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SOCIODEMOGRAPHIC DETERMINANTS OF PRODUCTIVITY, TECHNOLOGY ADOPTION, AND PERCEIVED SUSTAINABILITY AMONG COMMERCIAL BEEKEEPERS IN MOROCCO

SUMMARY

Beekeeping provides essential pollination services and livelihoods, yet it faces growing threats from climate change, pathogens, and management challenges. In Morocco, these pressures have reduced colony numbers and honey yields, but the influence of beekeepers' sociodemographic characteristics on productivity and sustainability remains underexplored. This study aimed to evaluate the sociodemographic, geographical, and economic determinants of beekeeping productivity and perceptions of sustainability among commercial beekeepers in Morocco. A face-to-face semi-structured questionnaire was completed by 599 beekeepers in all parts of Morocco. The data measured included socio-demographic, operational structure, honey production, product diversification, and colony renewal strategies. Chi-square, multinomial logistic, and generalized ordered logit analyses were conducted. Beekeepers were predominantly male (70.1%), aged 31–50 years (79.3%), and highly experienced (>10 years, 88.2%). Most operated >500 hives (55.4%) using modern hives (79.0%). Modern hive adoption was strongly predicted by educational level (Nagelkerke $R^2=0.307$), with secondary-educated beekeepers showing substantially higher adoption (OR=32.87, 95% CI: 12.23–88.39). Product diversification was moderately predicted by sex (Nagelkerke $R^2=0.175$), with females showing notably higher diversification (OR=0.071–0.125 for males vs. females). Generalized ordered logit models revealed that sociodemographic factors explained substantial variance in honey production across both thresholds (Nagelkerke $R^2=0.431$ for ≥ 1 tonne; 0.590 for >5 tonnes), with sex showing the

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largest effects (OR=0.214 for ≥ 1 tonne; OR=0.113 for >5 tonnes). Beekeepers perceived both positive social and environmental effects of renewal strategies, but 43% of beekeeping operators observed that operational costs were high. For the commercial layer, there is potential to improve productivity by providing targeted support to semi-illiterate, less-educated, and less-experienced female beekeepers to mitigate apparent sustainability issues. Firm policy recommendations should await objective validation of these perceptions through ecological and longitudinal studies

Keywords: beekeeping, biodiversity, climate change, colonies, pollination, sustainability

INTRODUCTION

The economic and ecological importance of beekeeping cannot be overstated, as bees are among the most important pollinators of biodiversity and crop productivity (Prodanović *et al.*, 2024). Pollination helps plants reproduce and is essential to the sustainability of ecosystems and food security worldwide (Thakur, 2012). In addition to its ecological value, apiculture is, in most cases, the primary source of income for rural populations, particularly in developing countries like Morocco (Bakour *et al.*, 2021), as honey and other beekeeping products support local household and market economies (Khabbach *et al.*, 2013). Although the beekeeping industry has extensive expanses and dimensions, its survival is faced with significant threats (Wakgari and Yigezu 2021). As a result, bee colonies demonstrate an increased vulnerability to pathogens, in particular, to strains associated with *Varroa destructor* that spread the viruses and degrade the health of the colonies (Barroso-Arévalo *et al.*, 2019; Traynor *et al.*, 2020).

Climate change disturbs the process of phenological cycles and exerts extra pressures hindering the accessibility of nectar and pollen by colonies and undermining productivity (Rankin *et al.*, 2020; Descamps *et al.*, 2021). These are the bees that are generally known to have contributed to the decline in global bee populations, the reduction in honey production, and the increase in the cost of beekeeping operations (Giacobino *et al.*, 2016; Neumann and Straub 2023). Those aforementioned international realities would be especially relevant to the beekeeping scenario in Morocco, in which apiarists have to deal with singular conditions that heighten the issue of colony collapse and compound production difficulties and impede. The beekeepers in this nation are already experiencing a sharp the decline in colony numbers, a reduction in honey harvest, and rising prices of medicines and equipment (Moujanni *et al.*, 2017, Bahouq *et al.*, 2024). The problems are not only dangerous to the livelihoods of individual beekeepers but also to the larger agricultural systems that rely on crop yields as a result of pollination services. The sociodemographic factors (gender, level of education, and experience). The variety of harvested products and local geographical conditions will likely affect colony management practices and honey production outcomes in such an environment. (Tadesse *et al.*, 2021; Nganso *et al.*, 2024). Studying these factors may help beekeepers modify their practices and identify

means to make beekeeping in Morocco more ecologically sustainable and economically viable. Despite the recognized economic and ecological importance of beekeeping in Morocco, empirical evidence on how beekeepers' sociodemographic characteristics influence productivity and sustainability remains scarce. Understandings about the relationship between sex, education, experience, and management suggested in previous studies have been more concerned with the volume of production or floral stocks than with specific interactions. Additionally, in Morocco, these effects on hive type adoption, product diversification, and colony renewal strategies, and their impact on them have not been assessed as a surrogate for their effects quantitatively at different operational scales. To address these gaps, the current study conducted a multi-regional analysis that covered all beekeeping sectors in Morocco. This study is distinctive in that it assessed and technological adoption, diversification patterns, and perceived effects on sustainability-all simultaneously. Specific objectives included (i) establishing a sociodemographic and operational profile of a large-scale commercial beekeeping population across ten Moroccan apiaries, and (ii) exploring linkages between sociodemographic aspects of beekeepers (sex, education, experience) and productivity, adoption of different hive types, and diversification of products, as well as (iii) documenting beekeepers' perceptions on the economic, environmental and social consequences of the implementation of strategies for colony renewal. Importantly, we measure perceived, not objective, sustainability outcomes: our data cannot directly measure ecological outcomes pesticides, such as colony mortality, pesticide exposure, or floral diversity.

MATERIAL AND METHODS

Study area

Morocco is the country of study in this investigation. It is located in the far northwest of Africa. It surrounds the Mediterranean Sea to the north, the Atlantic Ocean to the east, Algeria to the west, and the Sahara to the south. Morocco serves as a bridge between Africa, Europe, and the Arab world due to its advantageous geographic location, situated near the border of Gibraltar (Collectivités territoriales 2024). According to the administrative plan, the country has been divided into eight regions since the 2015 reform: Tangier-Tetouan-Al Hoceima, Oriental Region, Fes-Meknes, Rabat-Sale-Kenitra, Beni Mellal-Khenifra, Casablanca-Settat, Marrakech-Safi, Draa-Tafilalet, Souss-Massa, Guelmim-Oued Noun, Laâyoune-Sakia El Hamra, and Dakhla-Oued Eddahab. Each has a regional elected council and a state representative, Wali, which encourages territorial governance tailored to local realities (Collectivités territoriales 2024). Morocco has a very high level of heterogeneity in its climatic landscape, with different regimes across its spatial areas. The eastern part is of oceanic climate, as is the central interior with continental climate; the eastern part of the northeast is arid with desert-like climatic conditions (Maroc Météo, 2024). There are direct impacts of such climatic variability on the apicultural sector,

which would affect the phenological cycles and developmental processes, as well as the availability of water resources. One of the most consistent ancient farming activities in both current societies is Apiculture, yet it is also among the exceedingly vulnerable to environmental changes. This, in turn, urges the urgent need to develop policy-based solutions addressing the effects of climate change on the yield of apicultural productivity that are to be formulated (Attar *et al.*, 2024).

Data collection

The data were gathered through direct, face-to-face interviews with a structured, pre-validated questionnaire. To make it clear and culturally relevant, the instrument was converted into the local dialects, i.e., Arabic and Tamazight. A pilot test was first done on a small sample of beekeepers to test the questionnaire and ensure it is relevant, comprehensive, and has clear meanings in all the items since the questionnaire will be administered to a large population. The questionnaire was arranged in a structured form to capture all necessary data, divided into four main parts (Appendix 1). The initial part was a sociodemographic information section whereby gender and age, as well as the level of education and years of experience in keeping bees, were recorded. The second part concerned the operational structure, asking about the operational area mainly, the kind of hives used, mostly traditional or modern, or a combination of both, and the number of hives manned. The third part evaluated the production of apicultural products and the range of products collected during the year, including honey, pollen, propolis, royal jelly, wax, bee bread, and bee venom. It calculated the average annual quantity of honey produced. In the last part, colony management and colony sustainability were investigated based on the strategies used to renew the herd (e.g., buying colonies, rearing queens, swarm capture, division), the rate of colony renewal, and the perceived economic, environmental, and social effects of this practice on the beekeepers. The interviews were trained enumerators within a specified time frame, and each session was estimated to take about 30 to 45 minutes to obtain comprehensive data.

Sampling Procedure

The investigation used a multi-stage sampling strategy to ensure that a sample of the cross-section of the beekeeping community in Morocco was effective. First, the major honey-producing areas were purposely selected, thus representing the diversity of the country's climatological and agrarian settings and reflecting the heterogeneity of the beekeeping tradition and problems. It was followed by a stratified random sampling design in these areas, where beekeepers were classified into three different operation groups in terms of colony numbers: small-scale (50-100 hives), medium-scale (101-500 hives), and large-scale beekeepers (more than 500 hives). This stratification was used to ensure proportionality of different management systems and economic sizes existing in the apicultural industry. The sampling design was developed in partnership with the institutional stakeholders, who were the Ministry of Agriculture, regional agricultural directorates, and beekeeping cooperatives. Such cooperation resulted

in an exhaustive list of possible participants. An overall programmed sample size of 599 beekeepers was determined through statistical power analysis to ensure high analysis. This sampling method allowed us to divide the region into strata (S), namely: S1: Tangier-Tetouan-Al Hoceima (n=278), S2: Oriental region (n=64), S3: Rabat-Sale-kenitra (n=33), S4: Fes Meknes (n=25), S5: Casablanca-Settat (n=16), S6: Beni Mellal-Khenifra (n=9), S7: Daraa-Tafilelt (n=13), S8: Marrakech-Safi (n=8), S9: Souss-Massa (n=117), S10: Guelmim-Oued Noun (n=36). In total, 599 beekeepers, both men and women, were distributed across different regions of the country (Figure 1).

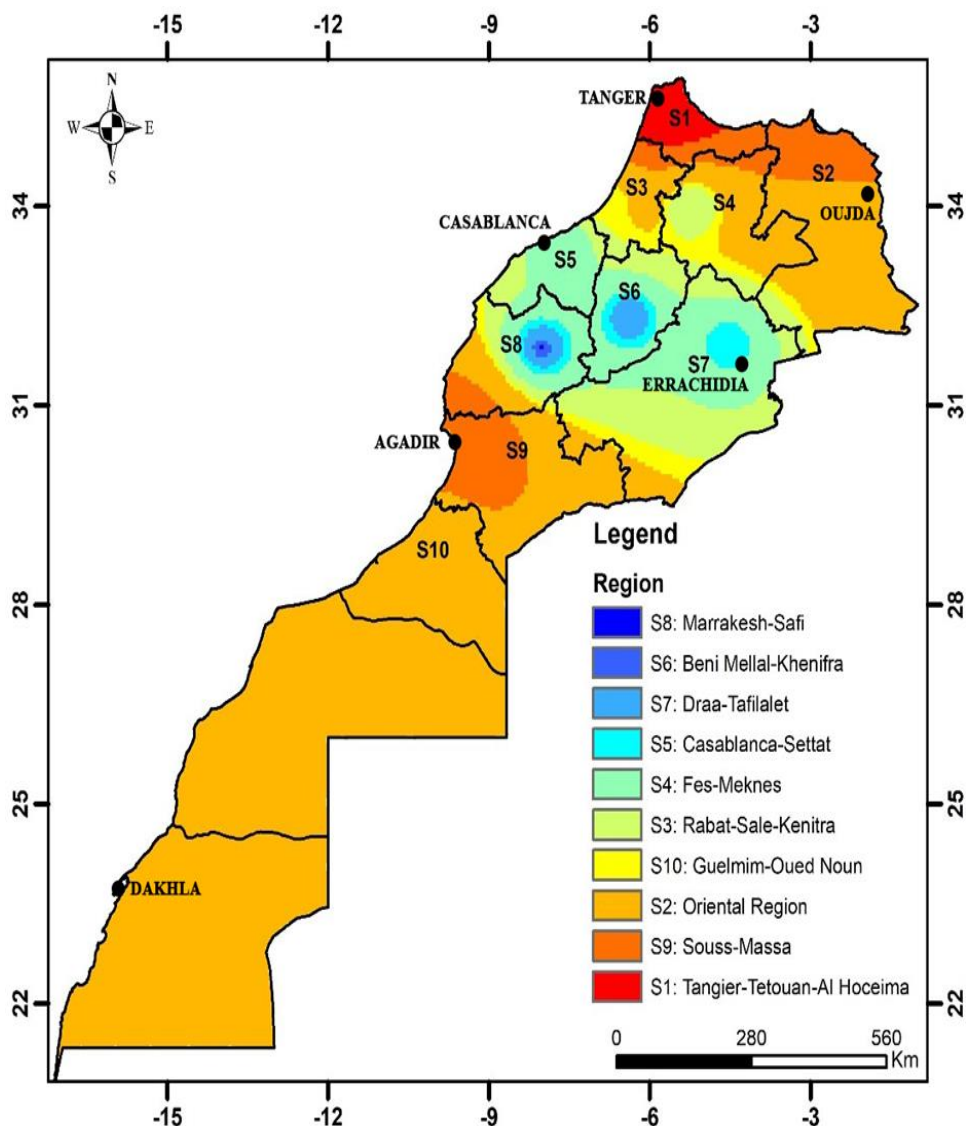


Figure 1. Regional distribution of beekeepers in Morocco

Inclusion and exclusion criteria

The study selection criteria required that participants be active beekeepers currently based in Morocco with at least 1 year of beekeeping. Beekeepers who had at least one hive were included in the study to cover both small- and large-scale operations. The sample consisted of those who volunteered to take part in the research and signed an informed consent. The exclusion criteria were beekeepers who had no colonies during the study or those who did not have previous experience of keeping bees, as well as individuals who refused to participate. Beekeepers who were involved in commercial activities outside the territorial borders of Morocco were also excluded to avoid bias, which would otherwise corrupt the data on the conditions and practices relevant to the Moroccan terrain.

Statistical Analysis

The statistical analysis was performed using SPSS version 25.0. Descriptive statistics were first used to highlight the sociodemographic profile of the 599 beekeepers and their operational characteristics in terms of frequencies and percentages for categorical variables: sex, age, education level, working years, geographic area of exploitation, working area, number and type of hives, products collected, quantity of honey production per year, and renewal strategies, perceived economic, environmental, and social impacts. The relationships between the categorical data and the outcome variables were explored by conducting chi-square tests. A multinomial logistic regression was analyzed to make a literature-based decision on whether educational level significantly predicts hive type (traditional hives, modern hives, or a mix of both). Nagelkerke R^2 was reported to show the variance explained. Product diversification, based on the types of harvested bee products, was explored by another multinomial logistic regression for prediction by sex. We therefore used a generalized ordered logit model—specifically by fitting two separate binary logistic regression models for each of the cumulative thresholds of honey production, as Long and Freese (2014) have. The first model compared beekeepers who produce less than 1 tonne with those who produce 1 tonne or more (Threshold 1). Beekeepers producing more than 5 tonnes (Threshold 2) were compared with those producing up to 5 tonnes. The variance explained (Nagelkerke R^2) was given as reported.

Questionnaire validation metrics

The questionnaire was pilot tested with 30 beekeepers (10/operation scale) and was not included in the main sample. Based on the pilot test results, unclear items were rewritten. For, improving internal consistency. Cronbach's alpha was measured at 0.84 for the questionnaire as a whole, indicating good internal consistency. The filled data missing information; with the structured face-to-face interviews, full information was obtained. The co-linearity between predictor variables (sex, age, education, experience) was evaluated with variance inflation factors (VIF of predictor variables <2.0), which indicated the nonexistence of significant multicollinearity. The age of studies and national agricultural statistics to ensure comparability with these sources. The category variables were determined based on previous Moroccan beekeeping studies and national

agricultural statistics to ensure comparability with the local data. The same was applied to the category variables of experience, hive numbers, and honey production.

Ethical approval

The Moroccan beekeepers involved in this research with 599, and the study adhered to ethical principles for research involving human subjects. The ethical clearance was granted by the Laboratory of Biochemistry, Neuroscience, Natural Resources, and Environment, and individual informed consent was obtained from all participants. Responses to all queries were anonymous and were given at their own volition, to ensure anonymity and because of the nature of the information collected. The study adhered to the principles of the Declaration of Helsinki and was conducted according to the ethical rules of institutions and countries.

RESULTS AND DISCUSSION

Sociodemographic characteristics in the study area

Five hundred and ninety-nine beekeepers participated in the study. As for the sex of the beekeepers, 420 were male, while 179 were female. For age, 116 of the beekeepers were 30 years or younger; 475 were between ages 31 and 50; and 8 were 51 years or older. From the educational perspective, 250 beekeepers had been through primary education, 295 secondary education, and 54 tertiary education. With respect to years of experience, 24 beekeepers had between 1 and 5 years of experience, 47 had between 6 and 10 years, and 528 had more than 10 years of experience (Table 1).

Table 1. Sociodemographic characteristics of beekeepers (N=599)

	Frequency	Percent
Sex	Male	420
	Female	179
Age	≤30 years	116
	31–50 years	475
	≥51 years	8
Educational level	Primary	250
	Secondary	295
	Tertiary	54
Years of experience	1–5 years	24
	6–10 years	47
	More than 10 years	528
Total		= 599

Structure of the operation

Region of exploitation

The data in Table 2 present the distribution of beekeepers by region of exploitation. Of the 599 beekeepers, 33 were located in Rabat-Salé-Kénitra, 8 in Marrakech-Safi, 9 in Béni Mellal-Khénifra, 278 in Tanger-Tétouan-Al Hoceïma, 64 in Oriental, 117 in Souss-Massa, 36 in Guelmim-Oued Noun, 13 in Drâa-Tafilalet, 25 in Fès-Meknès, and 16 in Casablanca-Settat.

Table 2. Regions of exploitation

Region	Frequency	Percent
Rabat-Sale-Kenitra	33	5.5
Marrakech-Safi	8	1.3
Beni Mellal-Khenifra	9	1.5
Tanger-Tetouan-Al Hoceïma	278	46.4
Oriental	64	10.7
Souss-Massa	117	19.5
Guelmim-Oued Noun	36	6.0
Draa-Tafilalet	13	2.2
Fez-Meknes	25	4.2
Casablanca-Settat	16	2.7
Total	599	100

Operating area

Of the 599 beekeepers, 266 (44.4%) operated on less than 1 hectare, 241 (40.2%) operated on between 1 and 5 hectares, and 92 (15.4%) operated on between 6 and 10 hectares (Table 3).

Table 3. Area of operation

	Frequency	Percent
Between 1 and 5 hectares	241	40.2
Between 6 and 10 hectares	92	15.4
Less than 1 hectare	266	44.4
Total	599	100

Number of beehives used

Regarding the number of hives used, more than half of the beekeepers (55.4%, n=332) operated more than 500 hives, 36.4% (n=218) operated between 100 and 500 hives, and 8.2% (n=49) operated between 50 and 100 hives. No beekeepers in the sample operated fewer than 50 hives (Table 4).

Table 4. Number of hives used

	Frequency	Percent
Between 50 and 100	49	8.2
Between 100 and 500	218	36.4
More than 500	332	55.4
Total	599	100

The type of beehives used

Regarding hive type, the majority of beekeepers used modern hives exclusively (79.0%), followed by mixed systems (19.0%) and traditional hives only (2.0%) (Table 5). Educational level showed a strong association with hive type adoption, explaining approximately 31% of the variance (Nagelkerke $R^2=0.307$, $\chi^2=142.101$, $p<0.001$). The most pronounced effect was observed for secondary versus tertiary education in modern hive adoption (OR=32.87, 95% CI: 12.23–88.39), indicating a very strong association. However, caution is warranted in interpreting this specific estimate due to small subgroup sizes (tertiary-educated: $n=54$; traditional hive users: $n=12$) and near-universal adoption (96.3%) among secondary-educated beekeepers. This estimate should be interpreted as indicative of a strong association rather than a precise effect size. No significant difference was observed between primary and tertiary education for modern hive use ($p=0.504$). Regarding traditional hive use, beekeepers with primary education were 82% less likely to use traditional hives than mixed hives compared to those with tertiary education ($\text{Exp}(B)=0.182$, $p=0.017$). At the same time, no significant difference was found between secondary and tertiary education ($p=0.423$).

Table 5. Type of hives used

Type of hives		Comparison	Exp(B)	95% CI	p-value
Traditional Only	12	Secondary vs Tertiary (Modern hives)	32.87	[12.23, 88.39]	<0.001
Modern Only	473	Primary vs Tertiary (Modern hives)	1.24	[0.66, 2.32]	0.504
Mixed System	114	Primary vs Tertiary (Traditional hives)	0.18	[0.05, 0.74]	0.017
Total	599	Secondary vs Tertiary (Traditional hives)	2.00	[0.37, 10.92]	0.423

Production of apicultural products

Products harvested

Regarding bee products harvested, the majority of beekeepers (55.4%) produced honey, pollen, propolis, and wax, followed by those producing honey, pollen, propolis, royal jelly, and wax (21.2%) (Figure 2). Sex was moderately associated with product diversification, explaining approximately 18% of the variance (Nagelkerke $R^2=0.175$, $\chi^2=108.273$, $p<0.001$). The effect sizes varied across product combinations. Male beekeepers were substantially less likely than females to harvest diverse portfolios: 'Honey + Pollen + Propolis' (OR=0.125, 95% CI: 0.025–0.625) and 'Honey + Pollen + Propolis + Royal jelly + Wax' (OR=0.071, 95% CI: 0.011–0.458), indicating that female beekeepers tended to diversify more than their male counterparts. Compared to female beekeepers, male beekeepers were significantly less likely to harvest "Honey + Pollen +

Propolis" (Exp (B)=0.125, $p=0.013$) and "Honey + Pollen + Propolis + Royal jelly + Wax" (Exp(B)=0.071, $p=0.001$), and marginally less likely to harvest "Honey + Wax" (Exp(B)=0.187, $p=0.050$). No significant sex differences were observed for other product combinations (all $p>0.05$).

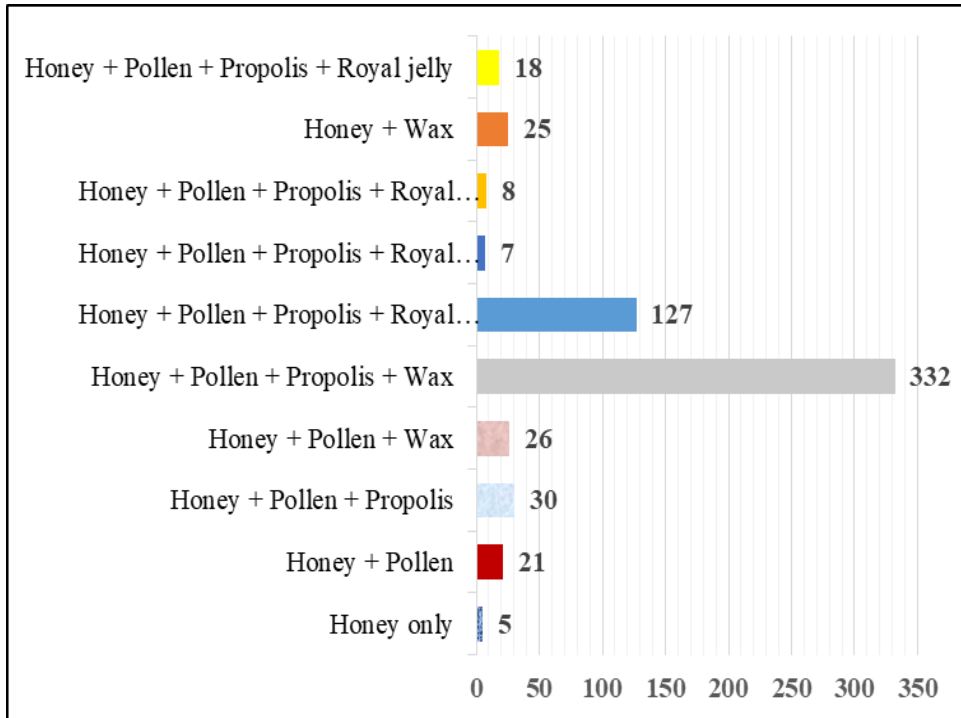


Figure 2. Types of products harvested

The quantity of honey produced

Regarding the annual quantity of honey produced, more than half of the beekeepers (52.1%, $n=312$) produced more than 5 tonnes, 28.0% ($n=168$) produced between 1 and 5 tonnes, and 19.9% ($n=119$) produced less than 1 tonne (Table 6). The analysis was conducted with a generalized ordered logit model and two different binary logistic regression models. The first model (less than 1 tonne vs. 1 tonne or more) was significant ($\chi^2=190.391$, $df=4$, $p<0.001$, Nagelkerke $R^2=0.431$). Male beekeepers had significantly lower odds of producing 1 tonne or more (OR=0.214, 95% CI: 0.131–0.349, $p<0.001$), while educational level showed a strong positive association (OR=12.566, 95% CI: 6.739–23.427, $p<0.001$). Age ($p=0.286$) and years of experience ($p=0.341$) were not significant. The second model (up to 5 tonnes vs. more than 5 tonnes) was significant ($\chi^2=349.648$, $df=4$, $p<0.001$, Nagelkerke $R^2=0.590$). Sex remained a significant predictor (OR=0.113, 95% CI: 0.066–0.193, $p<0.001$), as did educational level (OR=7.189, 95% CI: 4.791–10.789, $p<0.001$). Age was not significant ($p=0.182$). This was the equivalent of unstable estimates of years of experience ($B=20.068$,

SE=3309.148, $p=0.995$), and produced a maximum iterations (I) warning. The results for both models were 84.1% and 84.8%, respectively, of correct classification. Gender is more influential at the higher production threshold (OR=0.113 vs. 0.214), indicating that gender differences may grow at higher levels of production.

Table 6. Generalized ordered logit models for the annual quantity of honey produced

Threshold / Predictor	B	S.E.	Wald	df	p-value	OR	95% CI for OR
Model 1: <1 tonne vs ≥1 tonne							
Sex (Male vs Female)	-1.540	0.250	38.001	1	<0.001	0.214	0.131–0.349
Age	-0.312	0.293	1.138	1	0.286	0.732	0.412–1.300
Educational level¹	2.531	0.318	63.259	1	<0.001	12.566	6.739–23.427
Years of experience	0.232	0.244	0.906	1	0.341	1.261	0.782–2.034
Constant	-0.068	0.856	0.006	1	0.937	0.934	–
<i>Model fit: $\chi^2 = 190.391$, $df = 4$, $p < 0.001$; Nagelkerke $R^2 = 0.431$; correctly classified 84.1%</i>							
Model 2: ≤5 tonnes vs >5 tonnes							
Sex (Male vs Female)	-2.182	0.275	63.029	1	<0.001	0.113	0.066–0.193
Age	0.428	0.320	1.781	1	0.182	1.534	0.819–2.874
Educational level¹	1.973	0.207	90.920	1	<0.001	7.189	4.791–10.789
Years of experience²	20.068	3309.148	0.000	1	0.995	5.19×10 ⁸	–
Constant	-61.149	9927.444	0.000	1	0.995	0.000	–
<i>Model fit: $\chi^2 = 349.648$, $df = 4$, $p < 0.001$; Nagelkerke $R^2 = 0.590$; correctly classified 84.8%</i>							

Colony management and sustainability of beekeeping operations **Renewal strategies**

Regarding renewal strategies used by beekeepers to maintain or increase their colony numbers, the majority (45.6%, $n=273$) employed a combination of swarm capture, colony division, and purchase of colonies. A further 13.7% ($n=82$) used queen rearing, swarm capture, and colony division together (Table 7). Smaller proportions used swarm capture combined with colony division (9.2%, $n=55$); queen rearing combined with colony division and purchase of colonies (7.0%, $n=42$); queen rearing combined with colony division alone (7.0%, $n=42$); colony division alone (5.2%, $n=31$); queen rearing combined with swarm capture, colony division, and purchase of colonies (4.0%, $n=24$); queen rearing combined with swarm capture (2.3%, $n=14$); queen rearing alone (2.2%, $n=13$); colony division combined with purchase of colonies (2.0%, $n=12$); and swarm capture combined with purchase of colonies (1.8%, $n=11$).

Table 7. Renewal strategies used by beekeepers

Renewal strategies	N
Queen rearing	13
Queen rearing + Swarm capture	14
Queen rearing + Swarm capture + Colony division	82
Queen rearing + Swarm capture + Colony division + Purchase of colonies	42
Queen rearing + Colony division	42
Queen rearing + Colony division + Purchase of colonies	24
Swarm capture + Colony division	55
Swarm capture + Colony division + Purchase of colonies	273
Swarm capture + Purchase of colonies	11
Colony division	31
Colony division + Purchase of colonies	12

Impact of renewal strategies

The following results reflect beekeepers' self-reported perceptions of the economic, environmental, and social consequences of their renewal strategies, rather than independently verified objective indicators. A significant level of economic implications is connected with the renewal strategies of apicultural enterprises. Interestingly, a significant percentage of the beekeepers (43 %) had high operational expenditure. At the same time, 18% noted stabilization of their revenues, and 12 % reported a notable increase in revenue. More subtle results were a 9 % increase in income and a decrease in costs, and 8 %, which saw an increase in income and a decrease in costs by measure, but highlighted the complex nature of financial trade-offs. Only 5% of them achieved a cost reduction despite no income adjustment. These results indicate that despite some economic benefits, there are still some concerns about the expense, which is a relevant variable in implementing the renewal strategies.

On the economic front, 41% of respondents associated these measures with a beneficial effect, most often through employment creation, increased cooperation among beekeepers, and greater awareness of apiculture. Some beekeepers (17 %) put more stress on the synergistic impact of job creation and public awareness, but 13 % put more focus on job creation alongside strengthened ties of community. A minor portion (10 %) only focused on public awareness. Environmental impacts were also overstated: 35% cited an overriding environmental benefit, including increased local biodiversity, reduced chemical use, and improved bee health. More specific answers showed that 20 % focused on the improvement of biodiversity, 15 % on the improvement of biodiversity with less chemical use, and 12 % on improved bee health.

On the social level, 41 % of the beekeepers associated strategies of renewal with positive outcomes primarily by way of improved cooperation of beekeepers and awareness of the population of apiculture. About 17 % of beekeepers emphasized the joint impact of awareness-raising and the more comprehensive involvement in the broader community, and 13 % perceived stronger community connections as a primary advantage. There was a small segment (10%) that focused on awareness-raising.

DISCUSSION

The sociodemographic profile of the 599 beekeepers reveals a workforce that is predominantly male, middle-aged, and highly experienced, with a near-equal distribution between primary and secondary education. The strong male predominance is consistent with global and African literature, which consistently reports beekeeping as a male-dominated activity due to cultural norms, limited access to training for women, and patriarchal ownership structures (FAO 2021; Carroll and Kinsella 2013). The female participation (29.9%) in this study was greater than the female participation rates of Ethiopia, 22% (Olana and Zerihun, 2018.), and parts of Tanzania, 11% (Akite *et al.*, 2018), but relatively poor. Unlike other studies, such as (Zee *et al.*, 2014), which have shown that beekeeping is aging quickly across Europe. However, while in sub-Saharan Africa, beekeeping is considered a long-term occupation transmitted intergenerationally with a relatively long tenure of beekeepers in the business, only 88.2% were accounted for in this study; a strong correlation between long tenures and experience in the beekeeping enterprise was established. However, the extremely low proportion of old beekeepers is unusual and possibly due to "survival bias", "early exit from the profession," or under-sampling of the older rural population, as in similar surveys (Tesfaye *et al.*, 2017). There is an even split between the primary education level and secondary education level, indicating that a balanced mix of education levels is attracted to beekeeping, unlike other agricultural industries where tertiary education is comparatively low (Tesfaye *et al.*, 2017). In general, the gender and experience patterns are consistent with the literature, but, as in the previous study, the tremendous dominance of the middle-aged group, 31 to 50, and the lack of seniors is an area of special interest for further research to determine if it is a sampling artifact or representative of the true experience of the demographic.

The results of this study show that a significant difference in educational level separates modern and traditional hive adopters, which is in line with a large body of literature in Africa and Asia. Across Ethiopia, various research studies have consistently found that formal education is associated with higher adoption of new technologies in beekeeping, such as the hive type (Tesfaye *et al.*, 2017; Mulatu *et al.*, 2021.). In Kenya, secondary school-educated beekeepers were three times more likely to use modern hives than non-school-educated beekeepers (Mburu *et al.*, 2017). Likewise, education level was in positive association with the use of top-bar hives and other modern technologies in Tanzania (Mujuni *et al.*, 2012.). The effect size reported in the current study is unusually high when compared to the other past studies, which generally have odds ratios ranging from 2 to 5. This may be due to the Moroccan context and the availability of extension services and beekeeping training courses to a specific group of people, such as those with a secondary education in the northern part of Morocco (Abdelkader 2020).

Results showed that 91.8% of the beekeepers in this sample had managed more than 100 hives of bees, with 55.4% raising more than 500 hives, showing

that the activity of beekeepers in this study was mainly large-scale and commercial, contrary to the international situation where small-scale individuals and backyard keepers dominate (FAO 2021; Porterfield, 2022.). In Florida, the number for commercial beekeeping is set at 100 registered colonies, and in Mediterranean Spain at 58.2% of beekeepers with more than 150 hives of bees (López-i-Gelats *et al.*, 2025; Florida Department of Agriculture and Consumer, 2026.). The Moroccan data figures are thus higher than those of normal commercial activities in North America and Europe. However, according to official Moroccan statistics from FED API MED (2026), it would be around 9.2 hives per beekeeper. The unique apicultural heritage of Morocco, particularly the Inzerki apiary, which is possibly the largest and oldest apicultural entity in the world, comprising more than 3,700 hives in a traditional cooperative management system (Morgan Hekking, J., 2020), can partly account for the large size of the operations documented. An average of 10-15 kg of honey can be harvested from a new, modern-style hive per year, which means that using more than 500 of these hives would yield a production of 5,000-7,500 kg of honey per year, a production level that could have a significant contribution to the total production of honey in Morocco of 7,500 tonnes per year in 2018 (Abdelkader, 2020).

Results show that the percentage of beekeepers reaping more than a single product of honey, pollen, propolis, wax, and even royal jelly, is quite high at 76.6% in Moroccan Beekeeping, a situation rarely seen in most developing countries where the beekeepers' main product is honey. In Ethiopia, for instance, most apiaries focus only on honey production, and wax and pollen production are often low due to a lack of equipment and a market for the export of these products (Gratzer *et al.*, 2021; Tesfaye *et al.*, 2017). In Kenya, on the other hand, few beekeepers export either propolis or royal jelly (<20 percent) because they are still not able to process them due to poor technical knowledge and equipment (Mburu *et al.*, 2017). This increases the diversity rate in Morocco compared to the other countries surveyed, which could be attributed to the majority of operations being large-sized commercial activities, and the majority of the population using modern frame hives. Very low harvest rates for bee bread (1.2%) and bee venom (1.3%) suggest that these minor products are still at very early stages of adoption, possibly due to limited demand in the market, the availability and use of specialized equipment to harvest these products, and the safety issues associated with the handling of bee venom (Carroll and Kinsella 2013). Economically, diversification is an effective risk management and income stabilisation strategy, highlighting that beekeepers are less affected by high honey prices or low production from drought or disease (Simenel *et al.*, 2015). The argan forest areas of Morocco have also been reported as particularly profitable, with diversification carried out into propolis and royal jelly, which, per kg, are priced up to 10 times higher than honey (Adam 2019). But the lack of any beekeepers keeping only pollen, only wax, and only propolis indicates that these activities always happen as an accompaniment to the production of honey, not as a separate business.

Generalized ordered logit models established the same significant variables and explained a significant amount of variance for both the thresholds (43.1% for the 1st and 59.0% for the 2nd). A significant difference in the risk of achieving higher production levels was found between males and females at both thresholds – there was a stronger difference at high production levels (OR=0.113 for >5 tonnes in production and OR=0.214 for high production levels of ≥ 1 tonne), which is indicative of increased gender disparity as production increases, and may be due to compounded inequalities in access to capital and markets (Carroll and Kinsella 2013). Reports from the education levels yielded significant results for both cut-offs, indicating that the probability of producing ≥ 1 tonne and >5 tonnes increased by 12.6 and 7.2 times, respectively, per education level increase, which is consistent with many other studies conducted in Tanzania and Kenya (Kuboja *et al.*, 2021; Mburu *et al.*, 2017). This greater impact at a lower threshold indicates the importance of formal education, especially for moving from subsistence to commercial production. The age was not significant, mainly due to the very narrow range of ages of the samples - the age between 31 and 50 years accounted for 79.3% of the sample. (Abdelkader 2020). In the second model, experience was unstable due to quasi-complete separation, making it less interpretable. Because of its importance for productivity (López-i-Gelats *et al.*, 2025; Zee *et al.*, 2014), this relationship could not be reliably estimated with the current sample for the highest production. Because of the violation of the proportional odds assumption ($p < 0.001$), a generalized approach was warranted, and this leads to the conclusion that predictor effects are different across different production levels (Adam 2019).

Multinomial logistic regression revealed that beekeepers' strategies for renewing their colonies significantly differed by operating area ($\chi^2=727.810$, $p < 0.001$), accounting for 72.2% of the variance (Nagelkerke $R^2=0.722$). However, model stability warnings (Hessian matrix singularities and wide confidence intervals) suggest caution in interpreting individual parameter estimates, likely due to the limited number of farm-size groups relative to the 11 strategy categories. However, this does not preclude the overall association that may be inferred from the literature that farm size influences adoption of new technologies in apiculture (Feder *et al.*, 1985). Some smaller-scale honey producers in Ethiopia and Kenya are constrained by beekeeping capital and therefore do not purchase colonies, instead relying on swarm capture, while larger ones practice the process of queen rearing (Gratzer *et al.*, 2021); Mburu *et al.*, 2017). 45.6% of Moroccan beekeepers practiced diversified renewal strategies (swarm capture, colony division, and purchase of colonies), indicating a risk-management approach to colony replacement (Bradbeer, 2009).

The economic results are complex: 43% of beekeepers report high operating expenses, and only 12% indicate significant gains in profits, yet renewal activities have considerable positive external benefits. It is important to emphasize that our data capture beekeepers' subjective perceptions rather than objectively measured sustainability outcomes. This is in accordance with findings

that high costs for colony replacement and for dealing with pests such as Varroa mites are common in beekeeping, and annual control measures for Varroa mites can reach up to \$20 per colony (Altschuler *et al.*, 2026). This lends credit to social benefits, not limited to better social coherence and community cooperation, as seen in the Apiflordev project in Guinea, which benefited local entrepreneurs and strengthened social bonds (Tchoumboue *et al.*, 2001). The positive environmental impacts claimed by 35% of the beekeepers are aligned with the research evidence of the positive effects that sustainable beekeeping practices have on pollination services, conservation of habitat, and pesticide dependence among beekeepers. The large percentage at high costs (43%) and stabilized revenues (18%) show the economic fragility of the sector and the importance of policy measures like subsidies, technical training, and market development to achieve long-term sustainability (Bertoni *et al.*, 2025).

Study Limitations

The study has a limitation related to its non-representative sample. Institutional and cooperative registration lists led to the exclusion of all beekeepers with fewer than 50 hives, and over half of our respondents (55.4%) reported keeping >500 colonies. Deliberate, but unfortunately, the vast majority of Moroccan beekeepers (small-scale, part-time operators, or traditional operators, national averages suggest around 9 hives/beekeeper) ended up not being included in this sampling frame. Therefore, our findings are only applicable to the dynamics of commercial/large-scale beekeeping and do not apply to other apicultural dynamics in the country. There is a significant need for future studies to be based on household or community sampling to account for the diversity of beekeeping practices that occur throughout Morocco. In addition, although we claim perceived economic, environmental, and social advantages for renewal activities, these are not linked to objective ecological and/or economic data (such as colony mortality, floral diversity indexes, or economic statements). This means that our results represent respondents' perceptions of the effectiveness of beekeeping for sustainability, and not objectively measurable outcomes.

CONCLUSIONS

The results of this study strongly confirm that there is a relationship between these factors and productivity, technology adoption, and product diversification among commercial beekeepers in Morocco, with the most important factors being 'sex', 'educational level', and 'years of experience'. The commercial beekeeping sector shows a strong concentration of experienced, middle-aged operators, as well as amongst the older age groups, male gender, and operators in modern hives having more than 500 colonies. From this, we can see that the sustainability outcomes that beekeepers report, such as an improvement in biodiversity or in chemical use and/or social cooperation, are not ecological or economic indicators per se but rather a self-assessment by the beekeeper. The expensive operation reported by 43% of respondents reflects the economic

fragility of the sector, with positive benefits perceived by the sector in terms of social and environmental, which could only be objectively validated through longitudinal ecological studies. The high association of secondary educational level with modern hive adoption implies the importance of formal education in the spread of technology. Likewise, the wide gender disparity in honey production which becomes more pronounced at higher production levels also highlights a need for targeted interventions for women, focusing on access to resources, training, and markets. The instability of the experience estimate at higher production levels underscores the need for larger-scale studies to confirm the role of experience in commercial-scale beekeeping. The non-representation of the small-scale and traditional beekeepers in the sampling frame degrades the generalizability of these data about the Moroccan apicultural sector, which is mainly made up of subsistence actors. Household-based sampling should be used in future studies, as should the inclusion of objective ecological indicators such as colony mortality rate, diversity indices of flora, etc., and also the inclusion of economic analysis to confirm perceived sustainability outcomes. The challenges in the recommendations for the policy are the improvement of the extension program given to the semi-literate and female beekeepers, the subsidy program given to the semi-literate and female beekeepers, subsidies to modernize the equipment, and monitoring mechanisms to establish productivity and environmental effects. This study's findings provide valuable information on aspects of the commercial beekeeping industry but are not meant to provide conclusive evidence of ecological or economic results; instead, they are perceptions of sustainability.

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CONFLICT OF INTEREST

We confirm that there are no cases of conflicting interests related to any commercial entity concerning the content presented in this paper.

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