EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 38: e167569
doi: 10.3897/ejfa.2026.167569

RESEARCH PAPER ADVANCING BEE SCIENCE

# Coping with climate change: Adaptive strategies and resilience profiles among Tunisian beekeepers*

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**Academic editor:** Habib Ali ♦ **Received** 2 August 2025 ♦ **Accepted** 7 April 2026 ♦ **Published** @@@@@@@@

## Abstract

Despite growing climate pressures, little is known about the resilience strategies of Tunisian beekeepers. This study identifies and classifies adaptation profiles based on coping strategies and examines their personal, agronomic, socio-economic, and institutional characteristics. Data was collected from a survey of 120 beekeepers and analysed using descriptive statistics and multivariate techniques. Fundings indicate that nearly all respondents (98.3%) reported experiencing environmental and economic pressures, particularly rising temperatures (92%), seasonal variability (88.3%), and increasing production costs (80.8%), with nearly half adopting measures to adapt to climate change. Factor analysis identified three principal dimensions of resilience strategies, explaining 71% of total variance: marketing and smart innovation strategies (38.37%), technological adaptation (19.87%), and financial adjustment (12.80%). Cluster analysis based on these dimensions revealed four distinct profiles: (1) beekeepers resistant to technological adaptation (16%), characterized by limited education and resources and a higher proportion of women; (2) experienced beekeepers relying primarily on traditional financial and technological practices (45.8%); (3) traditional technology adopters with financial reluctance (16.7%), generally experienced and educated but resistant to financial diversification; and (4) young, highly educated, innovation-oriented beekeepers (21.7%) who actively adopt marketing and smart technologies. The largest group consists of beekeepers who use traditional adaptation strategies while the other three groups are almost equal in size. The predominance of traditional adaptation strategies highlights structural constraints in innovation uptake. Strengthening targeted training, financial access, and knowledge exchange, while promoting a balanced integration of traditional practices and modern innovations, appears essential to enhancing collective resilience to climate change.

## Keywords

Beekeepers, climate change, resilience strategies, cluster analysis, Tunisia

* Topical Collection "Advancing Bee Science: Exploring Key Themes in Bee Biology, Conservation, and Health", edited by Habib Ali.

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## Introduction

Beekeeping extends beyond honey production, serving a vital role in food and nutrition security by pollinating up to 30% of global food crops (Liang 2024). By supporting pollination services, beekeeping enhances crop yield, quality, and diversity, contributing to increased productivity and dietary variety in agricultural landscapes (Yılmaz and Gültekin 2023). In addition to these direct benefits, beekeeping sustains rural livelihoods through income from honey and other hive products. Pollination also underpins agricultural sustainability by maintaining ecosystem functions and biodiversity: bees facilitate plant gene flow, improve habitat complexity, and support soil and vegetation health, linking apiculture to ecological integrity and resilient food production systems (Feketéné Ferenczi et al. 2023). However, climate change imposes unprecedented environmental stress on bees and their keepers, necessitating adjustments in management strategies and agricultural practices to enhance biodiversity, agricultural sustainability, and food security (Vercelli et al. 2021).

In recent years, climate change represents an overarching threat, altering floral resource availability, causing phenological mismatches between bees and flowering plants, and exposing colonies to extreme weather events that reduce foraging success and increase colony loss (Kerr et al. 2015; Vercelli et al. 2021). Climate change threatens honeybees by increasing diseases, parasites, and environmental stressors, which significantly affect their behavior, physiology, and distribution. Warmer temperatures and direct sunlight exposure influence bee population dynamics, affecting survival, reproduction, and dispersal (Pătruică et al. 2021; Vercelli et al. 2021). Temperature and humidity are critical for nectar production, which directly influences bee foraging and pollination activities (Switanek et al. 2017; Pătruică et al. 2021).

In addition to climate change, beekeeping has faced a complex set of challenges that have substantially affected both the ecological sustainability and the economic viability of apiculture. A primary concern remains the deteriorating health of honeybee populations, driven by a combination of parasitic infestations, pathogens, and environmental stressors such as pesticides; for instance, Varroa destructor mites and associated viruses undermine colony resilience and increase winter mortality rates, exacerbating phenomena like Colony Collapse Disorder (Le Conte and Navajas 2008; Goulson et al. 2015). Economically, beekeepers face rising operational costs, including equipment, supplemental feeding, labor, and transportation; while market pressures such as declining demand in some regions and competition from imported honey products create unstable revenue streams (OECD/FAO 2023). Fraudulent practices in the honey market, particularly adulteration with cheaper sweeteners, further erode consumer trust and undermine legitimate producers' competitiveness (European Commission 2023; Gajek et al. 2026). High colony losses also disrupt pollination-dependent agricultural systems; unprecedented mortality rates have threatened supply chains for key crops, contributing to shortages of pollination services and amplifying costs for commercial growers (Smith and Johnson 2024).

With particular emphasis on climate change, scientific research increasingly highlights its impact on beekeeping and emphasizes the need for adaptation strategies at both national and international levels (Rahman et al. 2022; Purwanti et al. 2023). Studies show that beekeepers must adopt new practices to sustain colony strength and profitability (Vercelli et al. 2021). A deepening analysis of adaptation practices and resilience strategies in beekeeping, both conventional and innovative, is necessary to face these hazards. Identifying practices that are appropriately tailored to specific agroecological, and socio-economic contexts is fundamental to promoting their effective dissemination and adoption among beekeepers. A comprehensive understanding of the adoption determinants is also essential. Integrating contextual suitability with insights into adoption drivers enhances the relevance of recommended practices and informs the design of targeted policies and capacity-building initiatives that strengthen long-term resilience in the beekeeping sector. Current research on climate change adaptation in the beekeeping sector predominantly focuses on technical and managerial responses, with comparatively limited attention given to the underlying socio-economic, personal and structural determinants that shape beekeepers' adaptive behavior (Vercelli et al. 2021; Landaverde et al. 2023; Van Espen et al. 2023). Consequently, a significant research gap persists regarding these factors driving the adoption of resilience strategies among beekeepers, particularly in the Tunisian context.

According to Debbabi et al. (2023), beekeeping holds a strategic position in Tunisia, supporting food security, biodiversity preservation, and the livelihoods of many rural households, yet the sector faces numerous substantial challenges that constrain its growth and competitiveness. The industry is confronted with issues of product quality and traceability, often related to fraudulent practices or adulteration, which undermine consumer confidence and the market value of local honey. The sector remains fragmented, dominated by small-scale or semi-professional operations that are frequently poorly organized and lack access to effective marketing networks. This situation is further exacerbated by competition from low-cost imports and high production costs, which reduce beekeepers' profitability. Moreover, the diversification of hive products remains limited, constraining opportunities for additional income, while institutional support and public policies are insufficient to guide the sector toward professionalization and enhanced product quality. Adding to these challenges is the significant impact of climate change. Climatic constraints, such as droughts, extreme temperatures, and reduced floral resources, place additional pressure on bee colonies, resulting in production losses and affecting the overall resilience of the sector.

As highlighted by Debbabi et al. (2023), Tunisian beekeepers employ a variety of strategies to cope with the im-

pacts of climate change and enhance the resilience of their colonies. These practices include diversifying melliferous resources and managing flowering calendars to reduce dependence on increasingly irregular production periods, as well as improving hive management techniques and honey quality to better withstand environmental fluctuations. Beekeepers also seek to preserve and develop melliferous plant potential by protecting pasture areas and planting high-nectar-value vegetation. Some operations are beginning to integrate technological tools, such as hive monitoring systems, which allow real-time tracking of internal conditions and early detection of climatic stress, although these innovations remain limited. Additional specific measures, such as placing hives in shaded areas, geographically rotating apiaries, increasing nectar and water resources, or selecting sites adapted to arid conditions, are also implemented to reduce production losses and enhance the overall resilience of the sector. To date, research has not examined the personal, structural, and socio-economic factors that influence Tunisian beekeepers' choices of resilience and adaptation practices.

Addressing this gap, the present study aims to investigate both the adaptation and resilience strategies employed by beekeepers in response to climate change and the factors shaping their decision-making.

It seeks to create a typology of beekeepers based on their adaptation practices, enabling an analysis of the profile of each category and a deeper understanding of the factors that influence their decisions and adaptation choices.

The remainder of the paper is organized as follows: A brief literature review is presented on adaptation and resilience strategies, with a focus on those adopted by beekeepers in response to climate change, as well as the main behavioral theories used to explain the factors influencing the selection of these strategies. The next section describes the methodological approach, which is based on a survey of beekeepers. This is followed by a presentation of the key findings from the factor and cluster analysis of beekeepers based on their resilience strategies to cope with climate change. The discussion of these results follows, and the paper concludes with a summary of the key deductions, along with managerial and policy implications.

## Beekeeping and climate change: A review of adaptation and resilience strategies

Recent research on adaptation and resilience highlights strategies that help social, economic, and ecological systems anticipate, absorb, and recover from various crises, including environmental hazards, public health emergencies, and socio-economic shocks. Resilience frameworks focus on key capacities (absorptive, adaptive, and transformative) that allow systems not only to cope with disturbances but also to reorganize and innovate, showing the importance of flexible, context-specific approaches (Nieuwborg et al. 2023). In the context of climate change, studies emphasize a range of adaptation measures to reduce vulnerability and strengthen the capacity of agricultural system. Effective adaptation includes both technical practices and organizational or socio-economic strategies that support farmers in adopting these practices (Rurii and Nzengya 2026).

Scientific research increasingly focuses on the impacts of climate change on beekeeping, leading to specific policy measures and adaptation strategies at national and international levels. In this context, adaptation strategies are crucial for minimizing negative effects on crop productivity, making it essential for farmers to adopt them to mitigate climate change impacts (Rahman et al. 2022; Purwanti et al. 2023). Qualitative research in Italy indicates that beekeepers must implement new practices to sustain their colonies' strength and profitability. Suggested strategies include sugar supplementation to counter nectar shortages, effective varroa control methods, and intensive transhumance (Vercelli et al. 2021). Beekeepers facing the challenges of climate change are increasingly turning to both traditional practices and innovative technologies to safeguard colony health. Traditional methods, such as improving hive insulation and ventilation using natural materials help maintain brood temperatures within the optimal range of 32–36 °C and reduce colony energy expenditure during cold periods (Lu et al. 2025). However, recent research has challenged the long-held belief that winter clustering is thermally protective; instead, it may increase thermal stress and metabolic demand, suggesting the need to reevaluate its role in climate adaptation strategies (Bastiaansen et al. 2021). At the same time, innovative approaches such as precision beekeeping integrate IoT sensors and machine learning to monitor hive conditions in real time, tracking variables like temperature, humidity, weight, and sound to detect signs of disease, stress, or colony decline (Uthoff et al. 2023). These smart systems enable early intervention and adaptive management based on environmental feedback. Together, these traditional and modern strategies form a complementary framework for enhancing the resilience of beekeeping systems under increasingly erratic climate conditions.

Personal qualities such as motivation and collaboration are vital for developing adaptation strategies, though challenges like financial constraints and inadequate support persist. In El Salvador, beekeepers reported a 50% loss in honey production between 2020 and 2021 attributed to climate change, resulting in a 35% decrease in national honey production. Adaptation measures in this context include modifying hive structures and increasing local pollen availability (Landaverde et al. 2023). Modifying hive structures involves altering the design and materials of beehives to better regulate internal conditions and protect colonies from climate extremes. This includes improving insulation to maintain stable brood temperatures, enhancing ventilation to reduce moisture and overheating, and using materials that respond well to temperature and humidity changes. Additionally, adjustments such as

adding sunshades, windbreaks, or modular components help shield hives from harsh weather and enable easier management. These structural changes reduce stress on the bees, improve colony health, and increase resilience against climate variability (Alburaki et al. 2021; Casado Sanz et al. 2024). However, beekeepers worldwide often feel ill-equipped to manage these complex environmental challenges and require ongoing technical assistance to adapt effectively.

Across different contexts, resilience strategies in beekeeping emphasize adaptation, diversification, and system-level preparedness to cope with climate and environmental stressors. Erdoğan (2023) highlights adaptive management approaches, including relocating apiaries, supplementing forage, modifying hive designs, and aligning harvests with shifting phenological cycles, alongside habitat management to stabilize local microclimates. Barroca and Serre (2013) present a conceptual model framing resilience across cognitive, functional, correlative, and organisational dimensions, suggesting that beekeepers can strengthen resilience by building knowledge, maintaining colony functions, adjusting practices to resource variability, and leveraging social and institutional networks. Yohana (2021) demonstrates the practical application of these concepts in semi-arid Tanzania, showing that beekeeping provides an adaptive livelihood in the face of agricultural losses due to climate change, with success dependent on access to modern hives, training, and extension support. Collectively, these studies illustrate that resilience in apiculture requires integrating ecological, technical, and socio-economic strategies to buffer colonies and livelihoods against climatic uncertainty.

The analysis of beekeepers' behaviors and their choices regarding resilience and adaptation strategies can be informed by several behavioral theories that identify determinants of behavioral intentions. Notably, the Theory of Planned Behavior (TPB) emphasize factors such as attitudes, subjective norms, perceived behavioral control, which influence the likelihood of adopting specific adaptive practices (Ajzen 1991). Complementing this framework, Social Cognitive Theory (SCT) provides a broader perspective by examining behavior as the product of interactions between personal, environmental, and behavioral factors (Bandura 1986). In the context of adaptation and resilience, SCT can explain how beekeepers' choices are influenced by personal factors (knowledge, experience, access to resources), environmental factors (peer influence, community support, institutional assistance), and behavioral factors (skills, past practices, etc.), offering a comprehensive lens for understanding how adaptive strategies are selected and implemented.

Concretely, recent research shows that socio-psychological factors strongly influence farmers' adaptation practices in the field. Kolapo et al. (2025) demonstrate that, among smallholder farmers in Southwest Nigeria, intentions mediate the influence of attitudes, subjective norms, and perceived behavioral control on the adoption of adaptation strategies. Similarly, Wani et al. (2025) integrate the Theory of Planned Behavior with the Value–Belief–Norm framework to explain adaptation and mitigation behaviors among rice farmers in India, showing that cognitive and normative factors, together with personal values, drive adaptive intentions. Complementing these TPB-based findings, Savari, Zhoolideh, and Limuie (2024) apply Social Cognitive Theory to farmers' use of climate information services, highlighting how personal factors, including self-efficacy and outcome expectations, and environmental factors, such as social perceptions and socio-structural conditions, jointly determine both intention and actual adoption. Collectively, these studies suggest that TPB and SCT offer complementary perspectives: TPB clarifies cognitive and normative antecedents of intention, while SCT emphasizes the interaction of personal and environmental factors in facilitating effective adaptation.

## Materials and methods

### Study area: Beekeeping sector in Tunisia

The Tunisian beekeeping sector is of particular importance in the agricultural sector. In 2022, there were approximately 13,200 beekeepers, with 65% managing less than 50 hives. Unfortunately, no official public source currently provides a geographical breakdown by percentage of the number of beekeepers per governorate in Tunisia but according to primary data from the Livestock and pasture office (2022), the Northwest region of Tunisia, which includes the governorates of Jendouba, Béja, Siliana, and Kef, is widely recognized as a key hub for beekeeping in the country. This area hosts a significant proportion of Tunisian beekeepers, largely due to its favorable climatic conditions, the rich diversity of nectar-producing plants, and the presence of vast forested landscapes. These natural advantages create an ideal environment for the development and sustainability of apiculture. The majority of beekeepers (60%) are semi-professionals, with 21.1% being professionals and 10% being hobbyists (Debbabi et al. 2023). Honey production has increased by 57% since 2011, reaching an average annual production of 2,360 tons in 2021. However, the sector is facing challenges due to climatic conditions, declining honey resources, resulting in significant fluctuations in honey production and colony losses of more than 40% (Livestock and pasture office 2022; Debbabi et al. 2023). To address these challenges, a place-based approach is required, considering the geographical and biological characteristics of each climatic zone, as well as monitoring the factors influencing honey production.

### Data collection

The methodology for this study is centred on a survey conducted from May to June 2024 involving 120 beekeepers from across Tunisia. Due to the absence of a recent national census of farmers, particularly beekeepers, in Tu-

nisia, and the limited availability of reliable data on the structure of beekeeping operations and beekeeper demographics, a purposive sampling strategy was adopted. This non-probability approach enabled the deliberate selection of participants based on predefined criteria consistent with the study objectives. Inclusion criteria were defined to select active beekeepers ensuring they had verifiable engagement in beekeeping activities, ensuring they were well positioned to accurately discuss the challenges they face and the solutions they have considered. Beekeepers who were inactive or lacked direct involvement in hive management were excluded. Efforts were made to ensure heterogeneity in both sociodemographic characteristics (e.g., age, gender, region, training background, primary occupation, and years of experience) and operational features (e.g., size of operation, legal status, and production practices), thereby capturing a broad range of beekeeper profiles. To facilitate participant identification and access, the study was conducted in collaboration with the Agricultural Investment Promotion Agency in Tunisia, which maintains contact information for beekeepers who had applied for financial incentives or who had participated in training programs to establish their beekeeping activities. This institutional partnership provided access to a structured database of active beekeepers and enhanced the credibility of the research process. Using these records, potential participants were contacted and invited to take part in the study, and data were subsequently collected through face-to-face interviews.

The questionnaire designed for this purpose is a structured and comprehensive tool aimed at collecting detailed data from beekeepers, with the objective of analyzing their profiles, practices, the challenges they face, and their adaptation strategies in the context of multiple crises. It is based on a logical structure divided into six major sections, combining sociodemographic, technical, economic, psychological, and behavioral dimensions. The first examines beekeepers' sociodemographic and professional characteristics using mainly closed-ended questions. The second addresses beekeeping activities, including their nature (main or secondary), experience, production systems, equipment, marketing channels, and operational scale. The third identifies recent constraints and threats (supply issues, bee health, climate, fraud, and costs) through multiple-choice items. The fourth assesses perceptions of health, economic, environmental, regulatory, and social crises and their impacts. The fifth evaluates resilience and adaptation strategies, whether planned or already implemented by beekeepers. It largely relies on Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree). Various items are dedicated to the assessment of barriers and enabling factors related to adaptation. The final section analyzes current adaptive behaviors.

Although this study does not aim to model beekeepers' behavior using theoretical behavioral frameworks, the selection of variables was guided by the Theory of Planned Behavior (TPB) and Social Cognitive Theory (SCT), which emphasize the role of personal, behavioral, and environmental factors in shaping actions. Sociodemographic and professional characteristics capture personal factors in SCT and provide context for beliefs and capacities in the TPB framework. Variables related to beekeeping activities, operational types, and adaptive behaviors reflect behavioral factors, while items addressing threats, crises, incentives, and facilitating factors represent environmental influences in SCT. The literature review on resilience and adaptation strategies provides a conceptual foundation for selecting the 17 variables representing adaptation strategies included in the questionnaire. This conceptual foundation ensures that the questionnaire comprehensively captures the determinants of resilience and adaptation strategies among beekeepers.

### Data analysis

The analysis was conducted using SPSS software (version 26.0) to perform descriptive statistics and create a typology of beekeepers. Initially, a descriptive analysis assessed the socio-demographic profile of beekeepers, their activities, and their perceptions of challenges and crises in beekeeping, with a particular focus on their awareness of climate change impacts. Additionally, it explored adaptation and resilience strategies and the factors influencing the intention to adopt these strategies. In the second part, exploratory factor analysis was employed to identify the key dimensions of resilience strategies and practices related to climate change. Of the 17 items, 14 were analyzed using principal component analysis (PCA) with Varimax rotation to delineate the dimensions of resilience strategies. The Varimax rotation enhances the distinction between extracted components while maintaining correlations within them. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test were utilized to evaluate data suitability, with a KMO value of 0.6 or higher indicating adequacy for PCA (Ding and He 2004). Following this, a hierarchical cluster analysis was conducted based on the identified dimensions of beekeepers' climate resilience strategies. Group selection relied on the significance of variable relationships, determined through ANOVA and chi-square ($\chi 2$) tests. Finally, cross-tabulation was used to profile beekeeper groups according to socio-demographic variables, and beekeeping activities (Ding and He 2004).

## Results

### Characteristics and practices of beekeepers

Fig. 1 summarizes the sociodemographic profile of respondents. The majority of beekeepers are men and middle-aged, with an average age (42 years). Most have a moderate to high level of education, though a small proportion are illiterate, and only a minority belong to professional agricultural organizations. Beekeepers have substantial experience, averaging around 14–15 years.

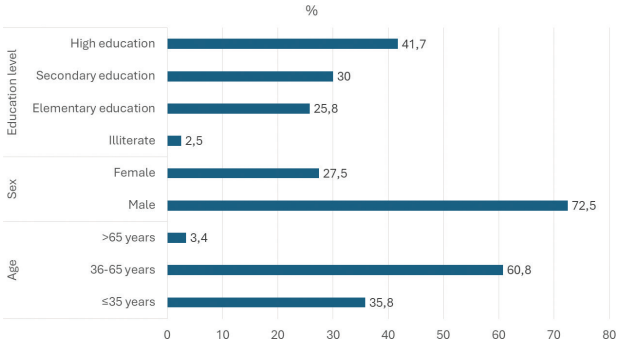


**Figure 1.** Demographic profile of the beekeepers surveyed (%).

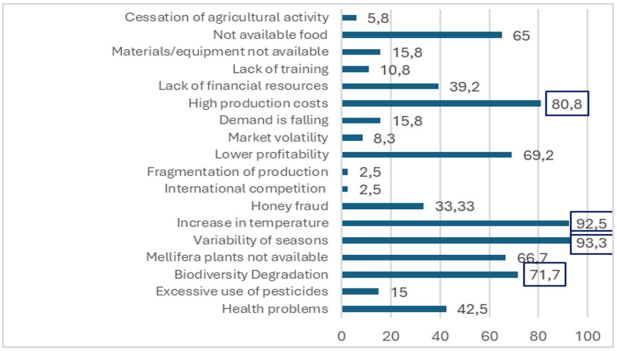


**Figure 2.** Key challenges faced by beekeepers in Tunisia (%).

Geographically, respondents are concentrated in Northern Tunisia (64.9%), followed by the Center (24.1%) and the South (11%).

Access to services, technical support, and funding is critical for enhancing beekeeping skills, productivity, and colony health, while also enabling sustainable practices and investment in modern equipment. The survey indicated limited access to credit (15.8%), constraining development and resilience strategies. In contrast, 65% of beekeepers have participated in training programs averaging 152 days, covering topics from basic and advanced beekeeping to organic practices and product processing to improve quality and marketability.

According to the survey, beekeeping is a primary occupation for 49.2% of respondents, while 50.8% pursue it as a secondary activity; among them, 32.8% are farmers and 26.2% are employees in the public or private sector. In 2023, beekeepers maintained an average of 116 hives, reflecting a mix of small- and large-scale operations.

The majority of beekeepers (65%) reported declining hive numbers over the past three years, attributed to environmental pressures, bee health issues, and rising costs, while 23.3% maintained stable hives and 11.7% increased them through effective management. Despite challenges, beekeepers reported an average of 5.2 transhumances per year covering 4,570 km.

Average honey production in 2023 was 720 kg per beekeeper (≈6.25 kg per hive), with high variability due to extreme weather, including heatwaves and droughts, which reduced yields from 8 kg to 4–5 kg per hive. Overall, 81.7% reported production declines linked to climate change. Indeed, irregular rainfall and drought in Tunisia limit floral resources, while high temperatures and extreme weather stress colonies and promote pests, collectively increasing bee mortality and reducing both productivity and honey yields.

## Problems and threats facing beekeeping activity in Tunisia

Results show that 98.3% of beekeepers face technical, economic, environmental, or bee health challenges (Fig. 2). The most prevalent issues include rising temperatures (92%), seasonal variability (88.3%), biodiversity loss (71.7%), reduced honey plant availability (66.7%), high production costs (80.8%), declining profitability (69.2%), and food shortages (65%). Only 1.7% of respondents reported no challenges, emphasizing the urgent need for targeted policies, training, and financial support. Additional details on less prevalent challenges are presented in Fig. 2.

## Climate change effects and beekeepers' adaptation strategies

Environmental crises have significant impacts on beekeeping. The majority of beekeepers report that harvest seasons are shifting (93.3%) and global warming affects bee activities (92.5%). High temperatures reduce colony fertility (85.8%), cause early flowering (84.2%), and contribute to laying failures due to water shortages (75%). Pollen and nectar collection and colony development are affected for 76.7% of respondents, while 65.8% notice changes in bee habitats and 60.8% report increased disease incidence. These effects, compounded by excessive chemical use and invasive species, threaten honey production and colony survival, highlighting the need for sustainable practices, habitat protection, and strategies to enhance colony resilience.

Nearly 98.3% of beekeepers have faced recent challenges, with 47.9% adopting climate change adaptation measures. Respondents rated a range of resilience strategies on a 1–5 scale (Table 1), revealing that financial stability is highly prioritized (prudent financial management, 4.26). Other widely adopted strategies include colony management and transhumance (3.91), crop diversification (3.89), hive movement (3.78), pest control (3.61), transhumance to track floral resources (3.14), income diversification (3.02), and access to additional funding (3.00). Strategies with lower adoption rates, including product valuation, marketing, new breeds, precision beekeeping, and blockchain implementation, fall below 2.5. The full list of adaptation and resilience practices is detailed in Table 1.

While traditional strategies are widely used, beekeepers are less inclined to adopt innovative technologies and collaborative approaches, which could hinder long-term resilience. To enhance resilience, there is a need for greater capacity building, improved resource access, and support for adopting innovative technologies.

**Table 1.** Current practices in addressing climate change.

| Items | Resilience strategies | Mean | Standard deviation |
|---|---|---|---|
| **SRA CC11** | I have managed my financial resources carefully. | 4.26 | 1.15 |
| **SRA CC4** | I have adapted my beekeeping practices (techniques of management of the colonies, transhumance, feeding). | 3.91 | 1.18 |
| **SRA CC3** | I have diversified honey crops. | 3.89 | 1.26 |
| **SRA CC15** | I moved my hives to new beehives. | 3.78 | 1.41 |
| **SRA CC5** | I have used pest and disease control techniques. | 3.61 | 1.34 |
| **SRA CC17** | I increased the number of transhumances. | 3.14 | 1.68 |
| **SRA CC1** | I have diversified my activities to multiply my sources of income | 3.02 | 1.72 |
| **SRA CC12** | I have sought additional funding and assistance. | 3 | 1.79 |
| **SRA CC7** | I have valued my beekeeping products. | 2.1 | 1.6 |
| **SRA CC8** | I made transparent communication about the quality and benefits of my honey. | 2.09 | 1.63 |
| **SRA CC6** | I have diversified my markets. | 1.95 | 1.49 |
| **SRA CC10** | I have been networking and collaborating with local partners. | 1.93 | 1.43 |
| **SRA CC9** | I have provided capacity building for myself and my employees on climate-smart production techniques to support adaptation to climate change. | 1.81 | 1.39 |
| **SRA CC16** | I imported bee breeds that I am not used to. | 1.6 | 1.16 |
| **SRA CC14** | I have installed Precision Beekeeping / Smart Beekeeping (connected hives). | 1.57 | 1.17 |
| **SRA C13** | I used innovative technologies like blockchain. | 1.51 | 1.12 |
| **SRA CC2** | I have taken out insurance for my beekeeping activity. | 1.5 | 1.03 |

The strategies with the highest variability were seeking additional funding (SD = 1.79), income diversification (SD = 1.72), and increasing transhumances (SD = 1.68), reflecting heterogeneous adoption among beekeepers. This suggests that these approaches are context-specific, influenced by individual capacity, access to resources, and local conditions.

## Factor analysis results of resilience strategies to climate change in beekeeping

Using Principal Component Analysis (PCA) and the Varimax rotation method, we factor-analysed 14 items of the total of 17 resilience strategies presented above and established different dimensions of beekeeper's resilience strategies. The choice to analyse only 14 items was based on criteria such as the relevance, variability, and quality of the data associated with each strategy. Typically, items that show very low mean scores or minimal variation, or those that are conceptually distinct from the main group, may be excluded to improve the clarity and robustness of the factor solution.

As detailed in table 2, the value of 0.858 for the Kaiser–Meyer– Olkin (KMO) measure indicates that data are adequate for PCA, and Bartlett's test was significant. Exploratory factor analysis with Varimax rotation resulted in the extraction of 3 dimensions that explain 71% of the total variance of the entire dataset. The three dimensions also present eigenvalues greater than 1, so they were retained because they were considered significant. Reliability testing for each construct uses the correlation of each question item. Based on research of Anto et al. (2023) and Gliem and Gliem (2003), the interpretation of reliability refers to the obtained Cronbach's alpha value. If alpha>0.90, then reliability is considered perfect. If the alpha is between 0.70 and 0.90, then the reliability is considered high. If alpha is between 0.50 and 0.70, then the reliability is considered moderate. Therefore, the three constructs are admitted as reliable constructs (Table 2).

The first construct of beekeeper resilience strategies was labelled "Marketing and smart innovation strategies". With 7 items, it explained 38.37% of the total variance. It is determined by items related commercial actions and techniques, market expansion alternative, practices to enhance beekeeping products' value, networking and collaboration, innovative technologies like blockchain) and smart innovation in beekeeping activities (capacity-building opportunities on climate-smart production techniques; precision beekeeping / smart beekeeping).

The second construct, "Technological adaptation", includes four items and explains 19.87% of the total variance. It incorporates traditional beekeeping practices and technologies used to face climate change such as adaptation of beekeeping practices, including colony management, transhumance, and feeding techniques to the new climate conditions, diversification of new crops, relocation of hives to other beekeepers (transhumance), pest and disease control methods.

The third construct, "Financial adjustment", is closely related to financial resources management, request of additional funding and support and diversification of income sources. It explains 12.80% of the total variance.

## Cluster analysis of beekeepers based on their resilience strategies to face climate change

Cluster analysis (Table 3) was performed using the 3 above constructs to identify beekeepers' segments. The option for 4 groups was selected based on the hierarchical clustering results and the significance of the analytical variables.

**Table 2.** Factor analysis results of resilience and adaptation strategies values' items – Varimax rotation.

| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | | .858 | | | Cronbach's Alpha |
|---|---|---|---|---|---|---|
| Bartlett's Test of Sphericity | | Approx. Chi-Square | 1192.508 | | | |
| | | Df | 91 | | | |
| | | Sig. | .000 | | | |
| | Code | Factors | 1 | 2 | 3 | |
| Marketing and smart innovation strategies | SRA CC8 | I have communicated transparently about the quality and benefits of my honey. | 0.929 | 0.194 | -0.004 | 0.947 |
| | SRA CC6 | I expanded into new markets. | 0.882 | 0.211 | 0.031 | |
| | SRA CC7 | I have enhanced the value of my beekeeping products. | 0.881 | 0.253 | 0.009 | |
| | SRA CC9 | I provided capacity-building opportunities for myself and my employees on climate-smart production techniques to facilitate adaptation to climate change. | 0.851 | 0.055 | -0.095 | |
| | SRACC10 | I have engaged in networking and collaboration with local partners. | 0.848 | 0.209 | -0.069 | |
| | SRA CC14 | I installed Precision Beekeeping / Smart Beekeeping (connected hives). | 0.838 | -0.016 | 0.178 | |
| | SRA C13 | I have incorporated innovative technologies like blockchain. | 0.779 | 0.059 | 0.269 | |
| Technological adaptation | SRA CC4 | I adapted my beekeeping practices, including colony management, transhumance, and feeding techniques. | 0.179 | 0.878 | 0.086 | 0.820 |
| | SRA CC3 | I diversified my honey crops. | 0.149 | 0.850 | -0.039 | |
| | SRA CC15 | I relocated my hives to other beekeepers. | 0.052 | 0.738 | 0.065 | |
| | SRA CC5 | I applied pest and disease control methods. | 0.231 | 0.68 | 0.339 | |
| Financial adjustment | SRA CC11 | I managed my financial resources with care. | -0.226 | 0.22 | 0.76 | 0.560 |
| | SRA CC12 | I pursued additional funding and support. | 0.084 | -0.087 | 0.742 | |
| | SRA CC1 | I diversified my activities to broaden and increase my income sources. | 0.183 | 0.171 | 0.646 | |
| Factor statistics | Eigenvalues | | 5,372 | 5.372 | 2.782 | 1.792 |
| | % of Variance | | 38,368 | 38.368 | 19.873 | 12.803 |
| | Cumulative % | | 38,368 | 38.368 | 58.241 | 71.044 |

**Table 3.** Cluster analysis based on the 3 constructs of beekeeper resilience strategies.

| | | | Beekeeper clusters | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| Number of Cases in each Cluster | | | 19 | 55 | 20 | 26 |
| % per class | | | 15.83 | 45.83 | 16.67 | 21.67 |
| Factors | F | Sig. | Resistant to technological adaptation | Adopters of traditional financial and technological adaptations | Traditional technology adopters with financial reluctance | Marketing and smart innovation adopters |
| Marketing and smart innovation strategies | 128.599 | ,000 | -0.19183 | -0.64446 | -0.14091 | 1.61187 |
| Technological adaptation | 63.102 | ,000 | -1.80364 | 0.38241 | 0.34734 | 0.24192 |
| Financial adjustment | 48.963 | ,000 | 0.0411 | 0.417 | -1.63911 | 0.34871 |

The ANOVA analysis shows the significance of all factors at p<0.001. "Marketing and smart innovation strategies" is the most critical factor in the cluster analysis (F=128.60), followed by "Technological adaptation" (F=63.10) and finally "Financial adjustment" (with F=48.96).

The first group represents beekeepers "Resistant to technological adaptation", with a very high negative score for technological adaptation (score= -1.8). It includes 19 beekeepers representing about 16% of the entire sample.

The second group, "Adopters of traditional financial and technological adaptations", attributes modest scores to the different factors (scores between -0.6 and 0.42). This group gives special attention to traditional practices to face climate change, whether it is technological or financial ones. This group represents the most important segment of beekeepers with 55 beekeepers (45.83% of the sample).

Group 3, "Traditional technology adopters with financial reluctance", represents beekeepers who are more resistance to financial changes (score = -1.6) against an affinity for technological adaptations" (score = 0.35). It accounts for 20 beekeepers representing 16.67% of the sample.

The last group, group 4, is titled "Marketing and smart innovation adopters". It concerns beekeepers with notable preference for marketing and smart innovation strategies with a high score equivalent to 1.61. This group covers 21.67% of the sample (26 beekeepers).

Fig. 3 illustrates the dispersion of beekeepers according to the three main factors of resilience strategies. This classification of beekeepers can be explained by several factors: personal characteristics (the beekeeper's profile), contextual and environmental conditions (access to production factors and the benefits provided by the surrounding ecosystem), as well as behavioral aspects (the nature of

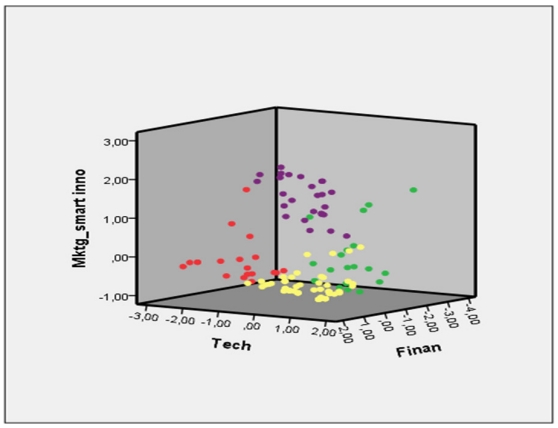


**Figure 3.** Beekeeper dispersion according to the three main factors of resilience strategies (3D plots*) (*Mktg_smart inno: Marketing and smart innovation strategies-Tech: Technological adaptation- Finan: Financial adjustment).

their beekeeping activity), among others. In the following sections, we examine the characteristics and functioning of each of the four categories of beekeepers, along with the various factors that may influence their intention to adopt adaptation strategies in response to climate change.

## Profiling the beekeeper segments

Table 4 outlines the profiles and activities of beekeepers in each group. In fact, the first group includes beekeepers who are resistant to technological adaptation. It is marked by the relatively large presence of women representing 42.1% versus 27.5% for the whole sample. The level of study of most beekeepers is basic. In fact, 36.8% of the beekeepers in the group have primary level education. The main feature of this group is the involvement of 36.8% in agricultural professional groups. Beekeepers in

**Table 4.** Beekeeper profiles and activities.

| | | Cluster number of case | | | | Total | p-value |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | | |
| | | Resistant to technological adaptation | Adopters of traditional financial and technological adaptations | Traditional technology adopters with financial reluctance | Marketing and smart innovation adopters | | |
| **Beekeeper profile** | | | | | | | |
| Age (years) | | 42.37 | 43.85 | 44.75 | 35.65 | 41.99 | 0.008 |
| Gender | Male (%) | 57,89 | 81,82 | 85,00 | 53,85 | 72,50 | 0.015 |
| | Female (%) | 42,11 | 18,18 | 15,00 | 46,15 | 27,50 | |
| Education level | Illiterate (%) | 5,26 | 1,82 | 5 | 0 | 2,5 | 0.000 |
| | Primary (%) | 36,84 | 36,36 | 20 | 0 | 25,83 | |
| | Secondary (%) | 26,32 | 38,18 | 35 | 11,54 | 30,00 | |
| | Academic (%) | 31,58 | 23,64 | 40 | 88,46 | 41,67 | |
| Affiliation to a Professional Agricultural Organization (%) | | 36.84 | 10.91 | 30 | 19.23 | 20 | 0.058 |
| Number of years of experience in beekeeping | | 11 | 16.69 | 16.65 | 11.15 | 14.56 | 0.060 |
| **Support for beekeepers** | | | | | | | |
| Access to credit (%) | | 0 | 20 | 5 | 26.92 | 15.83 | 0.038 |
| Training in beekeeping (%) | | 78.95 | 54.55 | 55 | 84.61 | 65 | 0.023 |
| Total duration of training in days | | 108.73 | 105.43 | 116.6 | 278.58 | 152.07 | 0.094 |
| **Beekeeping activity** | | | | | | | |
| Total number of hives in 2023 | | 49.05 | 138.58 | 152.45 | 85.69 | 115.26 | 0.223 |
| Average distance travelled for transhumance (Km/year) | | 645.53 | 3773.91 | 7898.5 | 6565.04 | 4570.76 | 0.422 |
| Total honey production in 2023 (kg) | | 737.68 | 716.15 | 916.75 | 561.69 | 719.53 | 0.897 |
| Honey harvest (%) | | 89.47 | 100 | 100 | 84.62 | 95 | 0.011 |
| Different treatments of the honey harvested (%) | | 10.53 | 21.82 | 55 | 84.62 | 39.17 | 0.000 |
| **Marketing of honey** | | | | | | | |
| Intermediate (%) | | 42.11 | 50.91 | 60 | 50 | 50.83 | 0.739 |
| Retailers (%) | | 0 | 1.82 | 5 | 23.08 | 6.67 | 0.002 |
| Final consumer directly (%) | | 89.47 | 85.45 | 90 | 88.46 | 87.5 | 0.937 |
| Hotels and guesthouses (%) | | 0 | 0 | 5 | 11.54 | 3.33 | 0.043 |
| Average price of honey sold in 2023 (Tunisian dinars/kg) | | 53.05 | 51.55 | 55.75 | 58.27 | 53.94 | 0.416 |

this group have no access to credit, which hampers their ability to adapt. It is also the group with the lowest number of hives, that could be explained by high mortality due to climate change between 2022 and 2023, in addition to the short distance travelled by transhumance, which is one of the technical adaptation practices adopted by beekeepers. Table 4 also shows that the beekeepers in the first group do not attach importance to post-harvest honey treatments, hence the absence of any efforts to enhance the product (10.5% of the beekeepers in this group use different treatments for honey after harvest). Also, on the market side, the usual channels of sales are end consumers and intermediaries, there is no request or prospecting for new customers who have a better willingness to pay for the product, this is reflected in the selling price of honey.

The second group, the adopters of traditional financial and technological adaptations**,** consists mainly of men (81.8%), with 75% having completed primary and secondary education. They are the least familiar with professional organizations (only 11%). But they are among the most experienced (16.7 years as the group average). In addition, they have low access to training (55% against 65% as the percentage for the sample). This explains the adoption of traditional, non-innovative strategies for adapting to climate change. Moreover, they have relatively good access to credit (20% against 15.8% for the entire sample), which explains the choice of financial adaptation strategies. They harvest their own honey but only 22% of them do the post-harvest treatments themselves. They prefer traditional sales channels targeting intermediaries or end consumers. Those who sell their honey in retail outlets account for only almost 2%.

The third group, traditional technology adopters with financial reluctance, is mainly men (85%), with a secondary and academic education level (35% and 40% respectively), of whom 30% are affiliated to professional organizations and have the longest experience in beekeeping compared to other groups (an average of 17 years of experience). Beekeepers in this group have difficulties accessing credits (only 5% were credit recipients) and have also the lowest training rates (55% compared to 85% for group 4 and 65% for the sample as a whole). They are also characterized by the highest average number of hives in 2023, the highest production levels and the greatest transhumance distances compared to other groups. They harvest their own honey, but only 55% of them provide post-harvest treatments. For the marketing of their honey, they mainly choose traditional networks of intermediaries and direct sales to final consumers.

The fourth group of beekeepers "Marketing and smart innovation adopters" is mainly made up of the youngest beekeepers (average age 35), mostly women (more than 46% well above the sample percentage of around 27%). It is mainly constituted by university-trained beekeepers (more than 88%). This group of beekeepers has the highest percentage of access to credit (27%) and training (84.6%), and the highest average in terms of duration of continuing training sessions. When analysing their operation, the attempts to value products are remarkable through their post-harvest honey activities (84.62%) and direct marketing choices to consumers, hotels, guesthouses and retailers. They adopted a diversification of honey distribution channels. This directly affects the selling prices, which are on average the highest prices compared to other groups and compared to the average of the whole sample. These features provide beekeepers with the advantage of mastering marketing tools and innovative technologies, particularly smart ones.

## Discussion

Our findings reveal that beekeepers face a range of technical, economic, environmental, and health-related challenges. The most pressing concerns include the effects of climate change (such as rising temperatures and seasonal variability), biodiversity loss, and the reduced availability of mellifera plants. These challenges align with the findings of Corrente et al. (2024), Van Espen et al. (2023) and Narang et al. (2022). Economic problems are, moreover, added to these challenges, and are particularly focused on high production costs, declining profitability, and limited financial resources. Market-related issues are identified such as honey fraud, market instability, lack of effective marketing strategies, international competition, and cheap imported honey, which further undermine product quality. These issues are aligned with the fundings of Narang et al. (2022), Adgaba et al. (2014), Lloyd (2021) and Vercelli et al. (2021). Technical and educational gaps are evident, with inadequate equipment and insufficient training. These results are also supported by Narang et al. (2022). Health threats to bees, such as pesticide overuse and various other health issues, pose significant challenges, as highlighted by Ghosh (1994) and Narang et al. (2022).

Climate change has a direct impact on bee colony fertility, food supply, and overall bee health, threatening honey production and the survival of colonies. Beekeepers have also noted other negative effects, including premature flowering, decreased egg-laying due to water shortages, shifts in bee habitats, and a rise in diseases. Moreover, the overuse of agricultural chemicals and the increase in invasive species further compound the difficulties faced by beekeepers. These results align with the findings of Vercelli et al. (2021) and Giannini et al. (2020).

Beekeepers' reports about climate impacts on honey production in Tunisia are not merely perceptions, they are supported by ecological and climatological evidence. However, not all challenges can be solely attributed to climate change. Some reflect broader systemic issues, such as lack of adaptation strategies, limited education, and exposure to multiple stressors. A more interdisciplinary approach is needed to fully understand and respond to these challenges.

The primary coping strategies employed by Tunisian beekeepers include careful financial management, and income diversification. Mugo and al. (2015) highlighted the

same results in the Kenyan context. Colony management, and transhumance to follow floral resources, as well as crop diversification and pest control are principal coping strategies for Tunisian beekeepers. Lloyd (2021) and Dimelu and Nwuba (2018) also highlight these practical adaptations based on beekeeper's experience across the globe.

However, they show limited engagement in product valuation, marketing, market diversification, and collaboration. These practices are highlighted by Chazovachii (2012) and Mucha et al. (2021) as very important climate resilience strategies.

The adoption of climate-smart practices, such as precision beekeeping and blockchain technology, remains low. These practices are expanding around the world, as raised by Danieli et al. (2024); Pacheco and Ocaña (2023) and Abdelbaset et al. (2023). However, they are currently emerging within the Tunisian context.

It is important to note that the literature review on global beekeepers' typologies primarily emphasizes classifications based on socio-economic characteristics, productivity, profitability, and related performance indicators (Castellanos-Potenciano et al. 2017; Guiné et al. 2021; Kaboré et al. 2022). However, typologies specifically centred on resilience strategies to climate change remain largely unexplored, constituting a novel contribution of the present study.

In this study, cluster analysis was used to classify beekeepers based on their resilience and adaptation strategies to climate change, revealing four distinct groups. The classification highlights how differences in resources, knowledge, experience, socio-demographic characteristics and access to material and non-material forms of support shape adaptive behaviors.

The first group, characterized by resistance to technological adoption and limited access to resources, appears to face structural constraints that hinder adaptive capacity. Their reluctance may stem not only from cultural or cognitive barriers but also from financial limitations, restricted access to information, or weak institutional support. This profile reflects a vulnerability trap, where low resource availability reinforces low innovation uptake, thereby constraining resilience.

The second group relies primarily on traditional practices and accumulated experience. While experiential knowledge can provide context-specific and time-tested coping mechanisms, exclusive dependence on tradition may limit responsiveness to emerging and complex challenges. This strategy reflects incremental adaptation rooted in continuity rather than transformation, suggesting moderate but potentially insufficient resilience under accelerating environmental or market pressures.

The third group demonstrates openness to technical innovation but hesitates to undertake financial adjustments. Their focus on operational adaptation, such as improving production techniques, without parallel changes in financial planning, investment structuring, or market positioning may reduce the overall effectiveness of their adaptation strategy. This partial modernization indicates an intermediate adaptive posture, where technical change is decoupled from broader economic transformation.

In contrast, the most proactive group adopts a comprehensive and forward-looking approach. By combining innovative technologies with market-oriented strategies, and leveraging higher levels of education and training, this group demonstrates integrated adaptation. Their strategy suggests not only reactive capacity but also anticipatory and strategic resilience. The alignment between technical innovation, financial management, and market engagement reflects a systemic understanding of change, positioning them as potential leaders or catalysts within the sector.

These clusters demonstrate that adaptation patterns emerge from the interplay of technical, financial, and market-oriented strategies, moderated by factors such as education, training, age, and gender. Importantly, these results provide guidance for targeted interventions and inform the implications of the study.

## Conclusion and implications

The purpose of this paper was to examen the characteristics and profiles of the four groups of beekeepers based on their chosen resilience strategies in response to climate change. The findings show that the largest and most frequent group is those adopting traditional adaptation strategies (Group 2 ≈ 46% of the sample), whether financial or technological. The remaining three groups exhibit nearly equal proportions within the sample, with Group 4 (approximately 22%), characterized by a stronger orientation toward marketing adaptations and smart innovations, being slightly more represented. It is also notable that Group 1, comprising 16% of the sample, represents the most resistant group to resilience strategies, particularly technological ones.

In light of this finding, a national strategy should be created to promote adaptation strategies among this target group of Tunisian beekeepers, particularly given the sector's strategic contribution to food security and biodiversity preservation. To support beekeepers in their adaptation to climate change, it will be necessary to take several actions, including strengthening of knowledge and awareness of the impacts of climate change and the challenges encountered and of the different adaptation strategies that can be used in the Tunisian context. Awareness sessions for beekeepers, information campaigns and training programs will therefore be of great use in raising awareness among beekeepers about the impacts of climate change, particularly on colony health, pollination cycles and extreme weather, but also relevant resilient practices.

To remove barriers to adopting resilience strategies, including cost barriers, it is important to provide specific grants and financial support to beekeepers to encourage them to adopt resilience practices, and the purchase of modern hives, the installation of colony health monitoring systems, or the improvement of bee management

techniques, would be a great asset for innovative and smart resilient practices. Infrastructure and technology constraints must also be addressed, with access to modern technologies to help beekeepers better understand and manage the impacts of climate change such as colony monitoring technologies (Internet of Things "IoT" sensors to monitor temperature, humidity and colony health, mobile apps to track local weather conditions and help beekeepers adjust their practices), in addition to climate forecasting tools. Indeed, IoT sensors help to detect problems such as diseases or climatic variations affecting the hive and anticipate actions to be taken. The use of digital hive management platforms such as HiveTracks or BeeSmart is an example of this evolution (Abdelbaset et al. 2023; Danieli et al. 2024; Pacheco and Ocaña 2023).

Using weather forecast applications and models can help decide when to move hives or what intervention to perform (Robustillo et al. 2022). In this case, it is necessary to offer continuing training on technological innovations in beekeeping for better adoption among beekeepers. These courses may be provided by universities, beekeeping cooperatives or support institutions, such as the "Livestock and pasture office" or the "Agricultural extension and raining agency". Ensuring access to suitable environmental funding and insurance mechanisms is essential to support them in managing climate risks (Tassew et al. 2019; Hinton et al. 2022; Colivicchi 2023).

Collaboration between beekeepers, farmers and other stakeholders is essential to building resilience to climate change. This could be possible through the establishment of beekeepers' networks where they can exchange good practices and strategies for adapting to the specific climatic conditions of their regions. For beekeepers who are interested in innovation and new technologies, the creation of collaborative digital platforms for beekeepers would allow them to share information on local climatic conditions, good practices and health alerts and technological innovations (Chazovachii 2012; Tassew et al. 2019; Abreu et al. 2021).

It is important to combine proven traditional practices with modern innovations. This hybrid approach allows for increased resilience while respecting traditional beekeeping skills. All these measures oriented towards innovative, smart practices do not in any way reduce the role of traditional and conventional adaptation strategies, whether financial or technological. Indeed, beekeepers must also be encouraged to integrate financial practices to support the economic sustainability of their activity in the face of climate change. This includes not only diversifying income sources but also capitalizing on hive-derived products (such as propolis, royal jelly, and wax) and providing pollination services to other agricultural sectors. This helps to limit financial risks associated with crop losses or adverse weather conditions (Chazovachii 2012; Mucha et al. 2021). In addition, in terms of traditional technological adaptation practices, beekeepers are encouraged to preserve and adapt traditional beekeeping methods. These include using traditional hives tailored to new climatic conditions, selecting local honey plants, rotating beehives based on climatic conditions, and providing complementary feeding (Corrente et al. 2024).

While the study provides valuable insights into beekeepers' awareness of climate change challenges and their impacts on their activities, as well as outlining the various practices, strategies, and resilience measures they adopt to form a typology of beekeepers, it has several limitations that should be addressed in future research. These include conducting comparative analysis with other countries and modelling the factors influencing beekeepers' adaptation choices using theoretical frameworks such as the Protection Motivation Theory and the Theory of Planned Behavior, to obtain valid and widely applicable results in an international context.

## Author contributions

Conceptualization: EO, YE. Data curation: EO. Formal analysis: EO. Funding acquisition: YE. Investigation: EO, YE. Methodology: EO, YE, LA. Software: EO. Supervision: EO. Validation: EO. Visualization: EO. Writing – original draft: EO. Writing – review and editing: YE, EO.

## Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
No AI tools were used in the preparation of this manuscript.

## Declarations of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

## Acknowledgements

This research is part of the R&D project **TECHONEY** – "Development of a blockchain-based ecosystem that allows an improved positioning of small producers of honey on local and international markets" (grant reference **PCI 2022-132950**), funded by the Tunisian Ministry of Higher Education and Scientific Research, as well as by the European Union, Next Generation EU/PRTR within the framework of the Partnership for Research and Innovation in the Mediterranean Area (**PRIMA Section 2 Call 2021 – Multi-topic**). The content of this paper reflects only the authors' view, and the European Union Agency is not responsible for any use that may be made of the information it contains.

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