, but rainfall during the beekeeping year is not fulfilling them enough (Taibi & Souag 2011; Zeroual et al. 2013). The water's quality is worsening progressively closer to the ground (Benmarce et al. 2023). Not all apiaries have equal access to the closest water supply with the appropriate quality.

Urbanization is putting pressure on **biodiversity** in the Roknia district because urban areas have grown in size while agricultural and forested areas have shrunk (Guechi et al. 2021; Saidi & Hamadi 2023). During field surveys, data were collected from different ecosystems, such as forests and woodlands, mountainous terrain, and urban and agricultural landscapes. The main forage sources for bees, according to the local beekeepers, are wildflowers, fruit trees, and herbs (classified deeper in the Table 5).

Table 5 Forage sources in the Roknia district (Abed 2023; Dib 2023; Laib 2023; Cherif 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Dittrichia viscosa	copious	copious	late summer - fall
Drimia numidica	lower	lower	spring
Quercus canariensis	higher	higher	spring
Drimia fugax	lower	lower	spring
Solanum bonariense	medium	medium	summer - early autumn
Limonium ramosissimum	lower	lower	summer
Medicago italica	lower	lower	spring - early summer
Stachys ocymastrum	medium	medium	summer
Barlia longibracteata	lower	lower	spring - summer
Medicago polymorpha	medium	medium	spring - early summer
Prunus armeniaca L.	medium	higher	mid spring
Morus alba	lower	lower	spring - mid spring
Vicia faba	medium	medium	spring
Lavandula stoechas	medium	excellent	late spring - early summer
Narcissus tazeta	medium	higher	spring


Figure 8 Apiary in the Roknia district - house with a view location (Husarčík 2023)

The flowering season in the late summer until autumn is missing crucial and copious sources of nectar or pollen; there is an increased risk of starving colonies.

Beekeepers in the Roknia district have established **robust relationships**, especially those with apiaries in close proximity. Collaborating and pooling resources has revealed concerns about the impact of climate change, including elevated temperatures and reduced precipitation, which have prompted bee colonies to migrate to more hospitable environments with greater water availability. Furthermore, swarming activity has risen in the Roknia district. Although certain areas within the region are still conducive to beekeeping, it may not be the most optimal environment for bees overall.

2.4. Bouchegouf district

Although the **bioclimatic characteristics** of the Bouchegouf and Guelma districts are similar, there are still some differences. Nearly the same as Guelma's average rainfall of 670 mm (Majour et al. 2023). The precipitation level and heavy rainfall occurrences are more evenly distributed than in the Guelma region, according to (Mrad et al. 2018). The Bouchegouf district is more affected by agricultural practices that degrade the land and reduce the potential for bee forage sources (Majour et al. 2023), but there are still many undeveloped areas – especially close to borders with the El Kala National Park Reservation, conservation efforts are more intense there.

Agriculture increases the possibility of surface pollution, which could later result in groundwater pollution (Majour et al. 2023). All these factors are negatively influencing habitat diversity level.

Despite the increased human activity, wide **varieties of flowers** are still available. The main flowering season begins in the late spring, and there are many sources of forage available. Bees provide a plant selection based on their needs.

Inconvenient times of the beekeeping year, such as the rainy season and winter, also have forage sources available. Many plant species are suitable for bees, and they are widely available. The abundance of diverse plant species also increases foraging opportunities.

It is important to keep track of the similarities in different types of ecosystems and plant species that are brought about by **biodiversity and habitat diversity** in the Guelma region. In the Bouchegouf district, ecosystems were found to be nearly identical. The Table 6 lists the primary sources of plant forage for bees. All these plants were indicated as a valuable nectar or pollen source.

Table 6 Forage sources in the Bouchegouf locality (Abaoub 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Pistacia lentiscus	higher	higher	late spring - early summer
Drimia numidica	yes	rich	during rainy season
Ibicella lutea	lower	higher	warm spring and summer
Borago officinalis	rich	yes	late spring - early fall
Galactites tomentosa	copious	copious	late spring - whole summer
Medicago truncatula	yes	rich	early spring - summer
Medicago constricta	yes	copious	late winter - early spring
Medicago intertexta	yes	copious	late winter - early spring
Solanum elaeagnifolium	higher	copious	summer - late fall
Cistus salviifolius	medium	higher	late spring - early summer
Lysimachia foemina	medium	higher	late spring - early summer
Lysimachia nummularia	medium	medium	late spring - early summer
Olea europaea	yes	vary - conditions	late spring - early summer
Medicago aculeata	medium	medium	late spring - early summer
Medicago orbicularis	medium	higher	late spring - early summer

Figure 9 Apiary in the Bouchegouf - farm locality (Asma Maklouf 2023)

2.5. Chetaibi district

Figure 10 Apiary at the Chetaibi hills location (Husarčík 2023)

The last sampled district, Chetaibi, is situated in the coastal zone in the northern part of Algeria, characterized by a mild climate with relatively high humidity and rainfall ranging between 550 mm to 700 mm, showing a tendency to increase towards the east direction. A significant climatic influence in this region is the sirocco, a wind blowing from the south of the Sahara desert (Hallouz et al. 2023). The average temperature in the area is 18.5°C (Zeroual et al. 2017), with a warming trend of 0.2–0.4°C per decade reported by beekeepers with longer beekeeping traditions (Norrant & Douguédroit 2006). Despite this warming trend, rainfall activity remains stable. The warmest month is August, with an average temperature of 30°C, while the coldest month is February, with an average temperature of 8°C, providing optimal conditions for beekeeping according to local beekeepers (Derdous et al. 2021; Brahimi 2023; Saidi 2023).

During sampling activities conducted in June, significant weather fluctuations were not observed. Instead, higher humidity levels exceeding 70% were recorded. However, in hot and dry conditions, higher humidity can be a supportive factor that helps colonies survive heat waves better (Abou-Shaara et al. 2017).

The typical temperature range in the Chetaibi district during the beekeeping year is 22.21 ± 5.71°C. Approximately 39.01 ± 38.37 mm of precipitation fall during the main season (Adila et al. 2024). Furthermore, this district is susceptible to the presence of alien invasive plant species; 16 species are under observation, and a considerable percentage of them are appropriate for use as bee forage (Brunel et al. 2010; Meddour et al. 2020). The following table lists the non-invasive species that are suitable as bee forage:

Table 7 Forage sources in the Chetaibi district (Brahimi 2023; Saidi 2023)

Plant	Pollen amount	Nectar amount	Flowering season
Daphne gnidium	medium	medium	late winter - early spring
Pallenis maritima	medium	copious	late spring - early summer
Scolymus hispanicus	medium	medium	late spring - early summer
Blackstonia grandiflora	medium	medium	whole summer
Sixalix atropurpurea	low	medium	late spring - whole summer
Reichardia picroides	medium	higher	early spring - fall
Andryala integrifolia	medium	higher	late spring - fall
Cichorium intybus	medium	higher	late spring - whole summer
Nerium oleander	higher	copious	late spring - early fall
Limonium spathulatum	modest	modest	late spring - early fall
Portulaca oleracea	medium	medium	late spring - early fall
Heliotropium europaeum	medium	medium	late spring - early fall
Plantago coronopus	low	low	late spring - summer
Limodorum abortivum	higher	medium	late spring - summer
Clematis flammula	higher	medium	late summer - early fall

Overall, the floral resources are abundant and widely distributed. They grow in various regions and prefer different soil types (as the sea is nearby, many halophytes are present) (Bendifallah & Ortiz-Sánchez 2018), for example *Salicornia fruticose* (Neffar et al. 2016).

3. Aims of the Thesis

Honey and wax production are important assets of local nonperishable production in rural areas. Control and modification of production conditions including type of bees, hives, seasonal dynamics, beekeepers intervention, etc. would be crucial for its size and quality. Therefore, this work would aim to determine and evaluate data on bee colony development, diurnal dynamics with the weather, and food sources description including swarming dynamics related to the colony size in specific areas of Northern Algeria. The thesis aims are to establish methods for effective colony monitoring, beekeeper interventions during seasonal dynamics and weather/resource changes based on hive inspections and evaluation and questionnaire on beekeeping method and interventions with beekeepers and to suggest strategies for improvement of production parameters level.

The specific predictions/hypotheses to a bee colony size and development are:

H0: Variation in local (microclimate) changes do not affect the overall colony size, because study is done in one region of Northern Algeria

H0: The choice of parasitic mite treatment method (Apivar, Thymol, powder sugar dusting, screened bottom boards, Formic Pro) does not significantly impact honeybee colony health and productivity.

H0: Beekeepers' levels of knowledge, awareness of stress factors impacting bees, and experience in beekeeping (low, moderate, high) do not significantly influence colony size and development due to harsh climate.

H0: The honey yields per colony (frames with honey reserves, total honey-producing colonies, total honey yield per colony) do not significantly differ across the surveyed districts, because data collection was done within narrow period at all localities

H0: The feeding practices among beekeepers do not significantly differ among the surveyed districts and will not influence colony size and development.

4. Methods

Samples and datasets were collected from different bioclimatic areas located in the Northern part of Algeria through questionnaires, datasets, internal and external hive observations and pollen loads (baskets). All these information are valuable in the determination of well-being of bees and their prosperity. In the process of sample collection it is important to mention that due to the dynamic nature of beekeeping activities and management techniques, no specific predetermined criteria were set for the selection of beekeepers or locations. Obtaining information and securing sampling activities were connected with the difficulties during the fieldwork (hesitancy from the beekeepers and cancelling scheduled meetings). Despite experienced difficulties, the dataset contains diverse and in-depth outcomes.

4.1. Questionnaire

To document and analyse the wide range of the beekeeping practices, approaches and interventions carried out by apiculturists in their apiaries, constraints and needs in the field were determined. Survey was based by a uniform questionnaire prepared specifically for this study with aim to maximise all covering points relevant to beekeeping (Table 24 - appendix), such as knowledge and practices of beekeepers, economy aspects, foraging and planting practices, feeding practices, disease and pest management, honey harvest and queen production, colony health and age and general beekeeping practices. The questionnaire contained fields covering the social and economic background of the beekeepers, activities connected with maintaining of hives and other production parameters.

The questionnaire survey was administered to a homogeneous population of beekeepers in the Northern part of Algeria through purposive sampling, where only beekeepers were interviewed (Ames et al. 2019). During the survey, the snowball method was employed for its flexibility (Palinkas et al. 2015; Hennink & Kaiser 2022; Kahane et al. 2022), in combination with purposive sampling where participants were selected based on parameters defined at the beginning of the survey (Valerio et al. 2016; Serra et al. 2018). The parameter set at the beginning was to find a key informant beekeeper who could provide as many contacts with other beekeepers as possible (Miake-Lye et al. 2021; Duan-Porter et al. 2022). During the survey, a saturation trend was observed, with no additional insights identified through further exploration, and data started to repeat across districts (Malterud et al. 2016; Hennink & Kaiser 2022). Time-limited data collection and a general overview of problems in beekeeping (problems perception) were monitored during rural appraisal principles to assess the reliability of information shared by local beekeepers through questionnaires (Chambers 1994; Takasaki et al. 2000).

The questionnaire was encouraged by modified worksheets containing information about the colony development level. The base of the worksheets was set by the Liebefelder method, which determines the number of bees and the brood or nutritional areas on the comb in the sampled hive (Spiewok et al. 2006). All these factors helps documenting and understanding key aspects of the colony actual condition (Gil-Lebrero et al. 2017).

As part of the economic analysis conducted in this study, various factors influencing the profitability of beekeeping operations were examined. Important variables such as the cost of a honey jar, the number of colonies, the monthly maintenance costs per colony, the apiary price, and the actual yields of honey were evaluated (Al-Ghamdi et al. 2017; Schouten 2021; Tubene et al. 2023).

Calculating the total fixed costs related to apiary operation allowed each beekeeper to determine their break-even point (**BEP**). For the BEP calculations, these equations were used (Alnasser et al. 2014; Alropy et al. 2019; Feketéné Ferenczi et al. 2023):

$$\boldsymbol{TOTAL\ FIXED\ COSTS}$$
$$apiary\ establishment\ costs + (\ monthly\ maintenance\ costs\ per\ colony\ x\ 12\ x\ number\ of\ colonies)$$

BEP *= TOTAL FIXED COSTS / price per honey jar*

Both questionnaires and worksheets were collected directly from the hive observations and intervention with the beekeepers during field trips. In total, 17 beekeepers from all sampled localities (22 localitites in 13 districts) conscientiously completed the questionnaire, contributing valuable insights into the diverse practices and conditions prevalent in the studied region.

In several instances, the same beekeeper possessed multiple properties within the study area. To account for potential variations in beekeeping practices across different locations, data collection was conducted independently at each locality owned by the beekeeper. However, to streamline the questionnaire survey process and maintain consistency, surveys were administered based on the identity of the beekeeper rather than the specific number of properties they owned, specifically in the Bouchegouf region, one beekeeper possessed three apiaries located in distinct areas. Similarly, in the Oued Seybouse district, one beekeeper maintained apiaries at two separate locations. This pattern (one beekeeper at two separate locations) was also observed in Chetaibi and the El Kala district, where individual beekeepers managed apiaries in multiple locations within the respective regions.

4.2. Internal and external hive observations

The sampling activity also contained external and internal hive observations. During **external observations** internal parts and components of the hive are not opened, disturbed or reorganised – the internal balance of a colony in the hive is undisruptive Marchal et al. 2020). This type of observation involves properly watching the overall behaviour of the colony whereas the main impact is focused on the activity of bees, the condition of the beehives and apiary surroundings (Meikle & Holst 2015; Capela et al. 2023). External hive observations are disposing of valuable information such as foraging activity of bees, orientation flight level, swarming signs, weather impact, pollen and nectar collection (Clarke & Robert 2018; Meikle et al. 2018; Catania & Vallone 2020).

Figure 11 External hive observations (Husarčík 2023)

In order to value colony strength, brood development, honey and pollen storage, and early warning indicators of disease, **internal hive observations** were closely correlated with routine internal inspections of specific hives (Siefert et al. 2021). For optimal honey production, the dynamics of the hive and the health and strength of the colony are critical (Khoury et al. 2013; Degenfellner & Templ 2024). Important insights were gained from internal inspections; the factors that were observed and researched are compiled in hive inspection sheets (Table 27 - appendix).

The internal hive observations were conducted using the Liebefelder method. This method, which emphasizes brood development, food storage, and actual colony strength, determines the assessment of colony strength. The honeybees' coverage of the area, their storage of nectar or pollen, and the different stages allow for the tracking or estimation of all of these variables on each side of the comb in the analysed hive. (Spiewok et al. 2006; Delaplane et al. 2013; Bargen et al. 2019; Dainat et al. 2020).

Statistical survey: To designate the effectiveness of the Liebefelder method for monitoring bee colony size and prosperity, we employed generalized mixed models. This approach allowed us to investigate the effects of various factors on honeybee health and productivity, considering the hierarchical structure of the data, which involved multiple levels of grouping: locality, farmer, hive number, and frame number.

The dataset was structured hierarchically as follows: Locality (Level 1): Different geographical regions where beekeeping observations were conducted. Farmer (Level 2): Individual beekeepers within each locality. Hive Number (Level 3): Unique identification for each hive within a farmer's operation. Frame (Level 4): Specific frames within each hive where observations were made.

The statistical data analyses were done in the software SPSS 29.0. Data were tested for normality via Kolmogorov – Smirnov test. We used a GLMM models to assess the effectiveness of the Liebefelder method for monitoring bee colony size, area of brood and area of honey stores. The GLMM allowed account for the hierarchical structure of the data, which involved multiple levels of grouping: locality, farmer, hive number, and frame number. Fixed effects (explanatory variables) were mentioned, such as variation in local (microclimate) changes (in 22 localities), mite treatment methods (screened bottom board usage, powder sugar dusting, ApiVar, Amitraz, Formic Pro, Thymol application) beekeeper knowledge levels (defined by 3 levels), forage availability (encouragement of colonies during harsh forage times), and other relevant factors. The interactions between mite treatment methods and encouragement methods (feeding practices) were monitored due to the increased effects on the monitored parameters. The random effects in the model accounted for the variability between farmers, hives within farmers, and frames within hives.

Fixed Effects Description (Explanatory Variables):

Variation in local (microclimate) changes: Investigating the effects of seasonal variations on honeybee colony size and health.

Mite treatment methods: Analyzing the impact of different mite treatment methods (such as application of Apivar, Thymol, powder sugar dusting, screened bottom boards, Formic Pro) on colony size and propserity.

Beekeeper knowledge levels: Examining how beekeepers' levels of knowledge, awareness of stress factors affecting bees, and experience in beekeeping (low, moderate, high level) influence monitored parameters.

Forage Availability: Studying the effects of forage availability and diversity on honeybee colony size and productivity.

Queen and bee production: Analyzing the factors influencing proper queen qualities, such as viral or pathogenic agens, meteorological fluctuations, and lack of forage sources.

Honey yields per colony: Keeping an eye on each colony's honey reserves to determine appropriate yields without harming other colonies.

Aspects of the economy: how monthly maintenance expenses might affect the health and productivity of colonies and how a beekeeper could maximize profits by analyzing market demand.

General practices: How the frequency of hive inspections may affect the requirements of colonies. Proper monitoring of colonies may reveal problems in their early stages (such as impropert management).

Other Relevant Factors: Considering additional factors such as colonies age and resurgence frequency of frames (combat against diseases)

4.3. Analysis of the pollen loads (baskets)

Pollen loads are structures on the hind legs of bees, where they transform collected pollen back to the hive (Martins et al. 2014; Hemmami et al. 2020). Pollen baskets were collected by device – pollen traps. Analysis of the pollen loads may bring valuable information about suitable forage possibilities, variability, distribution and nutritional diversity of the floral sources for bees (Ouchemoukh et al. 2007; Wang & Li 2011; Frankel et al. 2015). Pollen loads were collected just from one district –

Bouchegouf at three localities (Bouchegouf farm, Bouchegouf hills, Bouchegouf garden managed by one beekeeper). Other regions beekeepers were more concerned with producing honey, thus they did not utilize pollen traps to get rid of their hives. While the analysis of pollen loads is not considered a primary focus of this research, it serves to affirm the potential plant forage sources that were validated in the palynological analyses.

4.4. Palynological analysis

Figure 12 Preparation of the samples for palynological analyses (Husarčík 2023)

Palynological analysis was primarily conducted in the Bouchegouf district of the Guelma province, which proved to be the most beneficial area for sampling.

To prepare pollen loads for analysis, 20 milliliters of distilled water (20-40 °C) were added to the centrifugation tube. After dissolution, low-speed centrifugation (1000-2500 G) for 10 minutes was performed, followed by the removal of excess water (Louveaux et al. 1978). A second centrifugation with 20 milliliters of distilled water at 1000 G for 5 minutes and a final centrifugation were conducted. Simultaneously, the heating pad was set to 40°C to melt glycerine for sample preservation. The prepared slide, featuring a 22 x 22 mm square, was placed on the hotplate until the sediment dried (Louveaux et al. 1978; Salgado-Labouriau & Rull 1986; Von Der Ohe et al. 2004). After even spreading for proper preservation, a cross was drawn with liquefied glycerine, and the sample was left on the hotplate until completely dry. The outcome of palynological analysis provided insight into the identification of the pollen sources, seasonal foraging patterns and assessment of the floral diversity within the district (Louveaux et al. 1978; Von Der Ohe et al. 2004; Dongock Nguemo & Tchoumboue 2015; Rodopoulou et al. 2018; Ghorab et al. 2021; Escriche et al. 2023).

4.5. Honey samples analysis

Honey samples from the Bouchegouf district of Guelma province, have also been analysed to confirm its origin and the type of honey from which it was subsequently produced. The analyses were carried out by determining the water content, acidity, optical rotation, and conductivity.

The honey analysis encompassed quantitative determination of water content (refractometrically), acidity of honey via pH value (potentiometrically) and free acid content (titrimetrically), electrical conductivity (conductometrically), sucrose content, and optical rotation (polarimetrically) (Kňazovická & Staroň 2021).

These parameters were selected based on their established significance in the botanical and geographical origin of honey as they provide valuable insights into the compositional profile and quality characteristics of honey samples, aiding in the differentiation between floral, blended, and honeydew varieties.

Water Content: The refractometric index was ascertained using an Abbé refractometer in the following method: A clean and dry prism of the refractometer was coated with the required amount of honey sample using a glass rod. Next, the temperature of the sample was measured and the refractometric index was read simultaneously (Guo et al. 2010; Belay et al. 2013; Damto et al. 2023).

Acidity pH and Free Acids Content: In a 250 cm^3 Erlenmeyer flask, 10 g of honey were dissolved in 75 cm^3 of distilled water to create a honey solution for the analysis. Using a pH meter, the solution's pH was calculated potentiometrically (HI 111). The samples' free acid content was determined through titration using a 0.1 mol/dm^3 sodium hydroxide (NaOH) solution. Then, three to four drops of an acid-base indicator (phenolphthalein) were added. The honey solutions were titrated with 0.1

Figure 13 Preparation of the honey samples for analyses (Husarčík 2023)

mol/dm^3 NaOH while being stirred continuously until a faint pink color appeared, signifying a pH of 8.4 (Habib et al. 2014; Pascual-Maté et al. 2018; Kňazovická & Staroň 2021). Equation 1 was utilized to determine the free acid content based on the reading of 0.1 mol/dm^3 NaOH from the burette scale:

$$VK \text{ (milliequivalents per kilogram)} = c \text{ (cm}^3\text{)} \times 10$$

VK = free acid content

c = consumption of 0.1 mol/dm^3 NaOH

Electrical conductivity: To get a 20% solution, the weight of honey used for the conductivity measurement was determined using the formula for honey solids content (100% - water content). A 100 cm^3 measuring cylinder was filled to the brim with distilled water after the measured honey and water had been combined in a beaker (Kaškonienė et al. 2010). The electrical conductivity of the sample (mS/cm) was computed using equation 2 after the conductivity of the honey solution was measured in a plastic beaker using a CO 3100 L conductometer (VWR®, Germany):

$$EV \text{ [mS/cm]} = K \times G \text{ [mS]}$$

EV = electrical conductivity

K = constant of the conductometer cell

G = conductance

Sucrose content and optical rotation: Two 50 cm^3 portions were taken from a 100 cm^3 20% honey solution. One portion underwent sugar inversion, while both were treated with aluminum hydroxide to precipitate impurities. After overnight settling, the

Figure 14 AP-300 polarimeter (Husarčík 2023)

clear filtrate was polarized using an AP-300 polarimeter (ATAGO®, Japan) to determine optical rotation. ISS = $\alpha \times 2.888$ relates optical rotation to the International Sugar Scale (ISS) (De Beer et al. 2021).

Sucrose content (%) was calculated using equation 3:

Sucrose content (%) = (ISS1 - ISS2) × 2.60126 / m'

ISS1 - direct polarization of a 10% honey solution (°Z)

ISS2 - polarization of the same honey solution after inversion (°Z)

m' - specific gravity of honey (based on water content)

Overall, the honey samples were measured multiple times, and average values were provided.

4.6. Conclusion of Methods

In this section, multifaceted approach for the parameters influencing honeybee productivity was outlined. Through a combination of surveys and depth analyses in the hives the factors contributing to the well-being and prosperity of the honeybee colonies were monitored. The questionnaire focused on beekeepers interventions provided valuable insights and explanatory variables used in statistical analysis of internal hive observations primary data and also into the economic and social context on the wide range of practices. Hive observations allowed evaluation of the colony strength, early warning indicators of diseases and brood development. The Liebefelder method played a pivotal role in the internal hive observation data collection and was key factor in hive dynamics dynamics. External observations offered valuable information on indicators of swarming risk, foraging activity of bees, weather and precipitation impact on colonies. Furthermore, the palynological analysis of pollen loads and analysis of the honey samples enriched the dataset and provided an insight to the forage possibilities, nutritional diversity and characteristic of local honeys. These methods were driven by the aim to explore the intricate interplay between variable beekeeping practices, health of honeybee colonies and environmental factors influencing them. The holistic understanding of the complex web of factors influencing colony productivity parameters in the specified region demonstrates integration across diverse methodologies.

5. Results

This section presents and analyses the questionnaire results that were distributed to various localities, with a primary focus on the Guelma district. The purpose of the questionnaires was to evaluate the productivity and health of bee colonies in various bioclimatological regions while considering beekeepers' management practices. The study also sought to investigate how socioeconomic variables affected beekeeping practices in these areas. By examining important indicators such as the frequency of hive maintenance, the production of queens and bees, and mite treatment methods, this analysis sheds light on the dynamics of beekeeping in the study areas.

5.1. Mite treatment methods

Various beekeepers in the surveyed districts employed diverse strategies for managing *Varroa destructor* mites and associated diseases, which pose a significant threat to the health of honeybee colonies.

The most prevalent treatment method employed by beekeepers is **Apivar (Amitraz)**. Amitraz, a formamidine compound, exerts both lethal and sublethal effects by interacting with octopamine receptors in the central nervous systems of ectoparasites (Randy 2017; Chaimanee et al. 2022). This treatment was utilized by 12 beekeepers (70.59%).

Thymol, one of the primary phenolic compounds found in *Thymus vulgaris*, serves as a potent acaricide effective against Varroa mites. Thymol is a component of the Api Life Var treatment (Carayon et al. 2014; Colin et al. 2019) and was used by 10 beekeepers (58.82%). Another form of thymol, **Apiguard**, was applied by 5 beekeepers (29.41%).

Powder sugar dusting emerged as another method for managing and protecting against mites. Directly dusting honeybees with fine sugar effectively increased Varroa mite fall by enhancing cleaning (grooming) behavior levels (Stevanovic et al. 2012; Danihlík 2013; Abou-Shaara et al. 2016). Powder sugar dusting was exclusively used by 2 beekeepers (11.76%). A less common approach involved the use of **screened bottom boards** for monitoring internal hive parts (El Agrebi et al. 2021), which was implemented by 3 beekeepers (17.46%). The least frequently employed method, **Formic Pro application** for reducing Varroa infestation (Menzies et al. 2019), was utilized by only 1 beekeeper (5.88%).

In addition to common treatments, two beekeepers used natural acarids, while synthetic ones were not used. One beekeeper in (Chetaibi Meadow locality) used unauthorized medicine due to limited options for addressing Varroa infestation effectively. No antibiotics were used in any apiary.

5.2. Queen and bees production

This analysis aims to examine the quantities of raised queens documented by beekeepers across sampled districts, categorizing them into distinct groups based on their management methodologies. By scrutinizing these disparities, I seek to elucidate the determinants affecting queen and bee production, ascertain the prevalence of particular management strategies, and discern their potential ramifications for colony well-being and productivity

The initial cohort encompasses **beekeepers who reported nil instances of bee queen production**. 2 beekeepers (11.76%) reported no bee queen production due to infestations by viral and pathogenic agens, while 6 (35.29%) cited meteorological fluctuations and lack of forage resources weakening colonies

The second cohort encompasses **beekeepers who delineated a quantifiable figure of queens reared**. Beekeepers' queen production ranges from none reported by 2 beekeeprs (Khezaras and Chetaibi Meadow locality) to higher numbers in other areas represented by 1 beekeeper, such as El Kala Forest (5 queens), Mullberry Alley and Highway (10 queens), and Bouchegouf (20 queens) and Roknia Farm (25 queens).

The final cohort comprises **beekeepers concentrating on natural selection**, whereby colonies autonomously foster their own queens contingent upon prevailing conditions. This cohort predominantly encompasses 3 beekeepers from the Roknia district, and 1 beekeeper from Oued Seybouse.

When analyzing beekeepers' **encounters with re-queening colonies**, several recurring issues emerge. These challenges can be categorized into various groups. The most prevalent issues, namely queen cessation of egg laying and swarming, were reported by 16 beekeepers (94.12%). Notably, only one beekeeper from Bouchegouf locality did not observe queen cessation of egg laying, while a one beekeeper from the BenDjeraah district did not encounter swarming.

Furthermore, 14 beekeepers (82.35%) reported an unsuccessful introduction of queens to existing colonies, while 13 beekeepers (76.47%) faced issues related to the unsatisfactory quality of newly raised queens. Additionally, 10 beekeepers (58.82%) reported inadvertently introducing diseases during the re-queening process, and the same number of beekeepers (58.82%) encountered drone-laying queens. Notably, no instances of queens remaining unreleased from cages were reported in any district.

Among the less frequently reported issues, accidental queen killings were noted by 2 beekeepers. Additionally, one beekeeper from the Bouchegouf region reported inadequate mating.

5.3. Knowledge and practices

In this section, a magnitude-based approach was employed to assess beekeepers' knowledge, awareness, and experience in beekeeping, as gleaned from their responses to specific inquiries – see the Table 25 (appendix).

Pre-Beekeeping Research Duration: Beekeepers were queried about the duration of their pre-beekeeping research efforts. Responses were stratified into: Low (Score: 1) for minimal or negligible research activities conducted before commencing beekeeping. Moderate (Score: 2) for a moderate level of research undertaken, albeit not exhaustive. High (Score: 3) for extensive research endeavors pursued prior to initiating beekeeping practices.

Awareness of Stressors Impacting Bees: Beekeepers were asked to identify stress factors adversely affecting bees and their production parameters. Their responses were categorized into: Low (Score: 1) for mentioning 1-2 stressors. Moderate (Score: 2) for acknowledging 3-4 stressors. High (Score: 3) for recognizing 5 or more stressors.

Beekeeping Experience Duration: Participants were queried about the duration of their beekeeping practice. Responses were categorized into: Novice (Score: 1) for individuals practicing beekeeping for less than 2 years. Intermediate (Score: 2) for practitioners with 2-5 years of beekeeping experience. Experienced (Score: 3) for those with over 5 years of beekeeping engagement.

Beekeeping purpose specification was added to this section, this element was not evaluated using a scoring system. Instead, it provided qualitative insights into the motivations and goals driving beekeepers' engagement in apiculture.

These scoring metrics were applied based on the participants' responses to the respective inquiries, offering insights into their levels of knowledge, awareness regarding stress factors affecting bees, objectives in beekeeping, and tenure in the apicultural field.

In the final analysis, it was observed that the lowest scores were recorded in El Kala Forest, Khezaras CNC, Roknia Center represented by 1 beekeeper in each locality, with all localities receiving 4 points. Remarkably, ITMA stood out as the only locality to achieve the maximum score of 9 points.

Beekeeping purpose specification revealed that out of the total respondents, 6 beekeepers (35.29%) identified themselves as hobby beekeepers, 4 beekeepers (25.53%) engaged in beekeeping for research purposes, while the majority, comprising 13 beekeepers (76.47%), stated that they pursued beekeeping as a source of income.

Beekeepers identified **various stress factors** that negatively affected production parameters in their colonies. The most commonly reported aspect was lack of precipitation (drought), mentioned by 8 beekeepers (47.06%), followed by *Varroa destructor* infestation and climate change effects, both reported by 7 beekeepers (41.18%). Increased agricultural activities were cited by 5 beekeepers (29.41%), while 4 beekeepers (23.53%) identified the presence of European Bee-eater birds (*Merops apiaster*) as a stress factor. The least reported problems included mice presence (2 beekeepers - 11.76%), noise/disturbance (1 beekeeper - 5.88%), forest fires (2 beekeepers - 11.76%), small hive-beetle (*Aethina tumida Murray*) infestation (1 beekeeper - 5.88%), and water problems (contamination) (1 beekeeper - 5.88%).

5.4. Honey harvest

The honey harvest data provides valuable insights into the productivity and performance of bee colonies across various districts. This analysis focuses on three key aspects: the number of frames with honey reserves per colony, the total number of honey-producing colonies, and the total honey yield per colony for the season. The following table presents a summary of the honey harvest data collected from the surveyed districts.

Table 8 Overview of the honey yields at the localities

District - 1 beekeeper in each location	Frames with Honey Reserves	Total Honey-Producing Colonies	Total Honey Yield per Colony (kg)
Guelma	0	5	0.1
BenDjeraah	1	2	0.8
El Kala Mullberry Alley + Highway	2	25	3
Hourari Boumédiéne	2	5	0.7
Chetaibi Forest + hills	2	11	0.8
Chetaibi Meadow	1	1	0
El Kala Forest	2	5	1
ITMA	3	14	1.42
Khezaras CNC	3	10	1.4
Khezaras 2	5	8	3.13
Meshta	2	5	0.25
Oued Seybouse	4	80	2.5
Roknia Center	2	8	1.25
Roknia Curve	1	7	3.14
Roknia Farm	4	>50	1
Roknia House with a View	2	8	2.12
Bouchegouf	4	>100	8

Overall, the honey harvest data highlights the diversity in beekeeping practices and productivity across the surveyed districts, emphasizing the importance of local factors in determining honey yields and colony health.

5.5. Economy aspects

Analyzing the economic data reveals significant regional disparities among beekeepers in different districts. The number of hives correlates with establishment costs, while maintenance costs per colony per month vary. Notably, 2 beekeepers in Khezaras 2 and Chetaibi Forest + Hills face higher expenses due to accessibility challenges.

The following table presents the establishment costs for the apiary and maintenance costs per colony per month for each beekeeper, offering a comprehensive overview of the data.

Table 9 Establishing and management costs

District – 1 beekeeper in each location	Establishing Costs (DN)	Maintenance Costs per Colony per Month (DN)	Establishing Costs (€)	Maintenance Costs per Colony per Month (€)
BenDjeraah	120000	500	800	3.33
Bouchegouf	10000000	500	66666	3.33
El Kala Mullberry + Highway	462500	700	3083.33	4.67
Guelma	140000	500	933.33	3.33
El Kala Forest	250000	500	1666.67	3.33
Hourari Boumédiéne	120000	300	800	2
Chetaibi Forest + Hills	155000	600	1033.33	4
Chetaibi Meadow	500000	300	3333.33	2
ITMA	280000	425	1866.67	2.83
Khezaras CNC	1200000	1000	8000	6.67
Khezaras 2	1080000	1500	7200	10
Meshta	85000	450	566.67	3
Oued Seybouse	7440000	400	49600	2.67
Roknia Center	140000	400	933.33	2.67
Roknia Curve	135000	200-400	900	1.33 - 2.67
Roknia Farm	1850000	400	12333.33	2.67
Roknia House with a View	275000	300-400	1833.33	2.2.1967

By considering potential honey yields during the season and various factors affecting costs, such as market demand, resource availability, and beekeeping skills, it's evident that investment returns are influenced by multiple variables. The observed higher investments in Bouchegouf, Oued Seybouse and Roknia Farm localities could be attributed to factors like better management practices, access to resources, and extensive experience in beekeeping, all of which contribute to maximizing returns on investment in these areas.

Table 10 BEP calculations

District	Price per honey jar (DN)	Price per Honey Jar (€)	BEP
BenDjeraah	2000	13.33	66 jars
Bouchegouf	2600	17.33	4077 jars
El Kala Mullberry + Highway	4000	26.67	168 jars
Guelma	2300	15.33	74 jars
El Kala Forest	3900	26.00	72 jars
Hourari Boumédiéne	2000	13.33	69 jars
Chetaibi Forest + Hills	2200	14.67	106 jars
Chetaibi Meadow	2200	14.67	229 jars
ITMA	2300	15.33	152 jars
Khezaras CNC	4300	28.67	307 jars
Khezaras 2	4300	28.67	285 jars
Meshta	2000	13.33	56 jars
Oued Seybouse	3900	26.00	2006 jars
Roknia Center	2000	13.33	89 jars
Roknia Curve	2600	17.33	62 jars
Roknia Farm	3000	20.00	697 jars
Roknia House with a View	2600	17.33	119 jars

In this table, the BEP indicates the number of jars of honey that a beekeeper must sell to cover all costs associated with maintaining the apiary and producing the honey. BEP is connected with the economical aspect closely.

5.6. Feeding practices

In this section, diverse feeding and foraging practices were assessed among beekeepers. Approximately 47.06% of beekeepers reported abstaining from stimulating bee colonies between honeyflows, while around 35.29% engaged in additional feeding at least 14 days prior to the main flow season to augment colony strength. During the main season, approximately 58.82% of beekeepers implemented supplementary feeding.

Different methods were employed to encourage colonies, with 58.82% of beekeepers using sugar syrup, 23.53% using honey, 23.53% using pollen, and an equal percentage resorting to other methods such as sugar paste or baking powder with lemon flavor.

Regarding forage and planting practices, approximately 35.29% of beekeepers relied solely on natural forage sources near their apiaries and did not engage in additional planting. Among those who did, common plantings included olive trees, pomegranates, meadow mix seeds, and citrus trees. Less common plantings encompassed mulberries, Calitus, corn, cereals, figs, and brassicaceae family plants.

5.7. General practices

This section elucidates the multifaceted nature of beekeeping practices and the complex interplay of factors influencing colony health and management strategies across diverse localities.

Table 11 Frequency of the internal inspections

District	Spring Frequency	Out of Season Frequency
BenDjeraah	1 time / week	1 time / 2 weeks
Bouchegouf	Daily	Daily
El Kala Mulberry Alley + Highway	3 times / week	3 times / week
El Kala Forest	2 times / week	2 times / week
Guelma	1 time / 2 weeks	1 time / 5 weeks (Winter)
Hourari Boumédiéne	Daily	1 time / 2 weeks (Winter)
Chetaibi Forest	Every 3 days	Once / 2 weeks (Winter)
Chetaibi Meadow	Once / week	Once / week
ITMA	Daily	Daily
Khezaras CNC	Once / week	Once / week
Khezaras 2	2 times / week	2 times / week
Meshta	2 times / week	2 times / week
Oued Seybouse	Once / week (February, March, April)	Once / 2 weeks (Winter)
Roknia Center	3 times / week	Once / 2 weeks (Winter)
Roknia Curve	2 times / week	Once / week
Roknia Farm	2 times / day	2 times / week
Roknia House with a view	2 times / week	2 times /week

The Table 11 shows hive maintenance frequencies. Activities and their duration is reflecting the dynamic nature of beekeeping practices influenced by environmental conditions and colony needs. Provided activities at the apiaries might be categorised to daily, weekly and monthly. Daily activities in beekeeping encompass crucial tasks such as hive observations and maintenance, which are integral for monitoring colony health and addressing immediate concerns. Weekly activities, including apiary cleaning and the application of antiparasitic treatments, contribute to the maintenance of hive hygiene and disease prevention. Monthly tasks, such as comprehensive hive maintenance, feeding, and studying forage sources and relevant literature, demonstrate the long-term planning and strategic management involved in beekeeping practices.

Negative aspects during spring development: Spring development represents a critical phase in the lifecycle of honeybee colonies, yet it is often accompanied by various challenges that adversely impact colony health and productivity in upcoming season. Factors such as weather fluctuations, intracolony competition, pest and disease pressures, queen quality issues, small hive beetle infestations, drought conditions, climate change effects, swarming tendencies, and inadequate forage sources were reported by beekeepers.

Decline in bee colonies due to forage shortage: The shortage of quality forage poses a significant threat to bee colonies, leading to observable declines in colony health and productivity across various districts. 13 beekeepers (76.47%) reported experiencing such declines.

Colony Resurgence and Maintenance: Beekeepers employ a range of strategies to ensure the resilience and vitality of their bee colonies, including comprehensive frame sorting before storage (13 beekeepers are sorting frames before the storage), proactive treatment against wax moth infestations and other diseases through methods such as airing under shelter, sulphur application, freezer treatment, and application of *Bacillus thuringiensis*. The following table (12) shows used treatment methods applied in diverse districts.

Table 12 Frame treatment methods

Treatment Method	Districts (1 beekeeper in each district)
Airing under the shelter	BenDjeraah, Bouchegouf, El Kala Mulberry Alley + Highway, El Kala Forest, Hourari Boumédiéne, Chetaibi Hills, ITMA, Khezaras CNC, Khezaras 2, Meshta, Oued Seybouse, Roknia Center, Roknia Curve, Roknia House with a View
Sulphur application	Bouchegouf, El Kala Mulberry Alley + Highway, El Kala Forest, Chetaibi Hills, ITMA, Khezaras CNC, Khezaras 2, Meshta, Roknia Farm, Roknia House with a View
Freezer	Guelma, Hourari Boumédiéne, ITMA, Oued Seybouse, Roknia Farm
Without treating	Chetaibi Meadow
Bacillus thuringiensis	Roknia Center

Additionally, it's possible to effectively combat many diseases by ensuring proper frame resurgence and overall tidiness at the apiaries. The following table (13) shows frequency of complete resurgence of all frames

Table 13 Resurgence frequency of frames

Resurgence Frequency	Districts (1 beekeeper in each district)
Last Season	Bouchegouf, El Kala Forest, Chetaibi Hills, Meshta, Roknia House
2 Seasons Ago	ITMA, Guelma, Roknia Curve, El Kala Mulberry Alley + Highway
Every Season	Roknia Farm, Hourari Boumédiéne, Oued Seybouse
Every 2 Seasons	Khezaras 2, Roknia Center
Not Provided	BenDjeraah, Chetaibi Meadow, Khezaras CNC

In addition to understanding colony resurgence and treatment methods, it's essential to consider the age of colonies and the methods used to start recent colonies across different districts. The following tables provide insights into the ages of colonies and the methods employed for starting recent colonies in each district.

Table 14 Colonies age

Age of Colonies	Districts (1 beekeeper in each district)
1 year	Chetaibi Meadow, Guelma
2	BenDjeraah, Oued Seybouse, Roknia House with a View, Chetaibi Forest
3	Hourari Boumédiéne, Roknia Center, Roknia Curve
4	Meshta
5	El Kala Forest, Khezaras CNC
7	Khezaras 2
10	ITMA
1 to 3 years	Bouchegouf, Roknia Farm
2 to 5 years	El Kala Mulberry Alley + Highway

Table 14 displays the age distribution of colonies in various districts, indicating the diversity in colony ages across the surveyed areas.

Table 15 Different methods of starting new colonies

Method of Starting Recent Colonies	Districts (1 beekeeper in each district)
Nucleus (Nuc)	BenDjeraah, Bouchegouf
Package	Chetaibi Meadow, Khezaras CNC
Split	El Kala Mulberry Alley + Highway, Guelma, Hourari Boumédiéne, Chetaibi Forest, ITMA, Khezaras 2, Meshta, Roknia Center, Roknia Farm, Roknia House with a View
Swarm	Roknia House with a View, Roknia Farm, Roknia Curve, Roknia Center, Oued Seybouse, Meshta, ITMA, Chetaibi Forest, Hourari Boumédiéne, El Kala Forest, El Kala Mulberry Alley + Highway
Natural Selection	Oued Seybouse

Table 15 outlines the methods used for starting the most recent colonies in each district, illustrating the different approaches taken by beekeepers to establish new colonies.

5.8. Palynological analysis results

Understanding honeybee foraging behaviour and evaluating the floral diversity within their foraging range depend heavily on identification of pollen loads. The findings of palynological analyses carried out in three localities within a single district are shown in this section, with an emphasis on pollen loads that were directly collected from three hives in each locality. The purpose of the analysis was to classify the pollen loads according to their colour, structure, and other characteristics. Understanding of the various pollen sources was gained by looking at the unique traits of each pollen load.

The Table 16 provide information about the sampling processes

Table 16 Palynological sampling information

Location	Hive number	Detected pollen samples colour	Date	Time	Air temperature	Date of the analysis
Bouchegouf hills	1, 2	Dark burgundy, yellow	11.6.2023	15:49	35°C	20.8. - 21. 8. 2023
Bouchegouf hills	3	Orange	11.6.2023	15:24	35°C	20.8. - 21. 8. 2023
Bouchegouf farm	1	Yellow	11.6.2023	13:41	32°C	20.8. - 21. 8. 2023
Bouchegouf farm	3	Light brown	11.6.2023	13:15	32°C	20.8. - 21. 8. 2023
Bouchegouf farm	2	Orange, light brown	11.6.2023	13:27	32°C	20.8. - 21. 8. 2023
Bouchegouf farm	1, 2, 3	Dark brown, yellow	11.6.2023	12:55	32°C	20.8. - 21. 8. 2023
Bouchegouf farm	1, 2, 3	Black, light brown	11.6.2023	12:45	32°C	20.8. - 21. 8. 2023
Bouchegouf garden	1, 2, 3	Light brown, brown with yellow tones, orange	11.6.2023	10:38	31°C	20.8. - 21. 8. 2023

Table 16 organizes the data by location, hive number, detected pollen samples, detected colour of pollen samples, date and time of sampling, air temperature during sampling, and date of analysis.

Conclusion: The analysis of pollen loads provides important insights into the botanical diversity of the sampled area, as indicated by the table and results mentioned. Additionally, the analysis's conclusions were supported by the beekeepers' accuracy in identifying the sources of pollen from plant forage during questionnaire interviews.

The characteristics of the pollen samples were analysed and compared using multivariate techniques, which revealed unique attributes among the various types. The results indicated the presence of polyfloral pollen, with eight types of pollen loads identified. This suggests that the area surrounding the apiary is rich in plant diversity. This table (17) represents the qualitative and quantitative analysis of collected pollen loads (Canlı & Bayram 2024; Kňazovická & Kačániová 2024; Pohl et al. 2024).

Table 17 Analysis of the pollen loads from Bouechegouf district

Pollen Type	Weight (mg)	Height (mm)	Width (mm)	Shape Index (width/height)	Symmetry	Depth of Excision	Homogeneity of Colors	Surface (Rating)
Black	6.12 (very low)	2.19 (very low)	2.71 (narrow)	1.23 (heart shape)	Non-Symmetrical	Shallow	Yellow Hairs	4.95 (Very Low)
Orange	11.14 (medium)	2.59 (low)	3.17 (mid-narrow)	1.22 (heart shape)	Non-Symmetrical	Very Shallow	Uniform Color	6.71 (Low)
Light Brown	18.47 (higher)	3.59 (high)	4.01 (wide)	1.11 (globular)	Symmetrical	Very Shallow	White Fragmentation	10.11 (High)
Brown	18.14 (higher)	3.30 (high)	3.58 (wide)	1.08 (globular)	Symmetrical	Very Shallow	Uniform Color	9.52 (High)
Brown with Yellow Tones	20.11 (very high)	3.98 (very high)	4.11 (very wide)	1.03 (globular)	Symmetrical	Without Excision	Brownish Fragmentation	11.71 (Very High)
Dark Burgundy	5.55 (very low)	1.99 (very low)	2.59 (very narrow)	1.30 (heart shape)	Non-Symmetrical	Deeper	Uniform Color	4.11 (Very Low)
Dark Brown	5.59 (very low)	2.21 (very low)	2.62 (narrow)	1.18 (globular)	Symmetrical	Without Excision	Uniform Color	4.99 (Very Low)
Yellow	20.87 (very high)	4.02 (very high)	4.42 (very wide)	1.09 (globular)	Non-Symmetrical	Without Excision	Light Yellow Fragments	11.88 (Very High)

Table 18 shows assumed forage sources in the Bouchegouf region. According to ("PalDat – a palynological database" 2000) several plant species were detected.

Table 18 Assumed forage sources detected by pollen loads

Pollen type (color)	Assumed forage source
Black	*Ophrys bombyliflora, Ophrys tenthredinifera*
Orange	Quercus, Ibicella lutea, Acer, *Bellis perennis*
Light brown	*Daucus carota*
Brown	*Cistus incanus*, Medicago sp.
Brown with yellow tones	*Myrtus communis, Eucalyptus bridgesiana*
Dark burgundy	*Echium boraginaceae*
Dark brown	Serapias sp, *Spiranthes cernua, Aristolochia macrophylla*
Yellow	oilseed crops, *Pistacia lentiscus, Drinia numidica*

5.9. Honey samples results

In order to validate the results of the questionnaire survey, this analytical approach was created as an additional methodology. The analysis specifically looked at the electrical conductivity and sucrose content of the honey samples.

These parameters were selected based on their established significance in the botanical and geographical origin of honey as they provide valuable insights into the compositional profile and quality characteristics of honey samples (Lopes et al. 2018), aiding in the differentiation between blossom, blended, and honeydew varieties.

Acidity is an auxiliary criterion for honey analyses (Titěra 2006), and the pH of the honey ranges from 3.95 to 4.10. The pH of the honey depends on the type of honey being analysed. Nectar (flower) honey reaches a pH of around 3.4 (they are more acidic from the pH perspective), and honeydew honey reaches a pH of around 6.1 (Bodó et al. 2020; Karabagias et al. 2020; Kňazovická & Staroň 2021). Floral honeys are more acidic in terms of pH. Paradoxically, most honeydew honeys have a higher content of free acids than floral honeys, however, the pH reaction in honeydew honeys is also influenced by the presence of mineral substances + other substances that act as buffers and therefore honeydew honeys generally have higher pH compared to floral honeys (Kňazovická 2024).

The water content influences the shelf life of the honey; as a standard, honey should contain up to 20% water to avoid the growth of filamentous fungi and the presence of yeasts, which would subsequently affect other parameters such as loss of aroma and limited storability (Al-Farsi et al. 2018; Zerrouk et al. 2018).

The electrical conductivity of honey is influenced by its acidity and mineral content. The electrical conductivity of honeydew honey must be determined at 0.8 mS/cm and more, while blossom and blended honey reach values up to 0.8 mS/cm. The determination of the electrical conductivity determines the origin of the honey (da Silva 2016; Karabagias et al. 2020; Kňazovická & Staroň 2021).

The sucrose content of honey is determined by optical rotation, and since bees convert sucrose to simple sugars like glucose and fructose, it should be low. Additional techniques for quantifying sucrose include polarimetry, which measures the honey's optical rotation and partially reveals the type of honey it is - honeydew or honey nectar, for example (Fechner et al. 2016; Zerrouk et al. 2018; Serrano et al. 2019).

The resulting dataset is summarized in the following table (19), offers a overview of the measured parameters and their implications for the classification and authentication of honey types.

Table 19 Analysis of the honey sample

Parameter	Honey	Limit by legislative (Badis & Kheira 2012; Ketfi et al. 2023)
Water (%)	17.8	less than 20%
Dry matter (%)	82.2	-
pH	4.14	-
Free acidity (meq/kg)	15.0	max 50 meq/kg
Electrical conductivity (mS/cm)	0.276	blossom/blended - max 0.8 mS/cm; honeydew - min 0.8 mS/cm
ISS before sugar inversion (°Z)	-9.02	-
ISS after sugar inversion (°Z)	-10.2	-
Sucrose (%)	2.16	max 5%
[α] before sugar inversion (°)	-11.96	-
[α] after sugar inversion (°)	-15.59	-
m'	1.85	-

One honey sample was tested multiple times for optical rotation to accurately determine its origin. In this case, it is a floral honey (negative values). For free acids, the maximum content is set at 50 meq/kg, and the sample contained 15.0 meq/kg. The electrical conductivity of 0.276 mS/cm determined the origin of the honey as floral (or floral blended). Electrical conductivity below 0.8 mS/cm as well as negative values of optical rotation in tested honey indicated its **blossom or blended** origin.

5.10. Evaluation of the Liebefelder method

In total, over 120 beehives across 22 locations were assessed using the SPSS 29.0 program.

Firstly, the tests of Normality were provided. These tests assess whether the data for each variable (Bees, Honey-dm², Capped brood, Uncapped brood) are normally distributed. Kolmogorov – Smirnov test was used to check the normality of variables (number of bees, honey stores and capped brood) presented in the study. Based on these Normality tests, none of the variables (Bees, Honey-dm², Capped brood, Uncapped brood) are normally distributed.

Table 20 Normality tests provided on variables

	Kolmogorov-Smirnov[a]		
Statistic	**df**	**Sig.**	**Statistic**
Bees	0.195	2134	<0.001
Honey-dm²	0.296	2134	<0.001
Capped brood	0.235	2134	<0.001
Uncapped brood	0.393	2134	<0.001

5.10.1. The multiple factors on combside size (depending variable - number of bees on one side of comb)

GLMMs for Factors Influencing Combside Size (Number of Bees on One Side of Comb) The GLMMs revealed several significant factors influencing the number of bees on one side of the comb. The first dependent variable, bees, is analyzed using gamma regression due to its non-normal distribution. This regression model employs a distribution with a log link function, which is appropriate when the target variable contains positive values and is skewed towards larger values.

Damaged and old hives had a significantly lower number of bees than new hives (damaged β= -18.547, $p < 0.002$); (old β= -19.770, $p < 0.001$).

Availability and diversity of forage sources had a significant negative effect (β = -0.182, $p = 0.005$), suggesting that higher availability and diversity of forage sources were associated with fewer bees on one side of the comb.

Experience duration before starting with beekeeping had a significant positive effect (β = 0.055, $p < 0.001$), indicating that longer experience duration was associated with more bees on one side of the comb.

Encouraging by lemon cooking solution had a significant positive effect (β = 0.257, $p < 0.020$). Beekeepers who encouraged their bees using the lemon cooking solution method reported a significant positive effect on the number of bees on the frames.

Factor encouraging by sugar paste had a significant positive effect (β = 0.299, $p < 0.001$). Beekeepers who utilized this method tended to observe higher amounts of bees on their frames compared to those who did not use this method.

Hive maintenance frequency in main season had a significant positive effect (β = 0.007, $p < 0.031$). Increasing hive maintenance frequency during the main season (β = 0.007) was associated with a slight increase in the number of bees on one side of the comb.

ApiVar Mite Treatment (β = 0.445, $p < 0.001$) had a stronger positive effect on the number of bees compared to Apiguard treatment (β = 0.167, $p < 0.108$).

Flight activity had a significant effect (β = 0.075, $p < 0.033$) increased flight activity is associated with more bees on one side of the comb.

Beekeepers in the hive part - Brood Chamber observed significantly more bees on one side of the comb compared to Honey Super part (β = 4.388, $p < 0.003$). Brood Chamber, is associated with a higher number of bees on the frames.

The combined contrast between Single Super Part and the combined effect of Brood Chamber and Honey Super (β = 0.335, $p < 0.531$) was not statistically significant. This indicates that, on average, beekeepers using Single Super Part observed a similar number of bees on one side of the comb compared to the combined effect of Brood Chamber and Honey Super.

Table 21 Factors influencing number of bees in the monitored beehives

Source	F	Sig.
Factors hive characteristics	6.350	0.002
Factor hive maintenance costs	3.446	0.064
Factor Availability and diversity of forage sources	7.797	0.005
Factor experience duration before starting with beekeeping	22.695	<0.001
Factor number of colonies at the locality 120 examined hives	1.597	0.207
Factor encouraging by lemon cooking solution	5.453	0.020
Factor encouraging by sugarpaste	10.160	0.001

FactorApiguard	2.580	0.108
FactorApiVar	17.850	<0.001
Factor hive maintenance frequency in main season	4.681	0.031
Varroa mites presence	0.237	0.627
Small hive beetle presence	0.006	0.941
Flight activity	4.551	0.033
Hive type	1.803	0.180
Superspart	5.298	0.005
SQC_Chalkbrood	0.016	0.899

5.10.2. The multiple factors on total area of honey stored at one comb (depending variable - total area of stored honey at one combside)

Linear regression was conducted on all independent factors to evaluate their mutual influence and explanatory power.

The contrasts between the hive characteristics did not show statistically significant differences. This suggests that, on average, there were no significant differences in the honey stores.

The number of colonies had a significant positive effect on honey production ($p < 0.001$, $\beta = 0.004$). This finding suggests that increasing the number of colonies is associated with an increase in honey production. Beekeepers can expect an average increase of 0.004 dm^2 in honey production for each additional unit (hive) they add to their apiary.

Number of bees had a significant positive effect ($p < 0.001$, $\beta = 0.005$), indicating that more bees led to increased honey production.

Capped brood ($p < 0.001$, $\beta = -0.006$) and uncapped brood ($p < 0.001$, $\beta = -0.007$) had negative effects on honey production. Each unit increase in capped brood was associated with a decrease of 0.006 in honey production, and each unit increase in uncapped brood was associated with a decrease of 0.007 in honey production.

Encouragement by honey ($p < 0.038$, $\beta = 0.178$); and the use of lemon cooking solution ($p < 0.053$, $\beta = 0.191$) are associated with increased honey production. Other methods of encouragement were not as successful, as they did not show statistically significant effects in this analysis.

The use of ApiVar has a statistically significant positive effect on honey production, with an estimated increase of 0.161 dm² ($p < 0.040$, $\beta = 0.161$). Other treatment methods were not statistically significant.

Multi super hive - honey super part compared to the Multi super hive - brood chamber part shows trend in increased amount of honey ($\beta = 1.183$, $p < 0.068$). Estimated increase of 1.183 dm² of honey in the honey super part compared to brood chamber part.

Multi super hive (brood chamber combined with honey super part) has an estimated 3.939 dm² more honey than the Single super hive, but this difference was not statistically significant at the 0.05 threshold ($\beta = 3.939$, $p < 0.281$).

Table 22 Factors influencing amount of honey stores in the monitored beehives

Source	F	Sig.
Corrected Model	20.089	<0.001
Factors hive characteristics	0.765	0.466
Factor hive maintenance costs	0.004	0.947
Factor Availability and diversity of forage sources	0.577	0.448
Factor experience duration before starting with beekeeping	1.867	0.172
Factor number of colonies at the locality 120 examined hives	11.887	<0.001
Factor encouraging by honey	2.256	0.133
Factor encouraging by lemon cooking solution	0.375	0.540
Factor ApiVar	0.114	0.736
Factor hive maintenance frequency in main season	0.231	0.631
Varroa mites presence	0.001	0.975
Small hive beetle presence	0.255	0.613
Hivetype	0.566	0.452
Superspart	2.067	0.127
Bees	111.785	<0.001
Cappedbrood	116.663	<0.001
Uncapped brood	47.860	<0.001
SQC_Chalkbrood	2.184	0.140

5.10.3. The multiple factors on total area of brood at one comb (depending variable - total area of brood at one combside):

In this section, the factors influencing the total area of brood at one comb side are explored. The selection of significant datasets is presented here, noting that statistics were not able to be provided on uncapped brood. The hive characteristics were not statistically significant, so in this section were not used.

The analysis comparing hive types (DADANT and Langstroth) shows a statistically significant result (β -0.475, $p < 0.001$). The negative coefficient (β = -0.475) indicates that DADANT hives tend to have less brood compared to Langstroth hives.

The pairwise contrasts between different hive parts showed that the comparison between hive parts indicates that the Multi Super Hive with a Brood Chamber tends to have approximately 3.977 more of capped brood (β = 3.977, $p < 0.001$) compared to the Multi Super Hive with a Honey Super. Additionaly, comparison between the Multi Super Hive with a Brood Chamber and the Single Super Part, the result is statistically significant (β = 4.739, $p < 0.035$), thus contain more capped brood compared to the Single Super Part.

Experience Duration Before Starting with Beekeeping: (β = 0.057, $p < 0.001$ Suggest, that longer duration of experience before starting with beekeeping is associated with more brood in colony, so can be explained by better skills of beekeeper to work with or intervene properly on time to support colony development.

Honey stores have a statistically significant negative effect on the brood area (β = -0.006, $p < 0.001$), indicating that as the area of honey production (dm^2) decreases, the amount of brood tends to increase.

Among the factors examined, only Syrup Encouraging had a statistically significant positive effect on the brood area (β = 0.071, $p < 0.05$). This suggests that when syrup encouragement is used, there tends to be more brood present.

Table 23 Factors influencing capped brood area in the monitored beehives

Source	**F**	**Sig.**
Corrected Model	10.430	<0.001
Side	0.588	0.443
Varroa mites presence	0.470	0.493
Small hive beetle presence	0.003	0.960
Hive type	12.290	<0.001
Supers part	8.260	<0.001
SQC_Chalkbrood	3.443	0.064
Factors hive characteristics	0.580	0.560
Factor hive maintenance costs	0.382	0.537
Factor Availability and diversity of forage sources	0.152	0.697
Factor experience duration before starting with beekeeping	23.545	<0.001
Factor number of colonies at the locality 120 examined hives	0.862	0.353
Factor encouraging by syrup	2.530	0.112

Factor hive maintenance frequency in main season	0.198	0.657
Honey dm²	105.812	<0.001

6. Discussion

The questionnaire survey aimed to gather insights from beekeepers regarding colony management and production parameters, providing valuable data on various aspects of beekeeping practices.

The findings regarding mite treatment methods showed the most common practices used by beekeepers in the surveyed districts. Certain treatments, such as Apivar (Amitraz) and Thymol-based treatments, have gained popularity due to their proven effectiveness in controlling parasitic Varroa mites. Due to its well-established effectiveness, Apivar, which has lethal and sublethal effects on ectoparasites, was preferred by most beekeepers (Chaimanee et al. 2022). Similarly, Thymol-based treatments such as Api Life Var and Apiguard have been recognized for their extractions derived from *Thymus vulgaris*, making them appealing options for mite management (Carayon et al. 2014; Colin et al. 2019).

However methods such as powder sugar dusting, while effective (Kovařík 2013; Fakhimzadeh 2015), were not widely used among interviewed beekeepers due to higher sugar prices and low self-sufficiency ratio (Woertz et al. 2014; Majabri 2023), which drastically limited their usefulness as a treatment option. Furthermore, the use of screened bottom boards was restricted, primarily due to the hives quality (Chaudhary 2008). Since many beekeepers in the area used older hives with structural issues such as holes, it is difficult to install screened bottom boards properly; in those situations, the hives do not offer colonies a stable or secure environment (Gregorc & Sampson 2019). The limited use of the Formic Pro application (Hendriksma et al. 2024), with only one beekeeper using it (in Bouchegouf region), raises important questions about accessibility and cost-effectiveness. In Algeria, where Formic Pro is expensive and difficult to obtain, beekeepers may prefer less expensive and more available treatment methods (Abaoub 2023). Furthermore, the handling and application requirements of Formic Pro and the potential risks if not properly administered may contribute to its limited use by beekeepers (Daniels et al. 2015). As a result, beekeepers may prefer treatments such as Apivar or Thymol, which provide effective mite control with simpler application procedures, lower costs and better availability. While chemical treatments like Apivar and Thymol-based products have proven efficacy in mite control, their long-term impact on bee health and environmental sustainability should be considered (Kovařík 2013). Alternative methods, such as powder sugar dusting or natural acarids, may provide more environmentally friendly options (Gregorc et al. 2017; Underwood et al. 2019).

These findings show the diversity of approaches taken by beekeepers in addressing mite infestations and highlight the influence of factors such as cost and accessibility on treatment decisions. Particularly in locations like Khezaras and Chetaibi, where accessibility to certain treatments may be problematic, beekeepers are likely to choose options that are both effective and easily accessible.

Issues related to queen rearing and bee production were reported by beekeepers across the surveyed districts. These issues have significant implications for colony health, productivity, and economic sustainability (Holmes et al. 2023).

Swarming, a natural reproductive behaviour in honeybee colonies (Uzunov et al. 2014) was reported by most beekeepers (16 of 17). Swarming can result in the loss of a part of the colony, reducing honey production and potentially causing economic losses for beekeepers (Zacepins et al. 2021). Interestingly, one beekeeper from the Ben Djeraah location did not report swarming, indicating environmental or management factors might influence swarming behaviour.

Beekeepers identified several challenges connected to queen health and performance. Fourteen beekeepers experienced problems with unsuccessful queen introductions, and 16 beekeepers reported situations in which their queens stopped with laying eggs. Furthermore, 13 beekeepers were dissatisfied with the quality of the queens reared, raising concerns about the genetic and reproductive fitness of queens sourced for colony requeening. Furthermore, the presence of drone-laying queens, as reported by 10 beekeepers, raises questions about colony productivity and stability.

Many beekeepers (10 out of 17) reported introducing and transmitting diseases within honeybee colonies. Disease outbreaks can jeopardize colony health and productivity, resulting in higher mortality rates and lower honey production (Genersch 2010). Economic losses from disease outbreaks highlight the importance of effective disease management strategies and regular colony health monitoring (McMenamin & Genersch 2015).

Swarming events and disease outbreaks present economic challenges for beekeepers, with potential losses in honey production and colony propserity (Wakgari et al. 2021). Furthermore, disease transmission between colonies can cause economic losses and jeopardize long-term viability (Forfert et al. 2015). Beekeepers must take proactive steps to reduce the economic impact of swarming and disease outbreaks, such as timely requeening (Harris 2008), following disease management protocols (Jacques et al. 2017), and improved biosecurity (De Carolis et al. 2024).

Education and awareness of all possible factors influencing colony in general honeybee biology are very important assets to successful beekeeping practices. An analysis of survey data revealed a clear link between formal beekeeping training and the adoption of sustainable practices (Vapa-Tankosić et al. 2020). Beekeepers with formal training or access to educational resources showed a higher level of knowledge about beekeeping proper practices. These beekeepers, for example, were more likely to use proactive hive management strategies such as regular hive inspections and disease monitoring than those who did not receive formal training. This proactive approach is critical for maintaining colony health and productivity because early detection and intervention can prevent disease spread and reduce the impact of pests and parasites on honeybee colonies.

Education and training programs should prioritize the incorporation of sustainable beekeeping practices, emphasizing the significance of regular hive inspections and disease monitoring as essential components of hive management protocols. Beekeepers' ability to maintain healthy and resilient bee colonies can be enhanced by providing them with the knowledge and skills required to conduct effective hive inspections and detect signs of disease (Nat Schouten & John Lloyd 2019; Prodanović et al. 2024).

Access to Education and Resources: Improvement might have crucial role for honey bee productivity and colony vitality. Despite the advantages of education and training, formal beekeeping education programs and resources may be limited in some areas. Addressing educational barriers, such as geographic distance (Oued Seybouse, Khezaras, Meshta) and financial constraints, is critical to ensuring that beekeepers have equitable access to knowledge and resources.

By investing in education and training programs, encouraging knowledge exchange, and providing mentorship opportunities, it is possible to empower beekeepers to follow environmentally responsible practices while also contributing to the resilience and well-being of bee colonies in their communities (Garbach & Morgan 2017; Kassa Degu & Regasa Megerssa 2020).

Foraging activity is important for honeybee colony health and productivity because it affects the availability of resources like nectar and pollen (Počuch 2016). The relationship between foraging activity and resource availability is complex and influenced by environmental factors such as climate, habitat diversity, and flowering season (Polatto & Chaud-Netto 2013; Abou-Shaara 2014).

Temperature and precipitation play another important roles in determining foraging patterns. Honeybees are more active during warmer months when flowers are blooming and nectar sources are plentiful (Slater et al. 2004; Alqarni 2020). In contrast, cold weather can limit foraging activity, limiting resource availability and potentially affecting colony growth and honey production (Sanchez et al. 2020). In regions with distinct seasons, such as those with Mediterranean or semi-arid climates, temperature and precipitation fluctuations can have a significant impact on foraging dynamics, resulting in periods of resource abundance followed by deficiency (Flores et al. 2019). For example, in regions with mild wet winters and warm dry summers, beekeepers observed fluctuations in forage availability that corresponded to seasonal shifts. To prevent nutritional stress and preserve colony health, beekeepers frequently added supplemental feeds to honeybee diets during times when there was a low availability of natural forage, such in the dry summer months (Daněk 2017; Turč 2017). Additionally, beekeepers emphasized the importance of understanding the phenology of local flora to effective manage their colonies.

By monitoring the blooming activity of key plant species, beekeepers can anticipate fluctuations in forage availability and adjust their management practices accordingly (Wang et al. 2024). This proactive approach enabled beekeepers to optimize honey production and promote the health of their colonies all year.

Forage availability has as well a significant impact on honeybee colony health and productivity (Villagomez et al. 2021; Olate-Olave et al. 2021). Beekeepers in the observed regions of Northern Algeria highlighted abundant and diverse forage sources in maintaining honeybee populations and increasing honey yields. The survey findings revealed fluctuations in forage availability throughout the season, with peak periods coinciding with the blooming seasons of key plant species. During periods of abundant forage, beekeepers reported increased honey production and colony growth. However, they also highlighted difficulties during times of low forage availability, particularly in areas with distinct seasonal changes. To reverse the effects of reduced forage, beekeepers implemented supplemental feeding regimes to ensure colony health and honey production levels.

Weather conditions spans a significant influence on honeybee foraging behavior and colony productivity (Polatto et al. 2014). Beekeepers participating in the survey noted the impact of precipitation, temperature and seasonal variability on honey yields. Mild winters and warm, dry summers were associated with increased foraging activity and higher honey production, while harsh weather and extreme temperatures posed challenges to colony growth and productivity. For instance, beekeeper in Bouchegouf reported impressive honey yields of 8 kg per colony during favorable weather conditions in the season.

Beekeepers adapted their management practices in response to weather fluctuations, implementing measures to protect colonies during adverse conditions and capitalize on favorable weather for honey production (Vercelli et al. 2021). By closely monitoring weather patterns and adjusting management practices accordingly, beekeepers aimed to optimize honey yields while safeguarding colony health.

Beekeeping incurs significant establishment and maintenance costs, which vary depending on equipment, hive maintenance, and feeding supplements. According to the survey results, beekeepers incurred a variety of expenses to establish, improve and maintain their apiaries. Maintenance costs included hive construction or purchase, equipment acquisition, and ongoing maintenance. Additionally, beekeepers invested in feeding supplements to support colony health and productivity during times of limited forage supply.

Beekeepers use a variety of investment strategies to increase profitability and ensure the viability of their operations. Strategies for monitoring niche markets may include hive expansion, equipment upgrades, or diversifying honey products (Pippinato et al. 2020; Schouten 2021). According to the survey results, beekeepers strategically allocated resources to maximize return on investment and profitability. For example, beekeeper in El Kala Mullberry + Highway locations invested in high-quality equipment and hive management practices, resulting in a higher price per honey jar and a lower Break-Even Point (BEP) than other districts.

Break-even points (BEPs) are important parameters for determining the financial viability of beekeeping operations. BEPs are the point at which total revenue equals total costs, indicating the minimum sales required to cover expenses (Mohd Fadzil et al. 2023). The analysis of BEP's from various districts revealed information about the financial performance of beekeeping operations and their profitability potential (Salatnaya et al. 2022). Beekeeper at Roknia Farm, for example, achieved a BEP equivalent to 697 jars of honey, indicating a strong financial position and profit potential. On the other hand, beekeeper in Meshta faced a higher BEP of 56 jars per district, highlighting the difficulties associated with achieving profitability in certain outlying region.

Feeding practices are critical for honeybee colony survival, especially during limited natural forage sources availability (Schmickl et al. 2017). The survey results showed the spectrum of feeding strategies used by beekeepers in the surveyed districts, highlighting the balance between natural forage and supplemental feeding to stimulate colony growth.

Beekeepers emphasized the significance of plentiful and diverse forage sources in sustaining honeybee populations and increasing honey yields. They acknowledge the challenges posed by fluctuations in forage availability throughout the year, particularly during scarcity seasons.

To address the challenges of limited forage, beekeepers implemented feeding strategies, providing colonies with artificial or supplemental feeds to support their actual nutritional needs (Masehela et al. 2020). In periods of scarce forage sources, beekeepers implemented various supplementary feeds, like sugar syrup and pollen substitutes, to maintain their colonies. For example, beekeepers in Meshta and Chetaibi Meadow, which have long dry seasons, reported using sugar syrup regularly to supplement natural forage and avoid nutritional stress in their colonies.

While supplemental feeding is necessary to support colonies during periods of low forage availability (Requier et al. 2020), beekeepers need to manage feeding practices prudently to avoid unfavourable effects on local ecosystems. Artificial feeds may alter local pollen and nectar dynamics, affecting native pollinator populations and upsetting ecological balances (Carvalheiro et al. 2014; Mishra et al. 2015; Petr 2016). For example, the beekeepers in El Kala Forest and Oued Seybouse reported strategically placing feeding stations in areas with minimal ecological disturbance, lowering the risk of negative impacts on local ecosystems.

The findings offer valuable insights into the particular challenges encountered by beekeepers in the observed districts, highlighting the significance of proactive management approaches in addressing these challenges and potential opportunities. The changing climate presents a significant challenge to beekeeping operations, worsening current conditions (Van Espen et al. 2023). Beekeepers across all surveyed districts reported adverse impacts on honeybee foraging patterns and colony health attributable to climate change. Temperature and precipitation fluctuations, for example, were closely linked to outages in forage availability, consequently influencing honey yields and colony productivity. Regions like El Kala Mullberry + Highway and Chetaibi Forest + Hills experienced heightened variability in forage availability due to weather patterns, presenting additional hurdles for colony management and resource acquisition.

The palynological analysis results provide valuable insights into the botanical diversity of the sampled areas (Meltsov et al. 2013), shedding light on honeybees' access to a wide range of floral resources. By examining pollen loads collected directly from multiple hives in each location (Melin et al. 2020), I classified the pollen samples located in the honeybee foraging range based on colour, structure, and other characteristics.

The sampling processes detailed in Table 16 is capturing key information such as sampling date and time, air temperature conditions, and subsequent analysis dates. These details are critical for finalisation of the outcomes.

The analysis revealed a diversity of pollen types, with eight identified using multivariate techniques. This diversity suggests that the apiaries' surroundings are copious in plant species, providing honeybees with plenty of foraging resources. Furthermore, the accuracy of the analysis was enriched by beekeepers' ability to identify pollen sources during questionnaire interviews, confirming the reliability of the results. The pollen sample characteristics, as shown in Table 17, provide additional information about the distinct characteristics of each pollen type characteristics, such as weight, size, shape, symmetry, and surface properties.

Furthermore, the assumed forage sources listed in Table 18 provide additional context for interpreting the palynological data by linking pollen types to estimated plant species found in the Bouchegouf region. By linking pollen colours to corresponding forage sources a proper understanding was gained of the floral landscape and its impact on honeybee foraging behaviour.

Based on the honey analysis results from the Bouchegouf region, several key parameters were measured to characterize the honey sample and determine its botanical and geographical origin. The parameters included water content, acidity, electrical conductivity, sucrose content, and optical rotation (Kaškonienė & Venskutonis 2010; Maione et al. 2019).

The water content of the honey samples ranged from 17.8%, well below the maximum threshold of 20%, indicating good stability and a low risk of spoilage caused by microbial growth (Bednář 2017). Acidity levels, measured in terms of pH and free acidity, were within acceptable limits, with a pH range of 3.95 to 4.10 and a free acidity content of 15.0 meq/kg, which was less than the maximum of 50 meq/kg (Ketfi et al. 2023). Electrical conductivity is used to differentiate honey type, with values below 0.8 mS/cm indicating blossom or blended honey and above 0.8 mS/cm indicating honeydew origin (Olga et al. 2012). The measured electrical conductivity of 0.276 mS/cm confirms the honey sample floral (or floral blended) origin. Sucrose content, another important parameter, was low at 2.16%, well below the maximum limit of 5%.

Bees convert sucrose into simpler sugars such as glucose and fructose during honey production, resulting in low sucrose levels in authentic honey (Soares et al. 2017). To better characterize the honey samples, optical rotation measurements were provided. Negative optical rotation values indicate floral honey origin, which is consistent with the results of the electrical conductivity analysis.

The evaluation of the Liebefelder method revealed multiple factors statistically significant on monitored parameters. The hive characteristics, availability and diversity of forage sources, experience duration, encouraging by lemon cooking solution and sugar paste, hive maintenance frequency, flight activity, ApiVar treatment application and brood chamber of multi super hive had a statistically significant impact on the number of bees. On the other hand, number of colonies, number of bees, encouragement of colonies by honey and lemon cooking solution, ApiVar treatment and honey super part in the multi super hive revealed the statistifically positive significant relationship to total area of stored honey. Finally, Langstroth hives, brood chamber in the multisuper hive, experience duration and sugar syrup encouraging showed significant impact on the total brood area.

7. Conclusions

By evaluating a diverse range of factors spanning from hive characteristics to forage availability, mite treatment methods, and feeding practices, this study offers a understanding of the challenges and opportunities faced by beekeepers within the sampled localities.

Findings and Implications:

Variability in mite treatment approaches: The dominant use of treatments such as Apivar and Thymol-based products among beekeepers signifies their proven efficacy in *Varroa destrcutor* mite control. However, the observed limited usage of techniques such as powder sugar dusting and Formic Pro suggests that factors like accessibility and cost-effectiveness significantly shape the choice of treatment methodologies.

Queen health and reproductive success: Challenges regarding queen health, including issues with successful introduction and reasons of egg-laying cessation, underscore the critical role of high-quality queens in maintaining optimal colony productivity. Addressing these challenges exact a focus on wide-spread queen rearing practices to ensure sustained colony growth and productivity. Beekeepers may benefit from educational initiatives focused on proper queen management.

Disease management protocols: Documented cases of disease transmission among colonies highlight the imperative of robust disease management strategies. Early detection especially during routine monitoring practices, and the implementation of appropriate treatment protocols stand as pivotal measures in minimizing economic losses and fullfilling overall colony well-being.

Forage availability and weather impact: The substantial impact of forage availability and weather conditions on honeybee foraging behaviors and colony productivity is obvious. Beekeepers' adaptive measures, such as supplemental feeding during periods of inadequate forage availability, arise their proactive efforts to mitigate the effects of climate variability on honey yields. Continued research into resilient forage plants and strategies to buffer colonies against environmental stressors is crucial for sustaining healthy bee colonies.

Economic considerations and financial viability: The examination of break-even points (BEPs) provided insights into the financial disposition of beekeepers. The strategic allocation of resources by beekeepers to reach profitability underscores the paramount importance of efficient investment strategies and cost management practices.

Educational Imperatives and Training Initiatives: Formalized beekeeping education and training programs play an important role in increasing sustainable practices. Beekeepers with access to proper training exhibit higher levels of education and are more likely to follow proactive hive management strategies, highlighting the critical role of educational initiatives in fostering sustainable beekeeping practices. Continued investment in educational programs can strenghten beekeepers with the knowledge and skills necessary for effective hive management and disease prevention.

The act of ecological balance: The balance between supplemental feeding practices and reliance on natural forage sources emerges as an important consideration for long-term beekeeping endeavors. Beekeepers' awareness of the ecological consequences of artificial feeds emphasizes the critical need for proper feeding practices aimed at minimizing ecological disruptions. By promoting a feasible balance between artificial and natural forage sources, beekeepers can contribute to the preservation of local ecosystems and biodiversity.

Strengthening climate resilience: With climate change posing major obstacles to beekeeping operations, and worsening existing faced issues with forage availability and colony health, beekeepers' proactive approaches to climate management are critical. Weather monitoring and strategic adaptation strategies can help strengthen climate resilience within beekeeping enterprises, ensuring the sustainability of honeybee populations in the face of changing environmental conditions.

In conclusion:

Variation in local (microclimate) changes: Contrary to the null hypothesis, local microclimate changes significantly affect bee population sizes, indicating a notable impact on colony size.

Mite treatment methods: The study refuses the null hypothesis, showing a significant impact of mite treatment methods on colony health and productivity, with Thymol and Apivar showing positive effects on colonies.

Beekeepers' knowledge and experience duration: The null hypothesis is rejected; beekeepers' knowledge and experience significantly correlate with the districts they operate in, implying a geographical influence on beekeeping practices.

Honey yields: The null hypothesis is rejected as honey yields per colony significantly differ across districts, influenced by range of factors like forage availability and beekeeper practices. Feeding practices: The null hypothesis is also rejected; feeding practices among beekeepers significantly differ among districts between farmers, indicating diverse approaches based on local conditions.

7.1.1. Suggestions for Future Practices in Northern Province of Algeria:

Improved disease management can be achieved by reducing the frequency and strength of disease outbreaks and enhancing colony health by adopting best practices in disease prevention and treatment and proper disease monitoring programs.

Improved Queen Rearing: Beekeepers should concentrate on rearing high-quality queens and follow proper queen-rearing techniques to ensure strong colony performance and reproductive success.

Sustainable Forage Management: Strategies for increasing natural forage availability, such as promoting diverse floral landscapes and conserving native vegetation, can help honeybee populations and enlarge honey yields.

Climate Adaptation Strategies: Creating climate adaptation plans and strategies fitted to regional weather patterns can help beekeepers mitigate the impacts.

Enhanced Apiary Tidiness: Recommendations for keeping apiaries clean and organized are essential. Bee colonies can have a healthier environment and significantly reduce the risk of disease by keeping their apiaries clean, organized, and regularly cleaned of equipment and waste materials.

Educational Initiatives for Beekeepers: Many beekeepers expressed confusion about hive management and troubleshooting issues. It is recommended that local beekeeping associations or government agricultural agencies offer accessible and comprehensive training programs. These initiatives should address topics such as disease identification, queen health assessment, and effective mite control strategies, providing beekeepers with the knowledge they need to detect and address problems quickly.

Educational Imperatives and Training Initiatives: The importance of formalized beekeeping education and training programs in promoting sustainable practices cannot be overemphasized. Beekeepers who have access to structured training have higher levels of knowledge acquisition and are more likely to adopt proactive hive management strategies, highlighting the critical role of educational initiatives in fostering sustainable beekeeping practices.

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Appendix 1: List of tables

Table 24 Observed factors during questionnaire survey

Research Question	Factors Observed
1) Research Time	Time spent researching beekeeping
2) Stress Factors	Negative stressors affecting bees and production parameters
3) Beekeeping Experience & Aim	Years of beekeeping practice and purpose of beekeeping
4) Apiary Establishment Cost	Cost of establishing an apiary
5) Colony Maintenance Cost	Cost of maintaining colonies
6) Hive Maintenance Frequency	Frequency of hive maintenance
7) Beekeeping Activities (Daily)	Daily activities connected with beekeeping
8) Beekeeping Activities (Weekly)	Weekly activities connected with beekeeping
9) Beekeeping Activities (Monthly)	Monthly activities connected with beekeeping
10) Plant Support for Bees	Plants or crops planted around the apiary
11) Negative Spring Factors	Factors negatively affecting colonies during spring development
12) Forage Shortage Decline (Y/N)	Decline in bee colonies due to shortage of quality forage
13) Use of Bee Products	Utilization of other beekeeping products (e.g., pollen, wax, propolis, etc.)
I) Bee Feeding	

- Additive Feeding (Before/During Main Flow)	Additional feeding between/during honey flows
- Feeding Methods	Methods used for feeding (e.g., honey, sugar syrup, etc.)
II) Medications	
- Acarids (Natural/Synthetic)	Use of natural or synthetic acarids
- Use of Unauthorized Medicine	Use of unauthorized medicine
- Antibiotics	Use of antibiotics
III) Frame Management	
- Frame Renewal	Resurgence of frames, sorting of combs, treatment for diseases
- Frame Size	Size of frames used in the apiary
IV) Honey Harvest	
- Frame Composition (Brood/Honey)	Presence of brood in frames, number of honey frames
- Timing of Honey Jarring	Timing of putting honey into jars after extraction
- Total Honey Production	Total honey-producing colonies and weight of honey produced
V) Queen & Bee Production	

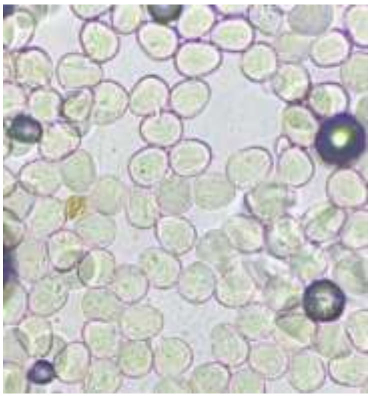
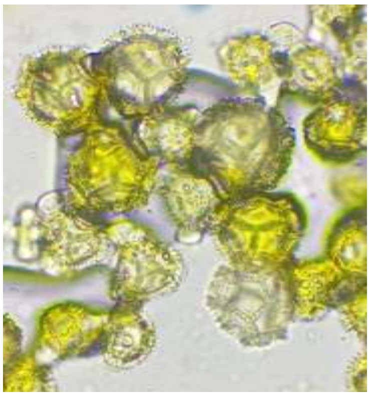
- Queen Rearing	Number of queens raised, species of bees kept
- Re-queening Issues	Issues during re-queening (e.g., queen issues, swarming)
VI) Other	
- Colony Age	Age(s) of colonies
- Colony Origin	How colonies were started
- Mite Treatments	Mite treatments applied in the current season

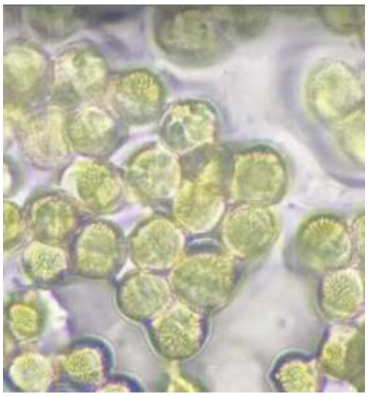
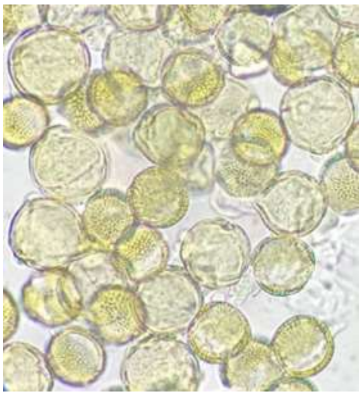
Table 25 Magnitude of monitored factors important for knowledge and practice part of the questionnaire - Knowledge and research before starting beekeeping, Awareness of the stress aspects and Duration of the beekeeping

District	Research question	Magnitude level
BenDjeraah	Knowledge and research before starting beekeeping	2
BenDjeraah	Awareness of the stress aspects	3
BenDjeraah	Duration of the beekeeping	2
Bouchegouf	Knowledge and research before starting beekeeping	3
Bouchegouf	Awareness of the stress aspects	3
Bouchegouf	Duration of the beekeeping	2
El Kala Mullberry alley + highway	Knowledge and research before starting beekeeping	2
El Kala Mullberry alley + highway	Awareness of the stress aspects	3
El Kala Mullberry alley + highway	Duration of the beekeeping	2
El Kala Forest	Knowledge and research before starting beekeeping	1
El Kala Forest	Awareness of the stress aspects	2
El Kala Forest	Duration of the beekeeping	1
Guelma	Knowledge and research before starting beekeeping	2
Guelma	Awareness of the stress aspects	3
Guelma	Duration of the beekeeping	2
Hourari Boumédiéne	Knowledge and research before starting beekeeping	2
Hourari Boumédiéne	Awareness of the stress aspects	3

Hourari Boumédiéne	Duration of the beekeeping	2
Chetaibi forest and hills	Knowledge and research before starting beekeeping	2.5
Chetaibi forest and hills	Awareness of the stress aspects	3
Chetaibi forest and hills	Duration of the beekeeping	2
Chetaibi meadow	Knowledge and research before starting beekeeping	2
Chetaibi meadow	Awareness of the stress aspects	3
Chetaibi meadow	Duration of the beekeeping	2
ITMA	Knowledge and research before starting beekeeping	3
ITMA	Awareness of the stress aspects	3
ITMA	Duration of the beekeeping	3
Khezaras CNC	Knowledge and research before starting beekeeping	1
Khezaras CNC	Awareness of the stress aspects	2
Khezaras CNC	Duration of the beekeeping	1
Khezaras 2	Knowledge and research before starting beekeeping	2
Khezaras 2	Awareness of the stress aspects	2
Khezaras 2	Duration of the beekeeping	1
Meshta	Knowledge and research before starting beekeeping	2
Meshta	Awareness of the stress aspects	3
Meshta	Duration of the beekeeping	1
Oued Seybouse	Knowledge and research before starting beekeeping	1
Oued Seybouse	Awareness of the stress aspects	2
Oued Seybouse	Duration of the beekeeping	2
Roknia center	Knowledge and research before starting beekeeping	1
Roknia center	Awareness of the stress aspects	2
Roknia center	Duration of the beekeeping	1
Roknia curve	Knowledge and research before starting beekeeping	2
Roknia curve	Awareness of the stress aspects	2
Roknia curve	Duration of the beekeeping	2
Roknia farm	Knowledge and research before starting beekeeping	3
Roknia farm	Awareness of the stress aspects	3
Roknia farm	Duration of the beekeeping	3
Roknia house with a view	Knowledge and research before starting beekeeping	1.5
Roknia house with a view	Awareness of the stress aspects	2
Roknia house with a view	Duration of the beekeeping	1

Table 26 Microscopic evaluation of pollen grains collected in Bouchegouf region (magnification 10 x 100)

Pollen Load	Colour of pollen load	Structure	Features of pollen grain	Microscopic view of pollen grains (magnification 10x100)
Pollen 1	Black	Elipsoid	Denser structure, more resistant Structure inside pollen observed with dots Inconspicuous inner edge of the grain Without visible pollen apertures Yellow hairs present on the surface Edges without notches	
Pollen 2	Orange	Elipsoid	Triple membranous structure inside the grain Three large pollen apertures located in protrusions Unstable structure - prone to easy disintegration Indistinct serrated edges	
Pollen 3	Light brown	Elongated - oval	2 pollen apertures In the central part of the grain, a noticeably visible narrowed section on the inner structure A lattice structure is found in the narrowing Lighter and smooth edges Surface covered with white fragments Heart-shaped notch	

Pollen 4	Brown	Globular	3 serrated pollen apertures Half of the inner part of the grain has a stepped structure (the structure looks rough) The second half of the inner part does not contain this structurelightly clumpy shape Smooth edges Slightly heart-shaped notch	
Pollen 5	Yellow	Irregular	Unstable structure (easily crumbled) Irregular grain boundary The surface is not smooth Larger notch 3 pollen apertures Apertures with a granular structure Small bumps are present on the edges	
Pollen 6	Brown with yellow tones	Irregular	3 apertures The interior of the pollen grain is hollow - without structures Firmer surface of the grain Irregular boundary Larger notch The base of the grain is brown, with yellow hairs present on the surface	
Pollen 7	Dark burgundy	Heart-shape	It had the hardest surface of all pollen grains The smallest pollen grain (the smallest grains) Rough surface Glossy and matte structure on the surface of the grain 3 smaller pollen apertures	

Pollen 8	Dark brown	Circular	3 large pollen apertures Hard structure Symmetrical Without notches Shape-defined Inner part of the grain overlaid with structures	

Table 27 Liebefelder method worksheets used in the field

Study		Date		Location	Time		Hive number	Flight activity				Hive type	Category	% cover
													0	0
Sampled (Y/N)					Weather								25	0-25
~ 250 bees for Varroa, FRAME:					Temperature								50	26-50
~ 100 bees for Nosema, FRAME:					Humidity								75	51-75
~ 100 bees for Viruses, FRAME:					Wind								100	76-100
Frame number		Cat (0-100)					Observed		Queen (Swarmed) cells (number)				Disease	NOTES
		Bees	Capped brood	Uncapped brood	Honey-dm²	Pollen-dm²	Eggs	Queen	Cups	w. Eggs	Open-prov	Capped	Chalkbrood	
1	a													
1	b													