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Investigation of factors affecting the performance of beekeeping farms in Fereydounshahr County

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ABSTRACT

Beekeeping plays a critical role in ecosystem sustainability by enhancing biodiversity through pollination. However, beekeeping farms face many pressures that affect their performance. This study identified the key determinants of beekeeping farm performance. Data were collected in 2022 from 140 beekeepers selected through stratified sampling among the beekeepers of Fereydunshahr county (N=210) in Iran. Multiple linear regression was used to identify the determinants of farm performance. Results show that higher income ($\beta = 0.836$) and colony numbers ($\beta = 0.358$) enhance productivity. In contrast, land slope ($\beta = -0.102$) and marital status ($\beta = -0.206$) limit operational capacity. The model explains approximately 71% of the variance in farm performance, highlighting key areas for policy intervention. Prioritizing these factors in interventions can strengthen beekeeping sustainability, benefiting both rural livelihoods and ecosystem health. These findings offer solutions to address global beekeeping challenges, advancing sustainability goals amid ecological and market uncertainties.

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Introduction

Managed honey bees (*Apis mellifera*) are indispensable for pollination and the production of health-promoting bioactive products (Pérez-Marcos et al., 2023; Pignagnoli et al., 2023). Their nutritional and bioactive constituents, recognized since antiquity, underpin their use as functional foods and therapeutic agents for various diseases (Sonmez Oskay et al., 2023). Beekeeping is an agricultural practice that involves managing bees to produce honey, pollen, propolis, wax, royal jelly, and bee venom for personal consumption and industrial use (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Jorjani et al., 2023). In addition to the many advantages of beekeeping to society, it promotes sustainable development in rural areas and contributes to the development of global sustainability. This is achieved through the production of goods and services that frequently raise families' per capita income, and provide significant direct and indirect employment opportunities (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Velardi et al., 2021). Moreover, beekeeping offers social benefits by ensuring food security, enhancing the quality of life in rural areas, promoting social cohesion, empowering women, and reducing rural-urban migration. Unlike other forms of livestock, bees can move freely and exploit available resources without depending on beekeepers. They also reproduce faster than other livestock. While the land is typically used for primary agricultural activities, beekeeping does not require land directly but instead relies on other resources or capital, such as natural resources, human resources, material or physical resources, social resources, and economic resources (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Schouten, 2020). However, the production and economic outcomes of the beekeeping industry are influenced by various factors (Levesque et al., 2023; Lupi et al., 2020).

Based on the statistics released by FAO, global honey production in 2023 exceeded 2.13 million tons. Iran secured the fourth position in the world by producing 80,388 tons of honey products, following China with 472,221 tons, Turkey with 114,886 tons, and Ethiopia with 84,591 tons (Food and Agriculture Organization of the United Nations, 2025a). The estimated global market value of honey in 2023 is about nine billion USD, with Iran's honey production valued at about 417 million USD this year (Food and Agriculture Organization of the United Nations, 2025b). These statistics indicate that Iran has immense potential to produce and supply bee products in the international markets. This study was conducted in Fereydunshahr county located in Isfahan province (Fig. **1**). Isfahan province has strong potential for beekeeping. According to statistics published by the Iranian Ministry of Agriculture in 2022, this province produced almost 5.54% of the country's total honey, ranking sixth in terms of production. Additionally, Isfahan province is the second-highest producer of honeybee by-products in the country, accounting for about 11.32% of the total production (Iranian Ministry of Agriculture-Jahad, 2023). Fereydunshahr boasts high plant diversity, thanks to its abundant pastures and cold climate. With over 68% of its total area made up of pastures and covering more than 153 thousand hectares, it holds nearly 16% of all pastures in the province. Despite being only 2% of the entire province's area, Fereydunshahr has 255 beekeeping farms and produced over 180 tons of honey in 2022, which is nearly 2.37% of the total honey produced in Isfahan province. These statistics indicate the immense potential of this region in the beekeeping industry. However, the beekeeping industry is currently facing several challenges and limitations. The significant differences in honeybee products production between various beekeeping farms in the county, as well as the noticeable performance gaps between Fereydunshahr farms and those from other regions in Iran and worldwide, indicate that beekeeping in this county is affected by these challenges and limitations. Consequently, it seems the beekeeping sector does not appear to be operating at its peak right now and needs to improve its performance.

Understanding the factors affecting beekeeping performance is essential for formulating better development plans. Understanding the most effective factors and the direction of their impact enables better development planning. Thus, policymakers and planners in the field of beekeeping need to identify and analyze the factors affecting the performance of beekeeping farms. Since Fereydunshahr is a mountainous region, 74% of the land cannot be used for farming. Therefore, the lack of suitable agricultural land is one of the region's greatest challenges. Other constraints include the small and rough nature of the available agricultural lands, limited access to farm mechanization, limited capital for developing agricultural businesses, prolonged frosts, short growing seasons, and spring frost damage to plants, and periodic droughts. Additionally, overgrazing has led to the destruction of pastures and reduced their carrying capacity. The welfare needs of villagers and small-scale farmers in mountainous areas require alternative livelihood opportunities. Beekeeping is easier to adapt to the limitations of production, such as the lack of credit resources, lack of land, and other inputs necessary for production. At the same time, it generates products with strong commercial and economic potential, which makes it a competitive option for conventional farming enterprises (Ahmad et al., 2017).

Hence, beekeeping is a valuable industry that supports social, economic, and regional development. However, the county's beekeeping farms are not operating at their optimal level, limiting employment, worker welfare, and sustainable resource use. Identifying and addressing the factors that influence farm performance could create alternative income sources for residents, promote sustainable pasture use, and strengthen the beekeeping value chain (Ahmad et al., 2017; Etxegarai-Legarreta & Sanchez-Famoso, 2022). Therefore, the purpose of this study is to determine and examine the factors influencing the performance of beekeeping farms in Fereydunshahr county.

Literature Review

Beekeeping farm performance is shaped by a complex interplay of technical, economic, social, and environmental factors. This review synthesizes findings from global studies, organized around four thematic pillars. Technical factors are pivotal in determining productivity. Al-Ghamdi et al. (2017) in Saudi Arabia, Saini et al. (2021) in India, and Tadesse et al. (2021) in Ethiopia confirmed that larger apiaries enhance technical efficiency. However, Rutschmann et al. (2023) in Germany revealed challenges in forest-dominated landscapes, where pollen scarcity and longer foraging distances reduced colony productivity despite forests serving as supplementary nectar sources. Sari et al. (2020) emphasized multi-criteria suitability analysis (incorporating land slope, altitude, and proximity to water) to optimize apiary placement. In Iraq, Al Tameemi et al. (2024) demonstrated that canola sowing maximized flowering duration and nectar production, though high temperatures reduced sugar concentration, highlighting climate's dual role as both enabler and constraint. Environmental and climatic variables also drive farm performance. Baez-Gonzalez et al. (2024) in Mexico identified that optimum temperatures are critical for honeybee activity in arid shrublands, while Dingtoumda et al. (2024) in Burkina Faso linked pesticide use near hives to colony collapse, stressing the need for farmer training. In Taiwan, Kafle and Chinkangsadarn (2022) noted climate change and invasive pests as major threats, prompting government-researcher collaborations to bolster colony resilience. Economic factors, including costs, profitability, and innovation, further shape outcomes. Čavlin et al. (2023) in Serbia found that competitive environments and innovation in product design significantly boosted business performance, while Tummeleht et al. (2022) in Estonia linked colony losses to apiary size and mite infestations. Varalan and Çevrimli (2024) in Turkey identified market instability and climate risks as barriers to sustainability, echoing Feketéné Ferenczi et al. (2024a) in Hungary, who highlighted rising costs and declining incomes as drivers of income diversification among beekeepers. Social and institutional dynamics are equally critical. Hosseini et al. (2024) stressed access to inputs and resources as vital for effective farm management. Kaňovská (2024) in Czechia revealed reluctance toward smart monitoring systems due to cost and tradition, underscoring the digital divide in beekeeping innovation. Earlier studies reinforce these themes. Elzaki and Tian (2020) in Sudan, and Underwood et al. (2019) in the U.S. emphasized apiary scale and pest management as universal challenges, while Zacepins et al. (2015) linked transportation access to profitability. Sperandio et al. (2019) and Wakjira et al. (2021) highlighted labor availability and pasture size as regional determinants of success.

Collectively, these studies advocate for integrated strategies: policy reforms to mitigate climate and market risks, technological adoption tailored to local contexts, ecological stewardship to enhance floral diversity, and socio-economic support to empower marginalized groups. For example, Rutschmann et al. (2023) recommended diversifying forest stands with pollinator-friendly species, while Setiadi et al. (2024) demonstrated youth engagement as a catalyst for rural development. Karakaya et al. (2023) emphasized organizational and sustainable practices to leverage Turkey's ecological richness, and Dingtoumda et al. (2024) urged pesticide education to protect Burkina Faso's traditional beekeeping heritage. However, gaps persist. Kaňovská (2024) noted the need for affordable smart technologies, while Feketéné Ferenczi et al. (2024b) called for policies addressing hobbyist beekeepers' non-economic motivations. Most importantly, previous studies have measured performance based on single-product production (typically honey alone), neglecting the full range of hive products. In contrast, the present study considers the production amount and selling price of all honeybee products to provide a composite index for a more realistic evaluation of beekeeping farm performance. Based on the literature review and after screening the variables related to farm performance, the research team selected and examined the variables presented in Table 2 (in the Results section).

Materials and Methods

Description of the study area

This study was carried out in Fereydunshahr, a mountainous county located in the westernmost region of Isfahan province, which is the highest-altitude county in Iran (**Fig. 1**), with an altitude of 2590 meters above mean sea level. Owing to its location on the Zagros mountain range, this region is characterized by a unique ecosystem. Fereydunshahr has a cold, humid, mountainous climate with long winters, cool summers, and an annual average temperature of 11.07°C. Average annual precipitation is 586.25 mm, with most occurring as snowfall during the cold period. Fereydunshahr covers an area of 2235 square kilometers and is located at Latitude 32.9406° N and Longitude 50.1260° E. This county comprises 85 villages and five settlements, namely Barf Anbar, Cheshmelengan, Ashayeri Qale Sorkh, Pishkouh Mogoui, and Poshtkouh Mogoui. According to the 2015 census, the county has a population of 35,600 people in the county, with over 80% of the population engaged in agriculture-related activities. The primary agricultural activities in Fereydunshahr include the cultivation of crops such as wheat, barley, and potatoes, horticulture, pasture animal husbandry, cultivation of medicinal plants, and beekeeping.

Data collection

This study focused on beekeeping farms in Fereydunshahr County during 2022, with all registered beekeepers (*N=210*) comprising the study population. Of the 145 registered beekeepers approached, 140 completed (*n=140*) the full interview (response rate = 96.6%), yielding a representative sample. According to the Krejcie and Morgan table, the minimum required sample size for a population of 210 is 136. To account for heterogeneity in operational scales, stratified sampling was implemented (Table 1), dividing the population into subgroups based on the number of colonies (apiary size). This approach, validated by Mweshi and Sakyi (2020) for diverse populations, ensures proportional representation of distinct operational characteristics, thereby reducing sampling bias and enhancing data accuracy across varying economic and production scales.

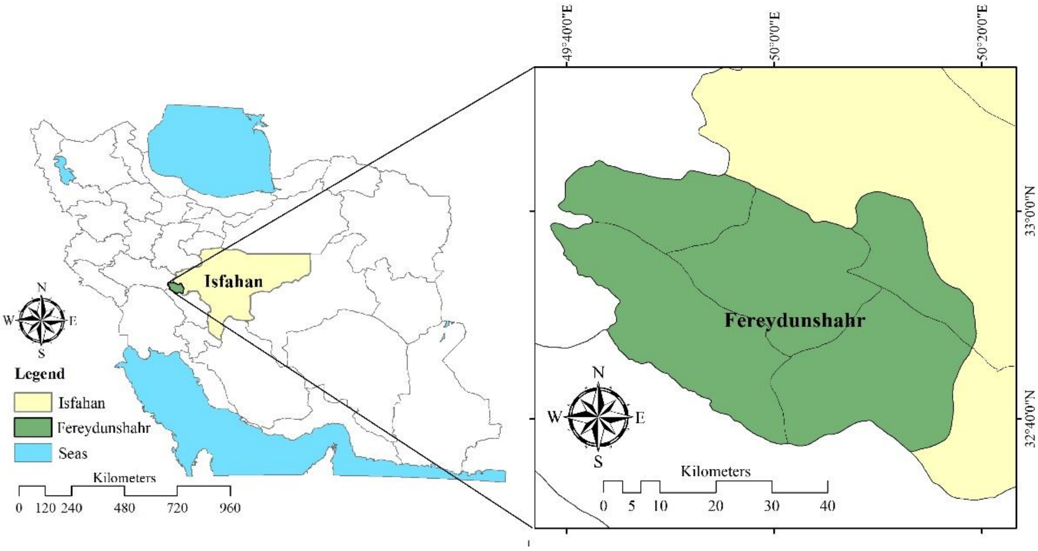

Fig. 1. Study area (Fereydunshar county in Isfahan province, Iran)

Table 1. Occupational size and sample size determined for each level

Occupational size	Stratum size	Sample size
Unprofessional (1-75 colonies)	63	42
Semi-professional (76-150 colonies)	84	56
Professional (more than 150 colonies)	63	42
Total	210	140

Primary data were gathered through structured interviews (face-to-face and telephone) using a three-part researcher-made questionnaire:

a) Individual Characteristics of Beekeepers: The first section focused on personal attributes of the beekeepers, capturing variables such as age, experience, and other demographic details presented in Table 2. These characteristics were measured using ratio scales and open-ended questions, for example: “How many years have you been involved in beekeeping?”

b) Performance of Beekeeping Farms: The second section examined variables related to the operational performance of the farms, including metrics like honey production and other indicators detailed in Table 3. Similar to the first section, these variables were assessed using ratio scales and open-ended queries, such as: “What was the total honey yield from your farm during the last breeding cycle?”

c) Factors Influencing Farm Performance: The third section explored factors impacting the productivity and success of beekeeping goals, incorporating non-characteristic variables listed in Table 2. Most of these factors were quantified using ratio scales and open-ended questions, while others were evaluated using a 5-point Likert scale (1=Very Low, 2=Low, 3=Moderate, 4=High, 5=Very High). For instance, respondents were asked questions like: “How much access do you have to proper transportation infrastructure?”

Trained interviewers administered the survey during spring 2022, recording responses and clarifying Likert scale interpretations as needed. To ensure measurement quality, content validity was assessed by a panel of five experts (Department of Agricultural Management and Development, University of Tehran), and face validity was confirmed through a pilot test with 10 beekeepers. Internal consistency of the overall questionnaire was assessed using Cronbach's alpha (0.780), indicating acceptable reliability. The Likert-scale items were each measured using a single question; therefore, Cronbach's alpha was calculated for the entire questionnaire rather than for individual constructs, as alpha is not meaningful for single-item measures. For objective single-item variables (e.g., age, income), face and content validity were deemed sufficient. Data reflected the most recent breeding season, with each farm representing a single beekeeper's operations.

At the beginning of each interview, the objectives of the research were clearly outlined to the participants. We emphasized that all information provided would remain strictly confidential and would be published only in the form of aggregated scientific results, ensuring no personally identifiable information would be disclosed. Participation was voluntary, and based on this understanding, verbal informed consent was secured from all interviewees before proceeding with the questions

Data processing and analysis

The present study utilized both descriptive and inferential statistics to investigate the factors affecting the performance of beekeeping farms. The descriptive statistics include mean, standard deviation, and minimum and maximum values.

Multiple linear regression was employed, which is an appropriate method for estimating the effects of explanatory variables on beekeeping farm performance. The performance of the beekeeping farm was the dependent variable in the analysis, while the independent variables were selected from the research literature review and researchers' observations. Equation 1 shows the regression expression.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon \quad (1)$$

Where Y is the dependent variable. β_0 is the y-intercept. The terms β_1, β_2, and β_n are the slope coefficients of the independent variables, terms X_1, X_2, and X_n are the independent variables, and ε represents the error term.

Prior to estimating the regression model, we assessed the underlying assumptions of multiple linear regression. The Durbin-Watson statistic (d=1.981), which falls within the acceptable range of 1.5 to 2.5, confirmed the independence of residuals. Normality and homoscedasticity were examined through visual inspection of residual plots (standardized residuals vs. standardized predicted values), which showed no obvious deviations from the assumptions. Additionally, multicollinearity was assessed using variance inflation factors (VIF), with all variance inflation factor (VIF) values below 10, indicating no substantial multicollinearity among predictors.

The variables were examined using the enter regression approach, which involves concurrently entering each variable into the equation. This approach ensures that the effect of each variable is estimated while controlling for all others, consistent with the study's exploratory objective of identifying key determinants of beekeeping farm performance. The statistical functions and data analysis were performed with SPSS v.26.

Calculate the dependent variable

This study created a composite index utilizing many observable factors, each of which was quantified with an indicator in the questionnaire, because the performance of the beekeeping farm, as the dependent variable, is difficult to quantify with a single indicator. The weighted average method was employed to calculate a single value for the performance of beekeeping farms. In this method, each variable is assigned a weight (coefficient) as its importance in calculating the average. For this purpose, each variable is multiplied by its coefficient. Then, all the results are summed, and the total results are divided by the sum of the coefficients. Equation 2 shows the weighted average method.

$$\overline{X} = \frac{\sum_{i=1}^{n} (w_i \times x_i)}{\sum_{i=1}^{n} w_i} \quad (2)$$

Where W_i is the weight assigned to each variable, X_i is the value of each variable, and n is the total number of variables (Clark-Carter, 2010).

The variables used to calculate the performance of the beekeeping farm include the production amount of honey, beeswax, propolis, pollen, royal jelly, bee swarm, and queen per colony. To calculate the weight (coefficient) of each bee product, the average selling price of all the products was compared to the average selling price of honey. The coefficient for honey was set to one (1.00), and the coefficients for other products were calculated by dividing their respective average selling prices by the average selling price of honey. These ratios were then used as coefficients for each bee product. Therefore, a composite index representing the performance of the beekeeping farm (used as the dependent variable (Y) in the regression model) was constructed based on the weighted production of all bee products.

Results

The results of the analysis carried out to investigate the factors affecting the performance of beekeeping farms are presented below. A total of 25 variables were examined for this purpose. The data were cleaned, processed, and used for the analysis described in the previous section. The description and summary statistics of the variables used in the analysis are shown in Table 2. The average age of beekeepers was 44 years, with 15 years of average experience. The least experienced beekeeper had two years of experience, while the most experienced had 50 years. The majority of the beekeepers (86%) were married and had an average of four family members. Over half of the beekeepers (52%) pursued beekeeping as a side job alongside their main job. Additionally, 47% of beekeepers had taken beekeeping training courses and were in contact with an average of more than seven beekeeping professionals. The average annual income of beekeepers from this profession was more than 1587 million Rials (6100 USD). Beekeepers spent an average of 3.13 million Rials (12 USD) per colony in different farms. The average number of colonies in each beekeeping farm was about 140, and the beekeepers started their business with an average of 24 colonies. The average distance of beekeeping farms from the road, residential areas, neighboring farms, and water source was approximately 2145 meters, 4766 meters, 2199 meters, and 305 meters, respectively. The average breeding period was nearly nine months. Non-migratory beekeepers had the shortest period (six months), while migrant beekeepers engaged in year-round breeding. The description and summary statistics of other studied variables are presented in Table 2.

Table 3 shows the description and summary statistics of the variables used to produce a composite beekeeping farm’s performance index (dependent variable). The analysis of production quantities and sales prices of honeybee products reveals significant heterogeneity in production quantities across beekeeping farms (Table 3). In contrast, selling prices remain relatively consistent across farms.

A multiple linear regression was used to illustrate the factors influencing the performance of beekeeping farms. The regression model used in this analysis had a good fit and can be utilized for data analysis (Table 4). The results of multiple regression analysis indicated that the following variables had a statistically significant ($p < 0.05$) impact on the performance of beekeeping farms: the annual income of the beekeeper ($\beta = 0.836$), the total number of colonies on the farm ($\beta = 0.358$), the marital status of the beekeeper ($\beta = -0.206$), the distance between the farm and the appropriate water source ($\beta = 0.169$), the total number of colonies at the time of starting the business ($\beta = 0.160$), the average cost per colony ($\beta = 0.146$), and the slope of the land in the farm settlement area ($\beta = -0.102$). Together, these variables may account for 69.4% of the variance in beekeeping farms’ performance. There was no collinearity among the independent variables, which ensures the reliability of the analysis results (

Table **5**).

Table 2. Details of selected variables for investigating factors affecting the performance of beekeeping farms

Independent Variable	Description (Unit)	Variable Type	Min	Max	Mean	SD
Age	Age of the beekeeper (Years)	Continuous	22	75	43.98	11.26
Experience	Experience of the beekeeper (Years)	Continuous	2	50	15.19	10.12
Breed Dur	Duration of the breeding period (Months)	Continuous	6	12	8.71	1.52
Income	Annual Income of the beekeeper (Million Rials)	Continuous	45	9500	1587.71	1705.06
Colony Cost	Average cost per colony (Million Rials)	Continuous	0.70	10	3.13	1.47
Access Farm	Time required to reach the farm (Minutes)	Continuous	5	120	28.18	26.83
Dist Road	Distance between the farm and the road (Meters)	Continuous	5	20000	2145.43	2956.24
Dist ResiArea	Distance between the farm and the residential area (Meters)	Continuous	5	40000	4766.75	6886.65
Dist NeighFarm	Distance to the neighboring farm (Meters)	Continuous	20	20000	2199.79	2808.08
Access Water	Distance between the farm and the appropriate water source (Meters)	Continuous	10	2000	305.07	310.85
Family Size	Total number of beekeeper's family members	Discrete	1	8	3.99	1.36
Labor Num	Total number of laborers on the farm	Discrete	1	3	1.36	0.55
Colony Num	Total number of colonies on the farm	Discrete	10	620	139.91	111.55
Init Invest	Total number of colonies at the time of starting the business	Discrete	2	100	24.06	18.52
Access Expert	Total number of experts available to beekeeper	Discrete	0	100	7.27	12.17
Aware Rule	Beekeeper's awareness of the rules of the beekeeping sector	Ordinal*	1	5	3.32	1.16
Access labor	Beekeeper's access to labor at the right time and quantity	Ordinal*	1	5	3.79	1.31
Access Trans	Beekeeper's access to suitable transportation services	Ordinal*	1	5	3.75	1.03
Security	Security of the farm settlement area	Ordinal*	1	5	3.47	1.32
Slope	Slope of the land in the farm settlement area	Ordinal*	1	5	3.18	1.24
Wind Speed	Wind speed in the farm settlement area	Ordinal*	1	5	3.43	0.87
Edu Level	Education level of the beekeeper	Ordinal*	1	5	3.17	1.16
Marital Stat	1 if the beekeeper is married, 0 otherwise	Nominal	0	1	0.86	0.35
Job Stat	1 if beekeeping is the main job of the beekeeper, 0 otherwise	Nominal	0	1	0.48	0.50
Attend Class	1 if the beekeeper has attended extension classes, 0 otherwise	Nominal	0	1	0.47	0.50

* Ordinal variables were measured by 5-point Likert scale (1=Very Low, 2=Low, 3= Moderate, 4=High, and 5=Very High)

Table 3. Details of variables used to calculate the beekeeping farm's performance (Dependent variable)

Variable	Description (Unit)	Variable Type	Min	Max	Mean	SD
HoneyProd	Amount of honey production (Kg)	Continuous	55	14500	1357.86	1772.12
WaxProd	Amount of beeswax production (Kg)	Continuous	0	500	25.89	63.65
PropoProd	Amount of propolis production (Kg)	Continuous	0	50	0.64	4.36
PollenProd	Amount of pollen production (Kg)	Continuous	0	300	13.95	43.84
RoyalProd	Amount of royal jelly production (Kg)	Continuous	0	10	0.23	1.03
SwarmProd	Total number of bee swarm produced	Continuous	0	200	12.42	30.90
QueenProd	Total number of queens produced	Continuous	0	3000	24.44	254.60
HoneyPrice	Selling price of honey (Million Rials)	Continuous	0.50	3.50	1.18	0.37
WaxPrice	Selling price of beeswax (Million Rials)	Continuous	0.70	1.60	0.99	0.19
PropoPrice	Selling price of propolis (Million Rials)	Continuous	3	7	4.73	1.17
PollenPrice	Selling price of pollen (Million Rials)	Continuous	0.70	2	1.56	0.43
RoyalPrice	Selling price of royal jelly (Million Rials)	Continuous	90	250	127.65	50.69
SwarmPrice	Selling price of bee swarm (Million Rials)	Continuous	3	15	6.74	2.72
QueenPrice	Selling price of queen (Million Rials)	Continuous	0.40	1.50	0.90	0.39

Table 4. Regression model fit (ANOVA)

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.643	24	0.027	13.151	0.000[b]
Residual	0.210	103	0.002	-	-
Total	0.853	127	-	-	-

a. Dependent Variable: Beekeeping farm's performance

b. Predictors: (Constant), Income, Colony Num, Marital Stat, Access Water, Init Invest, Colony Cost, slope

Table 5. Output of multiple regression analysis

Variables	Standardized Coefficients (β)	t	Sig.	Collinearity Statistics	
				Tolerance	VIF
(Constant)	-	5.552	0.000	-	-
Income	0.836	8.528	0.000	0.229	3.368
Colony Num	0.358	3.880	0.000	0.259	2.862
Marital Stat	-0.206	-4.247	0.000	0.938	1.066
Access Water	0.169	3.457	0.001	0.916	1.091
Init Invest	0.160	2.784	0.006	0.665	1.503
Colony Cost	0.146	2.368	0.019	0.582	1.718
Slope	-0.102	-2.089	0.039	0.924	1.082

Dependent Variable: Beekeeping farm's performance, R Squared = 0.710, Adjusted R Squared = 0.694, n = 140

Discussion

This study aimed to determine factors affecting beekeeping farm performance in Fereydunshahr County, Iran. The findings highlight critical issues requiring attention for sector sustainability. The discussion is organized around four thematic pillars: demographic and social, economic, technical, and environmental factors. A key observation was the dominance of middle-aged beekeepers, with limited youth participation. This aligns with Aydın et al. (2020) and Tadesse et al. (2021), who noted similar trends. Youth reluctance likely stems from perceptions of low profitability, technical demands, and urban job appeal. An aging workforce threatens sector decline and pollination services. Over half of beekeepers practiced beekeeping as a side job, suggesting insufficient income from the profession alone. Challenges including seasonal migration and physical demands reduce its full-time appeal. Marital status negatively impacted performance (β = –0.206), as family responsibilities limited time for training, innovation, and hive migration. Married individuals may also avoid risky investments due to financial concerns. Tadesse et al. (2021) similarly found family obligations compete with farm management, though their study did not report a comparable effect size. This discrepancy may reflect cultural differences in family structures or varying levels of spousal support.

Economic factors played a central role. Annual income had the largest effect (β = 0.836), indicating it is the most influential determinant. Beekeepers with higher incomes managed more productive farms, consistent with Ogunjimi et al. (2016), Elzaki and Tian (2020), and Saini et al. (2021). Financial stability enables investment in quality inputs, labor, and innovations. Wealthier beekeepers can afford feed supplements during droughts or migrate hives, ensuring consistent production. Conversely, low-income beekeepers often sell honey hastily at lower prices, reducing profits. Average cost per colony (β = 0.146) also influenced performance, consistent with Tadesse et al. (2021), Alropy et al. (2019), and Aydın et al. (2020). However, many small-scale beekeepers cannot afford these costs, highlighting the need for subsidized inputs or microloans.

Colony numbers were strongly linked to performance. Colony number had a moderate positive effect (β = 0.358), while initial colony numbers (β = 0.160) also contributed positively. This aligns with Alropy et al. (2019), Underwood et al. (2019), Aydın et al. (2020), and Tadesse et al. (2021). Larger farms benefit from economies of scale, reducing per-colony costs. Beekeepers starting with more colonies often had formal training or mentorship, enabling better planning. Hobbyists starting with few colonies lack knowledge or confidence to expand, trapping them in low-productivity cycles. The average farm size of 140 colonies limits growth opportunities for small-scale beekeepers. While allowing modest production, it limits growth opportunities. Small-scale beekeepers often lack resources to adopt modern technologies or improve hive management.

Land slope had a smaller negative effect (β = –0.102), indicating farms on steep slopes struggled due to poor soil quality and reduced plant growth (Sari et al., 2020). In such terrain, planting drought-resistant floral species could sustain bee populations. Notably, the positive coefficient for distance to water sources (access water, β = 0.169) was counterintuitive, as greater distance would typically reduce performance. This unexpected finding requires careful interpretation. One explanation is that professional beekeepers prioritize floral-rich pastures over water proximity, accepting longer travel for superior forage (Rivera-Gomis et al., 2019; Sari et al., 2020). Similar counterintuitive patterns have been observed in livestock systems, where forage quality sometimes outweighs water access. Alternative explanations include confounding factors, unmeasured vegetation density or land use type may covary with distance. Measurement issues cannot be ruled out; distance was self-reported and subject to recall bias. Reverse causality is also possible: higher-performing farms may be located in areas with abundant floral resources that happen to be farther from water. Water scarcity in these areas can stress colonies, requiring manual water transport. Installing artificial drinking cups near apiaries could mitigate this.

Conclusions and policy implications

This study identified seven determinants of beekeeping farm performance in Fereydunshahr County. Annual income (β = 0.836) and colony numbers (β = 0.358) exerted the strongest positive effects, while marital status (β = –0.206) and land slope (β = –0.102) showed negative impacts. Access to water (β = 0.169), initial colony numbers (β = 0.160), and cost per colony (β = 0.146) also contributed positively. The predominance of middle-aged beekeepers and prevalence of beekeeping as a secondary occupation raise sustainability concerns, threatening ecological services and rural livelihoods without targeted interventions. Based on these findings, we propose four evidence-based policy recommendations:

A) Financial support mechanisms including subsidized inputs, microloans, and insurance schemes should be prioritized to strengthen beekeeper income and enable investment in quality equipment and disease management.

B) Incentive programs such as grants, preferential loans, and cooperative models should encourage farm consolidation and expansion to optimal colony numbers, harnessing economies of scale.

C) Certification standards and mandatory training should be introduced to professionalize the sector, addressing the negative effect of marital status by reducing reliance on informal practices and supporting beekeepers with family responsibilities.

D) Technical guidance on apiary site selection (considering land slope and water access) should be provided, with artificial water sources subsidized in water-scarce areas.

Strengthening beekeeper income and optimizing farm scale (not merely expanding technical training) represent the most effective pathways toward sustainable beekeeping in Iran's mountainous regions.

Limitations and directions for future research

Several methodological limitations should be acknowledged. First, the sample was restricted to officially registered beekeepers. This may have excluded informal practitioners, potentially introducing selection bias. Unregistered beekeepers may differ systematically in terms of scale, management practices, and performance, limiting the generalizability of findings. Second, the regression model explained 69.4% of the variance in farm performance, indicating that approximately 30% remains unexplained. Omitted variables (including pasture quality, pesticide exposure, floral diversity, market access, and climate variability) may influence performance and should be examined in future research. Third, the findings are derived from a single county in a mountainous region of Iran and cannot be assumed to apply to other ecological or socioeconomic contexts without further validation. Replication studies across diverse regions are needed to establish generalizability. Fourth, given the cross-sectional nature of the data, the relationships reported are associational and should not be interpreted as causal. For example, it is unclear whether higher income leads to better farm performance or if more productive farms generate higher income. This fundamental limitation precludes causal inference.

Based on these limitations, we propose the following specific directions for future research:

A) Given the unexpected positive coefficient for distance to water sources, further studies should test whether this pattern replicates in other semi-arid mountainous regions, incorporating objective measurements of floral richness and water availability.

B) To address the unexplained variance, future research should examine omitted factors such as pasture quality, pesticide exposure, floral diversity, and market access.

C) Longitudinal data collection would enable causal inference and disentangle the directionality between income and performance.

D) Multi-item scales should be developed for latent constructs to enable more robust validity and reliability testing.

E) Comparative studies across multiple regions (including both mountainous and lowland areas) would clarify the contextual factors that moderate the determinants of beekeeping farm performance.

Author Contributions

The first author conceived and designed the research based on the approved research project, conducted the data analysis, interpreted the findings, drew the conclusions, and prepared the original manuscript. The second author critically reviewed and revised the manuscript. The third author contributed to the English editing and language refinement of the manuscript. All authors read and approved the final version of the manuscript

Data Availability Statement

The data used in this study are available from the corresponding author upon reasonable request

Ethical considerations

The authors conducted this research in accordance with accepted ethical standards in scientific publishing. They avoided data fabrication, data falsification, plagiarism, and any form of research misconduct.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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کلیدواژه‌ها:
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چکیده

زنبورداری از طریق تقویت تنوع زیستی با گرده‌افشانی، نقش مهمی در پایداری اکوسیستم‌ها ایفا می‌کند. با این حال، واحدهای زنبورداری با فشارها و چالش‌های متعددی روبه‌رو هستند که بر عملکرد آن‌ها تأثیر می‌گذارد. هدف این پژوهش، شناسایی مهم‌ترین عوامل تعیین‌کننده عملکرد واحدهای زنبورداری بود. داده‌های مورد نیاز در سال ۲۰۲۲ از ۱۴۰ زنبوردار انتخاب‌شده به روش نمونه‌گیری طبقه‌ای از میان زنبورداران شهرستان فریدون‌شهر در ایران (N=210) گردآوری شد. برای شناسایی عوامل مؤثر بر عملکرد واحدهای زنبورداری از رگرسیون خطی چندگانه استفاده شد. نتایج نشان داد که سطح درآمد بهره‌بردار ($\beta = 0.836$) و تعداد کلنی‌های موجود در مزرعه ($\beta = 0.358$) موجب ارتقای عملکرد واحدهای زنبورداری می‌شوند. در مقابل، شیب زمین ($\beta = -0.102$) و وضعیت تأهل ($\beta = -0.206$) ظرفیت عملیاتی واحدهای زنبورداری را محدود می‌کنند. مدل رگرسیون برازش داده شده حدود ۷۱ درصد از واریانس عملکرد واحدهای زنبورداری را تبیین می‌کند که بیانگر اهمیت این عوامل به‌عنوان حوزه‌های کلیدی مداخله سیاستی است. اولویت‌بخشی به این عوامل در برنامه‌ها و مداخلات توسعه‌ای می‌تواند پایداری فعالیت‌های زنبورداری را تقویت کرده و در نتیجه، بهبود معیشت روستایی و سلامت اکوسیستم‌ها را به همراه داشته باشد. همچنین، یافته‌های این پژوهش راهکارهایی برای مقابله با چالش‌های جهانی زنبورداری ارائه می‌دهد که در شرایط عدم قطعیت‌های اکولوژیکی و بازار، به پیشبرد اهداف پایداری کمک می‌کند.

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