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Effects of the epidemic and obstacle factors on the evolution of livelihood resilience of scenic farm households: a case study of the Wulingyuan scenic area, China

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Introduction: Investigating the dynamic transformation of livelihood strategies of scenic farm households affected by COVID-19 is required for farmers to cope with external influencing factors, optimize their livelihoods, and ensure the sustainable development of scenic farm households' livelihoods.

Methods: This study analyzes 364 farm households in five tourist villages in the Wulingyuan Scenic and Historic Area of Zhangjiajie City and establishes an index system to evaluate farm household livelihood resilience based on buffering, learning, and self-organizing capacities. The obstacle degree model is used to analyze resilience in the normal tourism stage (2019), epidemic disruption stage (2021), and tourism recovery stage (2023). The evolution characteristics of livelihood resilience and obstacle factors of farm households in the scenic area are assessed in the three stages and for different livelihood strategies.

Results: The results show the following. (1) The epidemic significantly affected farmers' livelihood resilience index. It was the highest in the normal tourism stage (0.449), followed by the tourism recovery stage (0.415) and the epidemic disruption stage (0.395). (2) The livelihood resilience indices of the four types of farm households had a clustered distribution and were relatively low. While there is considerable variability in the composition of health and education within farm households, and the livelihood resilience of farmers with different livelihood strategies was imbalanced. (3) The per capita forest land area (B_2), skill training opportunities (L_4), borrowing opportunities (S_3), and migrant work (entrepreneurship) (S_4) significantly affected the livelihood resilience of different types of farm households in different stages.

Discussion: This study enhances the dynamic assessment of farmers' livelihood resilience at the micro level, providing a valuable decision-making reference for addressing external disturbances, such as epidemics, and implementing diversified livelihood strategies.

KEYWORDS

COVID-19, livelihood resilience, evolutionary characterization, barrier factors, Wulingyuan

1 Introduction

The report of the 20th National Congress of the Communist Party of China proposed a strategy for promoting rural revitalization, emphasizing the importance of agriculture, rural areas, and farmers (Zhang and Wang, 2024; Huang, 2024). Farmers are critical for rural revitalization, and improving their livelihood resilience is essential (Gao and Liu, 2024). The outbreak of COVID-19 significantly affected the tourism industry and tourism farmers who depend on tourists (Wang and Wang, 2024). Many scholars believe resilience is required to improve farmers' livelihoods and ensure sustainable development. Examining the livelihood resilience of farmers in scenic spots is necessary to implement rural revitalization strategies and achieve high-quality development of the tourism industry (Li et al., 2024).

Livelihood resilience is an important indicator of the livelihood adaptability of vulnerable groups after external disturbances. High livelihood resilience means families can cope with external shocks and adapt to uncertainties and changing conditions (Marschke and Berkes, 2006; Tanner et al., 2015; Sina et al., 2019). Due to the complexity of livelihood issues and the difficulty of resilience research, different scholars have proposed various concepts of livelihood resilience. The consensus is that livelihood resilience is the ability of rural residents or families to deal with changes and disturbances by self-adjustment, adaptation, and transformation to maintain a healthy livelihood and achieve better development (Zhou et al., 2021; Liu et al., 2023). Livelihood resilience is a critical aspect of sustainability research, but the optimal indicators are unclear. Speranza et al. (2014) established a three-dimensional analysis framework for assessing livelihood resilience based on buffering, self-organization, and learning abilities. Quandts refined the buffer capacity and decomposed capital into financial, human, social, material, and natural capital (Quandt, 2018; Sina et al., 2019; Li et al., 2022). Subsequent research followed these two concepts. Multi-dimensional research has been conducted on analytical frameworks, quantitative evaluations, and the influencing factors of livelihood resilience based on ability and capital. Some scholars have combined the three dimensions with the five livelihood capitals to estimate the buffer capacity. They established comprehensive and representative evaluation and analysis frameworks for farmers' livelihood resilience (Xie et al., 2024; Su et al., 2022; Xiao et al., 2022).

In terms of methods for measuring livelihood resilience, various approaches have been employed, including comprehensive indices (Su et al., 2022; Hu et al., 2021), set pair analysis (Su et al., 2021), the TOPSIS method (Li et al., 2022; Yang et al., 2020), multi-level fuzzy comprehensive evaluation based on a cloud model (Sun et al., 2023), and other statistical techniques. Comprehensive indices are the most commonly used. When assessing influencing factors, common methods include the obstacle degree model (Wu et al., 2021; Ma S. S. et al., 2023; Ma H. Q. et al., 2023), regression analysis (Wang et al., 2023), and the grey structural equation model (He et al., 2020). The obstacle degree model is the most widely applied, while the geographical detector (Meng et al., 2023) has gained popularity in recent years. Livelihood resilience studies are mainly categorized into macro-level and micro-level research. At the macro level, some scholars have used provincial tourism data from 2012 to 2022 to construct resilience evaluation index systems, analyzing the spatial evolution and driving factors of tourism economic resilience across Chinese provinces (Sun and Zhao, 2023). At the micro level, researchers have focused on villages in the ethnic regions of western Sichuan, using the sustainable livelihood framework and a livelihood resilience analysis framework for rural residents to construct a resilience evaluation index system, exploring influencing factors with the OLS parameter estimation method (Zhang et al., 2023). However, while existing research on livelihood resilience primarily focuses on the macro-level dynamic evolution or micro-static assessments through indicator system construction, there has been limited research on the dynamic evolution of livelihood resilience at the micro-scale for farm households.

In recent years, due to the frequency of extreme weather, this research has focused on the characteristics of livelihood resilience of different types of farmers affected by natural disasters, policies, and other influences, such as poverty (Zheng et al., 2023), relocation (Li C. et al., 2023; Li Y. C. et al., 2023; Ran et al., 2023), and urban marginal groups (Zhou and Nie, 2021; He et al., 2017a). The livelihood resilience of rural residents in China exhibits considerable fluctuations but generally shows an upward trend. It is significantly positively correlated with livelihood quality, livelihood enhancement, and livelihood supply, while being significantly negatively correlated with disaster stress (Liu et al., 2022) Household livelihood resilience differs between relocated and non-relocated individuals, with participation in disaster-related resettlement having a notably negative impact on resilience (Liu et al., 2020). The stronger the buffering capacity, self-organization capacity, and learning ability of residents, the more likely they are to adopt non-farm livelihood strategies. However, the study found no correlation between residents' disaster prevention and mitigation capacity and their livelihood strategies, likely due to the generally weak disaster prevention capabilities of rural residents in earthquake-affected areas (Zhou and Nie, 2021). For farmers who have escaped poverty in mountainous regions, multiple livelihood interventions, including industrial, employment, and educational support, have a significant positive impact on resilience. In contrast, factors such as household dependency ratios and the average altitude of the village area negatively affect village subsistence resilience (Wang et al., 2024). The overall livelihood resilience of landless peasants in urban fringe areas of economically developed regions remains low. Key factors influencing this include the management of household assets, as well as differences in the peasants' personal attributes, value orientation, behavioral styles, and cultural identities (Su et al., 2022). Additionally, with the normalization of epidemic prevention and control, there has been growing research on the resilience of farmers' livelihoods during sudden crisis events.

Tourism plays an irreplaceable role in the livelihoods of local farming households, and the COVID-19 pandemic has had a significant impact on their livelihoods. However, few studies have explored the evolutionary divergence of livelihood resilience among farming households in tourist destinations under the influence of the pandemic, as well as the factors that drive these changes. In light of this, we use field survey data for 364 farmers in 5 tourism villages in the Wulingyuan District to investigate the evolution and obstacle factors of farmers' livelihood resilience for different livelihood strategies in the normal tourism stage (before 2019), epidemic disruption stage (2020–2022), and tourism recovery stage (after 2023). The results can be used to improve the development of the regional tourism industry and improve farmers' livelihood resilience.

2 Data and methods

2.1 Study area

The Wulingyuan Scenic Area is located in the Wulingyuan District of Zhangjiajie City, Hunan Province, China. It is an iconic tourist attraction in Zhangjiajie City and has a high reputation in China and internationally. It is one of the first scenic spots in China to be included in the World Natural Heritage list and the first Global Geological Park; thus, it has an important position. In addition, the scenic spot was the first national forest park in China and ranked among the first 5A-level tourist attractions in the country. Due to its unique natural landscape and rich natural resources, it has excellent conditions for tourism development. The tourism industry is a key industry in the Wuling Mountain area. It is a central location for rural revitalization, resulting in excellent employment opportunities and economic benefits to residents. In 2019, 26.35 million tourists visited the Wulingyuan District, reaching 37.4 billion yuan. Despite challenges related to the COVID epidemic, 21.28 million tourists visited the Wulingyuan District in 2021. The tourism revenue was 22.5 billion yuan. In 2023, the number of tourists peaked at 15.917 million tourists per year. The total tourism income was 21.938 billion yuan. These numbers indicate that the Wulingyuan District has made significant progress in promoting tourism.

We conducted a case study in five villages of five ticketing stations in the core scenic area of the Wulingyuan Scenic Area: Longweiba Village at the Zimugang Ticketing Station, Luoguta Village at the Forest Park Ticketing Station, Sinanyu Village at the Tianzishan Ticketing Station, Wujiayu Village at the Logo Ticketing Station, and Yejipu Village at the Yangjiajie Ticketing Station. These villages have a well-developed rural tourism industry. Tourism has a significant impact on farmers' livelihoods. The five villages offer tourism experiences based on different types of farmers' livelihoods. Thus, they are highly representative and are used to analyze farmers' livelihood resilience and the key factors affecting it. The results are critical for tourism development in the Zhangjiajie area and other areas (Figure 1).

2.2 Data source

To ensure the richness of the data and enhance the reliability and accuracy of the study, a variety of data collection methods were employed. First, basic information about the Wulingyuan Scenic Area and the five selected villages was gathered from official websites and policy documents of the local government. Field research was then conducted with two visits to the case villages in January and April 2024. This research included both structured questionnaires and unstructured interviews. The survey primarily focused on changes in farmers' livelihood capital, as well as their participation in and attitudes toward ecological and cultural tourism in recent years. It was conducted on a household and family basis, with each survey lasting between 45 and 60 min. The respondents were predominantly the household head or the primary labor force within the household (Liu, et al., 2022). The data collection process involved several steps: initially, in-depth interviews were conducted with key leaders from the scenic area and each village to understand the farmers' basic circumstances. Next, a presentation was made by a member of the village council, followed by a questionnaire survey of farmers involved in tourism. Additionally, a random sample of farm households not directly involved in tourism was surveyed to analyze livelihood differentiation across various household types. Researchers also lived with the villagers to gain insights into eco-cultural tourism from their perspective, observing farmers' daily livelihood activities and their engagement in rural tourism. A total of 378 questionnaires were distributed and all were returned. After removing missing values and outliers for key variables, 364 valid responses were obtained, representing 96.56% of the sample. The number of questionnaires in each village exceeded 70, ensuring the reliability, validity, and representativeness of the data.

2.3 Indicator system

Livelihood resilience is determined by the capacity and assets of the family. Sustainable livelihood analysis (SLA) is a comprehensive approach to assess livelihood sustainability. It has five dimensions:

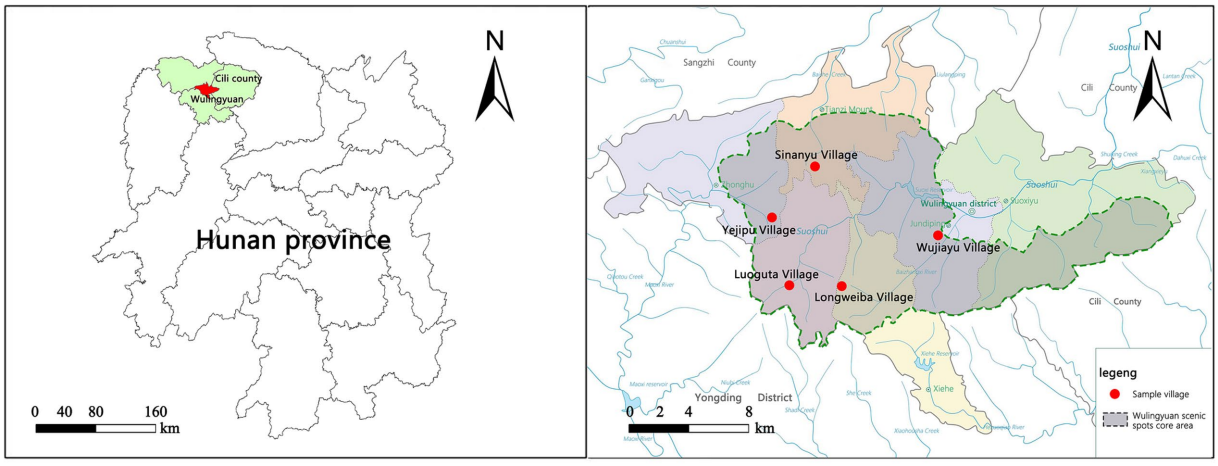

FIGURE 1
Location of the study area.

vulnerability, livelihood capital, livelihood strategy, process transformation, and livelihood output (Thulstrup, 2014). Livelihood resilience is a hot topic in academic research. The livelihood resilience analysis framework developed by Speranza et al. (2014) has been widely used. It includes three dimensions: buffering, self-organization, and learning abilities. However, the livelihood resilience of rural residents is affected not only by internal factors but also by external ones, such as natural, social, political, and environmental factors (Wu et al., 2023). Therefore, we included external factors in the framework to understand their influence on livelihood resilience (Wu J. et al., 2024). We chose 18 indicators of buffering, self-organization, and learning abilities to establish the evaluation index system for farmers' livelihood resilience.

(1) Buffering capacity refers to the ability of a person to withstand external shocks and take advantage of new opportunities to achieve better livelihood outcomes when experiencing changes or disturbances (Wang et al., 2023). Farmers' ability to resist livelihood pressures or disturbances by increasing resource endowments includes five types of livelihood capital (Matter et al., 2021): natural capital (Liu et al., 2020), human capital (Su et al., 2022), social capital (Zhao et al., 2023), physical capital (Zhao et al., 2023), and financial capital (Sun et al., 2023).
(2) Self-organization ability is the ability of a group, such as an institutional system, social network, or village organization, to create order through interactions (Zhao and Ren, 2022). The stronger the self-organization ability, the stronger the livelihood resilience of farmers. Self-organizing capabilities include organizational empowerment and participation in social networks for social affairs management and transportation convenience (Liu et al., 2023), borrowing opportunities, and migrant work (entrepreneurial) (Meng et al., 2023) to reflect social networks (Sun et al., 2023).
(3) Learning ability refers to the ability of a person to acquire knowledge and skills and apply past experiences and knowledge to guide current actions (Xie et al., 2024; Wang et al., 2023). It depends on the individual and the interactions between them and the broader socio-economic group. The stronger the learning ability, the stronger the livelihood resilience of farmers. The ability to acquire information and the closeness of contact with organizations (Sun and Zhao, 2022) reflect the ability to apply experience. The level of education (Zhao et al., 2023) and skill training opportunities (Liu et al., 2020) reflect the ability to acquire knowledge and skills.

2.4 Research methods

2.4.1 Participatory rural assessment (PRA)

Participatory rural appraisal (PRA) is an efficient field survey method to collect information on village resources, current development status, and the desires and needs of individuals or groups of farmers through direct participation and interaction. We designed a questionnaire and semi-structured interview outline based on the proposed evaluation index system. Field research and in-depth interviews were used to determine living conditions, development history, industrial structure change, and population composition of tourism villages (Wu J. L. et al., 2024; Fan et al., 2022). The questions focused on livelihood resilience, family situation, buffering capacity, and self-organizing and learning abilities. A grid system and random selection were used to determine which households were visited.

2.4.2 Entropy weight method

In terms of measuring the comprehensive indicator system, common methods include the entropy weight method, principal component analysis, and factor analysis, among others. Typically, there are two approaches for assigning weights to indicators: objective and subjective assignment (Fan et al., 2022). The entropy weight method has the advantage of overcoming the information loss that can occur with principal component analysis and factor analysis due to dimensionality reduction. It also avoids the potential subjectivity and arbitrariness associated with subjective assignment methods. Therefore, in this study, the entropy weight method was used to determine the weights of the indicators representing the livelihood resilience of farmers in the scenic area (Equations 1–9). The formula is as follows:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{1}$$

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{2}$$

$$\omega_j = \frac{1 - E_j}{\sum_{j-1}^{m} 1 - E_j} \tag{3}$$

Where P_{ij} represents the weight of the *i-th* sample value under the *j-th* indicator, E_j is the entropy value of the *j-th* indicator, and ω_j denotes the weight of the *j-th* indicator.

2.4.3 Composite index method

In this paper, the livelihood resilience of farm households in scenic areas is composed of three dimensions: buffering capacity, self-organizing capacity, and learning capacity. The livelihood resilience index for these households can be calculated using the composite index method (Bai et al., 2024; Ma S. S. et al., 2023; Ma H. Q. et al., 2023; Chen et al., 2009). The formula is as follows:

$$B_I = W_B \sum_{j=1}^{10} \omega_j Y_{ij} \tag{4}$$

$$S_I = W_S \sum_{j=11}^{14} \omega_j Y_{ij} \tag{5}$$

$$L_I = W_L \sum_{j=15}^{18} \omega_j Y_{ij} \tag{6}$$

$$R_I = B_I + S_I + L_I \quad (7)$$

Where R_I represents the livelihood resilience index of farmers in the landscape, and B_I, S_I, and L_I denote the buffer capacity index, self-organization capacity index, and learning capacity index, respectively. W_B, W_S, and W_L represent the weights of buffer capacity, self-organization capacity, and learning capacity within the three-dimensional framework, respectively. ω_j denotes the weight of the *j-th* indicator layer, and Y_{ij} refers to the standardized value of the *i-th* indicator for the *j-th* research unit.

2.4.4 Reliability tests

Using SPSS 24.0 statistical analysis software, Cronbach's alpha coefficient was employed to test the reliability of the raw data, while the KMO test coefficient and Bartlett's test were used to assess its validity. The Cronbach's alpha coefficient was calculated to be 0.867, which is generally considered to indicate good reliability, as a value greater than 0.700 suggests substantial reliability. Additionally, the KMO test coefficient was 0.836, which exceeds the acceptable threshold of 0.500, and the Bartlett's test yielded a significance value of 0.000, indicating that the validity of the measurement is satisfactory.

2.4.5 Obstacle degree model

Farm household livelihoods are influenced by a combination of buffering capacity, self-organization capacity, and learning capacity. When any of these capacities are deficient or insufficient, they negatively affect the sustainability of farmers' livelihoods, and this impact can be quantitatively assessed using a handicap model. Specifically, a higher barrier index for a given indicator signifies a greater negative impact on the sustainable livelihoods of farm households. We used this model to identify the influencing factors of livelihood resilience (Wang et al., 2023; Wu J. L. et al., 2024). The calculation formula is as follows:

$$P_{ij} = 1 - Y_{ij} \quad (8)$$

$$I_j = P_{ij}\omega_j \sum_{j=1}^{18} P_{ij}\omega_j \times 100\% \quad (9)$$

where P_{ij} is the index deviation degree, which represents the distance between the standardized value and the optimal value of the index. Y_{ij} is the standardized value of the index; ω_j is the weight of the index, which is used to measure the index's contribution to livelihood resilience. I_j is the index obstacle degree (see Table 1).

3 Results

3.1 Classification of farmers' livelihood strategies

The tourism economy in the Wulingyuan District has changed in recent years, altering the livelihood of farmers from agriculture to diverse activities, such as work and tourism. Based on existing research and actual conditions, we categorized farmers into four types: traditional livelihood, balanced income, tourism franchise, and tourism-oriented according to the income source structure (Figure 2, Table 2) (Zhai et al., 2024).

The livelihood strategies and capital of farmers changed after the coronavirus epidemic. There were 145 traditional livelihood farmers in the normal tourism stage (before 2019), and traditional migrant work or farming was the primary income source. There were 24 tourism franchise farmers whose income came solely from tourism and 152 tourism-oriented farmers, whose main income was derived from tourism. They were mostly young and middle-aged people with a high education level, and their income was high. Forty-three households had a balanced income with two or more combinations of agriculture + migrant work, agriculture + tourism, agriculture + migrant work + tourism. The number of tourism franchise and tourism-oriented farmers was significantly lower in the epidemic disruption stage (2020–2022). The number of balanced-income households increased the most, with a growth rate of 62.79%. The growth rate of households with traditional livelihood was 15.86%. The largest reduction occurred in the tourism-oriented household (30.92%), whereas the reduction rate of tourism franchise households was 12.5%. The tourism industry recovered after the epidemic, and the number of tourism franchise and tourism-oriented farmers increased and was higher in the tourism recovery stage (after 2023) than in the epidemic disruption stage. The growth rate of tourism-oriented farmers was 26.67%, and that of the tourism franchise farmers was 9.52%. The number of balanced-income farmers decreased by 41.43%, whereas the number of traditional livelihood farmers remained almost unchanged.

3.2 Livelihood resilience of different types of farmers

3.2.1 Livelihood resilience at different stages

The level of farmers' livelihood resilience index reflects their ability to deal with interference by external shocks and maintain or improve their livelihood through learning and self-organization. The results in Table 3 show that the livelihood resilience index of farmers declined from the normal tourism stage (before 2019) to the epidemic disruption stage (2020–2022), with an average annual decline rate of 5.92%. The livelihood resilience index of farmers increased from the epidemic disruption stage (2020–2022) to the tourism recovery stage (after 2023), with an average annual growth rate of 2.52%. These results indicate that external risks affected farmers' livelihood resilience.

Since the outbreak of COVID-19 at the end of 2019, the government implemented emergency measures and restrictions, severely limiting both domestic and international transportation. This disrupted the mobility of individuals worldwide, triggering a health and economic crisis that posed significant challenges to the tourism industry and had a profound impact on tourism demand. The Zhangjiajie Wulingyuan Scenic Area, which heavily relies on cross-border transportation, experienced a sharp decline in both domestic and international tourist arrivals, negatively affecting lodging, hotels, and public services. COVID-19 has not only threatened public health but also jeopardized people's lives and property. The increased likelihood of illness among friends and family, coupled with rising healthcare costs, has had significant economic consequences. Furthermore, the pandemic has altered people's thinking and behaviors, influencing social distancing practices during travel and

TABLE 1 Evaluation indicator system for the livelihood resilience of farm households.

Dimension	Indicator		Description and definition	Weight
Buffer ability	Natural capital	B_1: Per capita arable land area	Household cultivated land area/household resident population (mu/person): 0 = 1; (0–0.2] = 2; (0.2–0.5] = 3; (0.5–1] = 4; (1, + ∞) = 5	0.0722
		B_2: per capita forest area	Household woodland area/household resident population (mu/person): 0 = 1; (0–1] = 2; (1–2] = 3; (2–5] = 4; (5, + ∞) = 5)	0.0737
	Human capital	B_3: Domestic Workforce	Labor ability * 0.5 + labor quantity * 0.5 (labor ability: children and disabled = 1, children = 2, the elderly = 3, adult assistant = 4, adults = 5). 1–6 for young children, 7–14 for children, 15–18 for adult assistants, and 19–65 for adults): (0–5] = 1; 5–8] = 2; 8–10] = 3; 10–15] = 4; (15, + ∞) = 5)	0.0164
		B_4: Agricultural or other professional skills	Number of agricultural or other professional skills mastered: 0 = 1,1 = 2,2 = 3,3 = 4,[4, + ∞] = 5	0.0449
	Social capital	B_5: Social interaction costs	The sum of telephone expenses, network expenses, and favors (ten thousand):[0, 0.5] = 1, (0.5, 1] = 2, (1, 2] = 3, (2, 4] = 4, (4, + ∞) = 5	0.0363
		B_6: Number of Relatives of Public Officials	The number of relatives and friends working in government and public institutions: (0 = 1,1 = 2,2–3 = 3,4–6 = 4, ≥ 7 = 5)	0.0568
	Material capital	B_7: Housing Capital	The total value of housing (housing quality × housing area, housing quality according to the building structure, and the old and new degree of comprehensive divided into: (dangerous house = 1, low = 2, medium = 3, high = 4, very high = 5):[0,200] = 1; (200–400] = 2; (400–600] = 3; (600–1,000] = 4; (1,000, + ∞) = 5	0.0329
		B_8: Total Value of Durable Goods	The total value of durable goods owned by the family (ten thousand):[0,2] = 1; (2,5] = 2; (5,15] = 3; (15,25] = 4; (25, + ∞) = 5	0.0354
	Financial capital	B_9: per capita income	Total annual household income/population (ten thousand/person):[0,1] = 1; (1,2] = 2; (2,3] = 3; (3,5] = 4; (5, + ∞) = 5	0.0264
		B_{10}: Expenditure per capita	Total annual household expenditure/population (ten thousand/person):[0,0.5] = 1; (0.5, 1] = 2; (1,3] = 3; (3,5] = 4; (5, + ∞) = 5	0.0280
Self-organizational ability	Organizational empowerment	S_1: Participation in the management of social affairs	Participation in social affairs management: yes = 1; no = 0	0.0092
		S_2: Transport accessibility	Unhardened road not open to traffic = 1; hardened impassable = 2; unhardened, but cars or buses can pass = 3; hardened road, cars can pass = 4; hardened road, buses can pass = 5	0.0900
	Social network	S_3: Lending opportunities	The number of available borrowing channels (bank, credit union loans, private lending, classmates, friends, brothers, sisters, pawnshop)	0.0327
		S_4: Migrant work (entrepreneurship)	Migrant work (entrepreneurship); yes = 1; no = 0	0.1598
Learning ability	The conversion process of experience	L_1: Information Capability	Number of channels for families to obtain information (village committees, relatives and friends, newspapers, television, Internet)	0.0197
		L_2: Tightness of linkages with relevant organizations	None = 1; occasionally = 2; sometimes = 3; often = 4; frequent = 5	0.0747
	Ability to acquire knowledge and skills	L_3: Level of education	The highest level of education for family members: illiteracy = 1, primary school =, 2, junior high school = 3, high school = 4, college and above = 5	0.0072
		L_4: Skills training opportunities	Participation in skills training: yes = 1; no = 0	0.1839

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shifting consumer attitudes. The resulting economic crisis led to production stagnation, a decline in employment, and increased job insecurity, all of which adversely affected consumer behavior. These negative impacts on consumer behavior, including reduced labor availability (B_5), lower per capita income (B_9), and higher per capita expenditure (B_{10}), have had a detrimental effect on the livelihoods of farm households, thereby reducing their resilience. However, with the recovery of the national economy and the gradual rebound of the tourism industry following the public health emergency, the influx of tourists and the creation of more employment opportunities led to an increase in the per capita income of farm households (B_9), which in turn contributed to an improvement in their livelihood resilience.

The learning ability exhibited the highest average annual decline rate (7.49%) from the normal tourism stage (before 2019) to the epidemic disruption stage (2020–2022), followed by the self-organization ability (6.60%). The average annual decline rate of the buffer capacity was 4.78%, indicating that farmers spent more time learning skills during the epidemic and were more willing to spend time working. The participants stated that they received subsidies. Therefore, it is difficult to obtain a rapid response to external shocks through learning. The average annual growth rate of the learning ability was the highest (4.93%) from the epidemic disruption stage (2020–2022) to the tourism recovery stage (after 2023), followed by the self-organization ability (3.62%) and the buffer capacity (0.84%). Although the epidemic was over, it adversely affected the tourism industry and the livelihood of farmers, making it difficult for farmers to obtain employment, and their income remained low.

Significant differences are observed in the livelihood resilience index of farmers in different stages. The farmers' abilities affected the livelihood resilience, and different types of farmers exhibited different responses (Figure 3).

3.2.2 Comparison of livelihood resilience of farmers with different livelihood strategies

Following Zhao's classification method (Zhao and Ren, 2022) of the resilience index in ecologically sensitive areas, we categorized the livelihood resilience index into low [0.00–0.35], medium [0.35–0.65], and high[0.65–1.00] levels. As shown in Figure 4, in the normal tourism stage (before 2019), 30.22, 57.14, and 12.64% of the farmers' livelihood resilience indices were low, medium, and high, respectively, with the highest value of 0.852 and the lowest value of 0.084. In the epidemic disruption stage (2020–2022), 41.76, 52.47, and 5.77% of the farmers' livelihood resilience indices were low, medium, and high, respectively, with the highest value of 0.803 and the lowest value of 0.093. In the tourism recovery stage (after 2023), 34.62, 60.44, and 4.95% of farmers' livelihood resilience indices were low, medium, and high, respectively, with the highest value of 0.811 and the lowest value of 0.086. More farmers had high livelihood resilience in the three stages. The ranking of the livelihood resilience for different types of farmers was tourism-oriented > traditional livelihood > tourism franchise > balanced.

Significant differences were observed in the family structure, production, and lifestyle of farmers with different livelihood types, affecting the three abilities (Figure 5). The buffering capacity was strong, and the self-organizing and learning abilities were low, exhibiting an imbalance between the three dimensions, affecting the farmers' livelihood resilience.

Tourism-oriented farmers can be categorized into two types: tourism-led and tourism-franchise farmers. The livelihood resilience indices for tourism-led farmers at different stages were 0.489, 0.422, and 0.445, respectively, making them the highest among the four types of farmers. The livelihood resilience level and the number of farmers followed a pattern of decline and then increase, with fluctuations largely influenced by the pandemic. Buffering capacity was concentrated in medium-high values, self-organizing capacity in low-middle values, and learning capacity in low-high values, indicating significant internal differentiation. Most of these farmers are involved in tourism-related services such as catering and lodging, which allow them to maintain strong connections with the outside world and adjust their livelihood strategies accordingly, ultimately improving their production and living standards. In contrast, the livelihood resilience indices for tourism-franchise farmers were 0.416, 0.369, and 0.366, ranking third among the four types of farmers. The resilience level and number of these farmers showed a continuous decline, strongly impacted by the pandemic. Tourism services such as catering and lodging were severely affected, and these farmers faced substantial financial losses, including significant external debts. Moreover, due to the relatively limited income sources, these farmers struggled to sustain their tourism-related activities.

Non-tourism-oriented farmers include traditional subsistence farmers and balanced income earners. The livelihood resilience indices for traditional subsistence farmers were 0.439, 0.407, and 0.414 at different stages, ranking second among the four types of farmers. The resilience level showed a downward trend followed by a recovery, while the number of farmers increased initially and then plateaued. This group was less affected by the pandemic's fluctuations. Their buffering, self-organizing, and learning capacities were at moderate levels. These farmers, who occasionally work outside the home and rely on the land, benefit from significant natural capital and are less vulnerable to epidemic disruptions. The livelihood resilience indices for balanced income earners were 0.354, 0.335, and 0.353, the lowest among all four types of farmers. Their resilience level showed a decreasing trend followed by an increase, while the number of farmers initially grew and then declined. Buffering and self-organizing capacities were evenly distributed, while learning capacity clustered around low values. This group of farmers relies on a variety of income sources but lacks specialization, which leads to lower overall incomes and resilience. Like traditional subsistence farmers, they are less affected by epidemic-related fluctuations, overall livelihood resilience ranked the worst.

In summary, the livelihood resilience indices across all four types of farmers were relatively low. While there is considerable variability in the composition of health and education within farm households, this diversity affects the three core dimensions of livelihood resilience—buffering, learning, and self-organization—resulting in uneven resilience outcomes across different livelihood strategies.

3.3 Factors influencing the livelihood resilience of different types of farmers

The obstacle degree model was used to calculate the obstacle degree scores of the livelihood resilience indices of different types of farmers. The top 6 obstacle factors are listed in Table 4. A cumulative contribution rate of more than 50% is the dominant obstacle factor

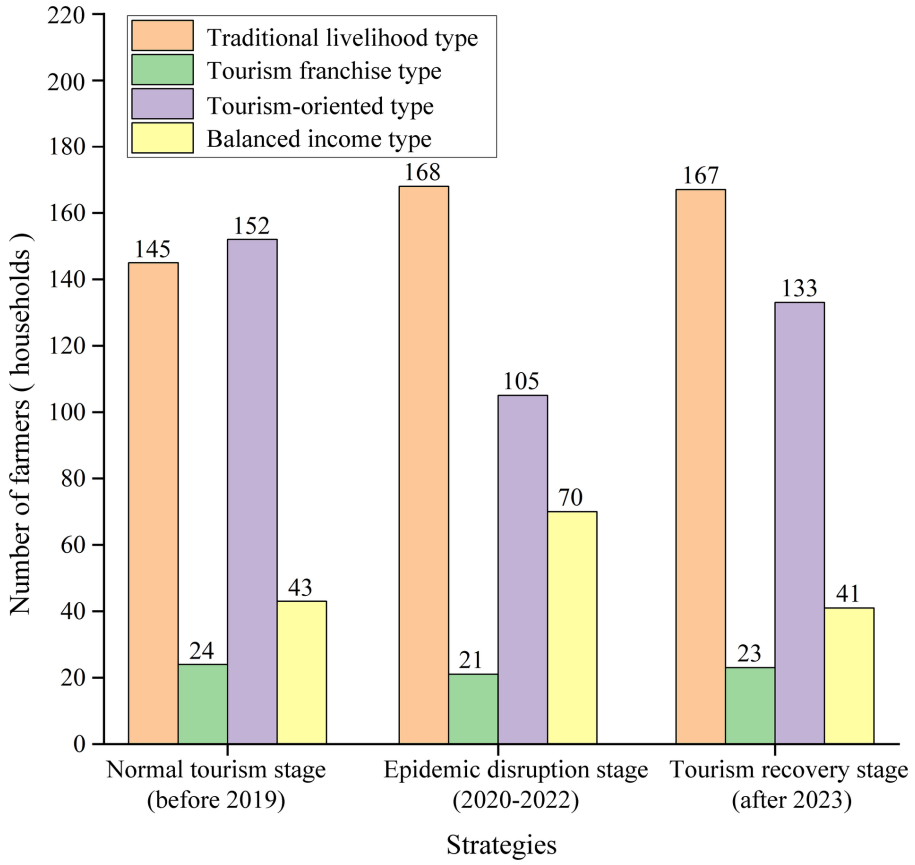

FIGURE 2
The number of farmers with different livelihood strategies in three stages.

TABLE 2 Types of livelihood strategies of farmers.

Type of farmers	Classification criteria		Proportion of farmers in the normal tourism stage (%)	Proportion of farmers in the epidemic disruption stage (%)	Proportion of farmers in the tourism recovery stage (%)
	Proportion of income	Primary labor input			
Traditional livelihood	The proportion of income from farming and other work exceeds 50%.	Agriculture and other work	39.84	46.15	45.88
Tourism franchise	The proportion of tourism income is 100%.	Tourism	6.59	5.77	6.32
Tourism-oriented	The proportion of tourism income is more than 50% but less than 100%.	Agriculture, other work, and tourism	41.76	28.85	36.54
Balanced income	The proportion of income from farming, other work, and tourism is balanced.	Agriculture, other work, and tourism	11.81	19.23	11.26

(He et al., 2017b). The cumulative obstacle degree of the top 6 obstacle factors for the four types of farmers exceeded 65%.Thus, they had significant impacts farmers' livelihood resilience.

In general, the obstacle factors affecting the livelihood resilience of various types of farmers show a convergence trend. Four key obstacle factors—per capita arable land area (B_1), per capita forested land area (B_2), out-of-home labor (entrepreneurship) experience (S_4), and skill training opportunities (L_4)—appear in all three periods of analysis. Among them, B_1 and B_2 are part of the buffering capacity dimension, S_4 belongs to the self-organization capacity dimension, and L_4 is related to the learning capacity dimension. The cumulative impact

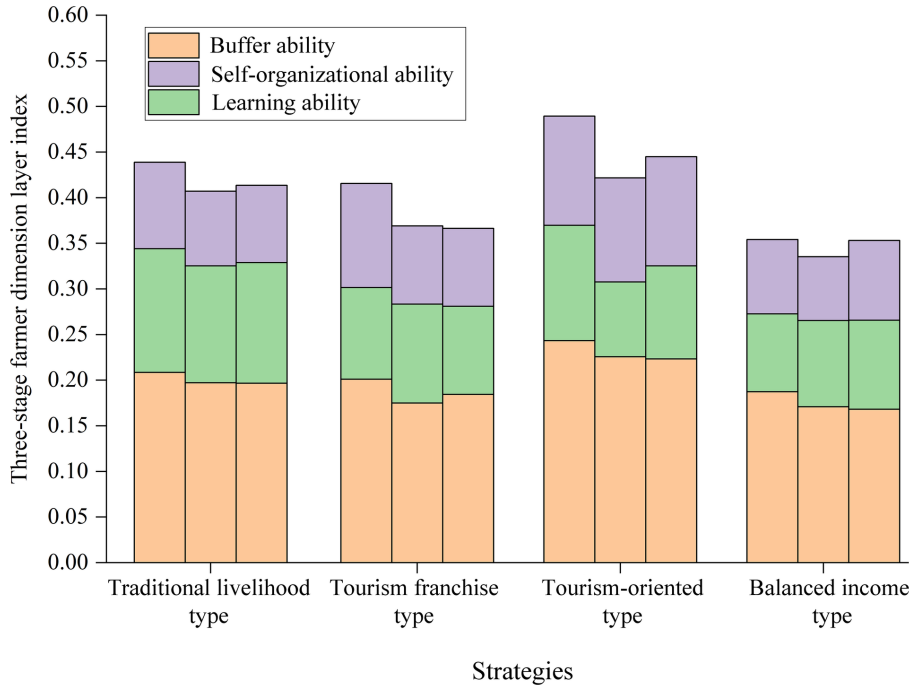

FIGURE 3
Different dimensions of livelihood resilience of farm households at different stages.

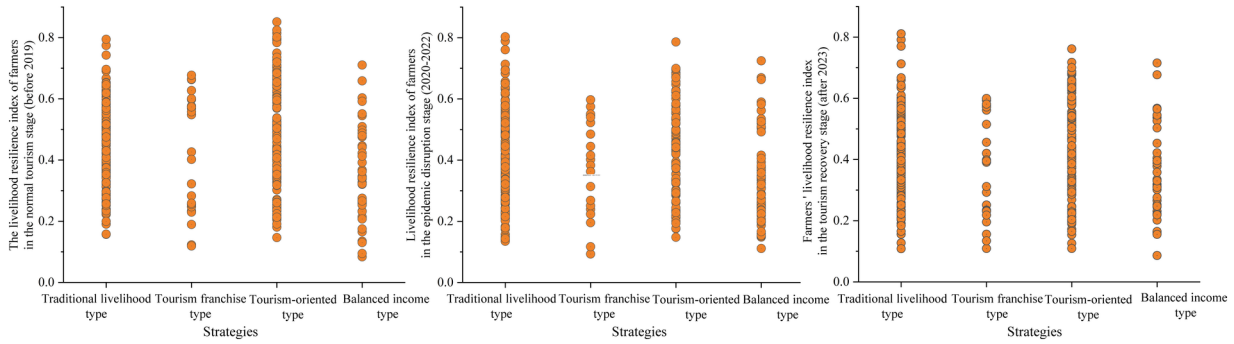

FIGURE 4
Livelihood resilience index of farm households with different livelihood strategies.

TABLE 3 **Livelihood resilience index for farm households in different stages.**

Different stages	Buffer capacity	Self-organizing ability	Learning ability	Livelihood resilience index
Normal tourism stage (before 2019)	0.220	0.124	0.105	0.449
Epidemic disruption stage (2020–2022)	0.199	0.107	0.089	0.395
Tourism recovery stage (after 2023)	0.202	0.115	0.098	0.415

of these four barrier factors on the livelihood resilience of farm households across the three periods is as follows: 32.86, 36.85, 66.76, and 74.89% during the tourism normal phase (pre-2019); 28.24, 29.96, 81.67, and 97.50% during the epidemic disruption phase (2020–2022); and 31.67, 31.78, 86.10, and 84.99% during the tourism recovery phase (2023 onwards). These four barrier

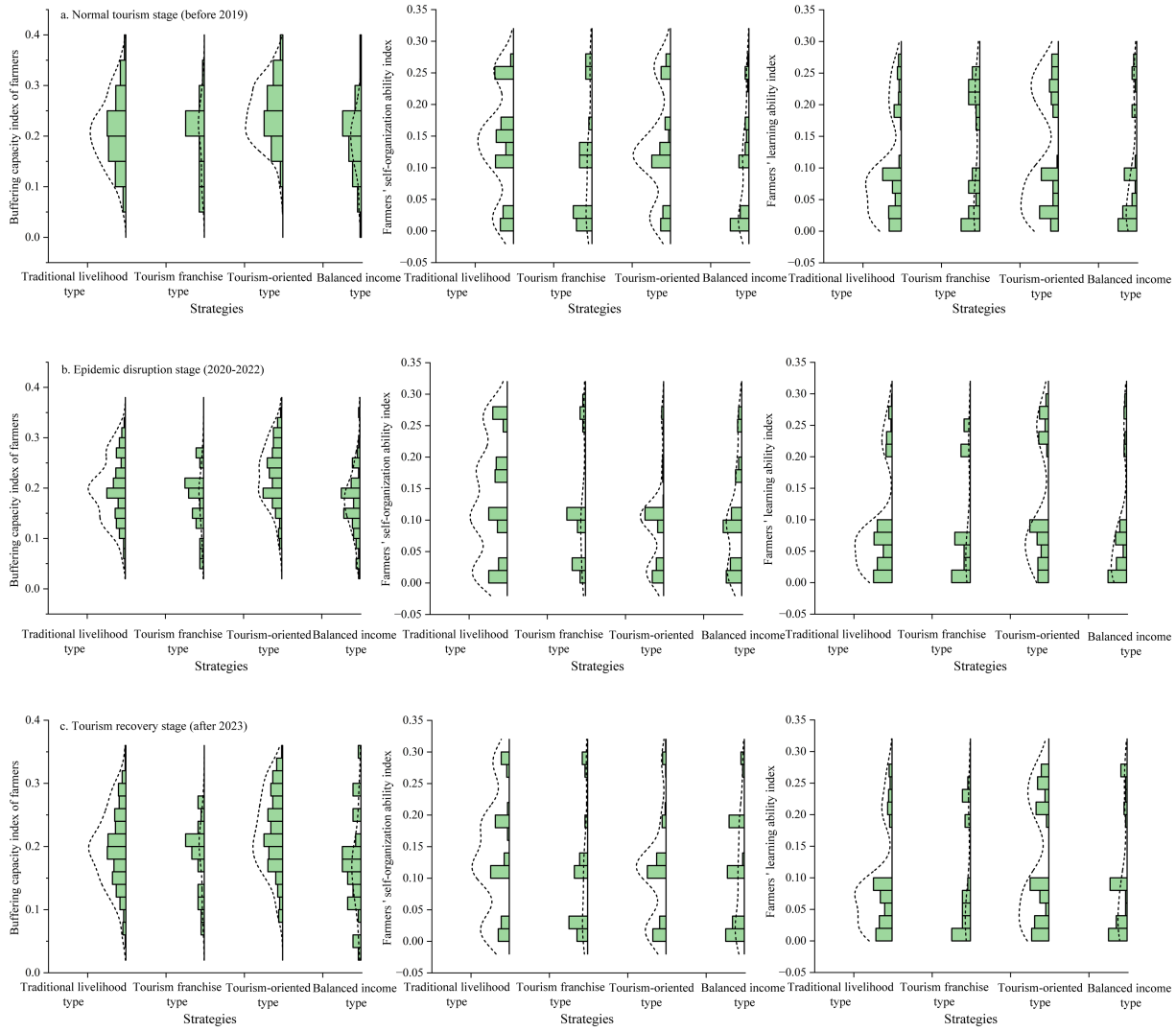

FIGURE 5
Farmers' livelihood resilience for different dimensions and livelihood strategies at different stages.

factors have consistently played a critical role in shaping the livelihood resilience of farm households in all three stages.

First, the barrier factor with the greatest impact on the livelihood resilience of all types of farm households is skill training opportunities (L_4). The degree of impact on the livelihood resilience of traditional subsistence, tourism franchise, tourism-led, and balanced-income farm households was 22.29, 14.73, 17.89, and 19.99%, respectively, during the tourism normal phase (up to 2019); 26.70, 23.92, 21.97, and 24.92% during the epidemic disruption phase (2020–2022); and 24.80, 20.59, 18.41, and 21.18% during the tourism recovery phase (after 2023). Overall, the impact shows an increasing and then decreasing trend. Participation in professional and systematic skills training is crucial for improving the livelihoods and income levels of farm households, especially for traditional subsistence and balanced-income farmers who rely on traditional agricultural labor and are in urgent need of skills upgrading. Conversely, tourism-franchise farmers experienced the largest shift in the degree of obstacles, largely due to the singularity of their income, which was severely impacted by the pandemic. Research indicates that the local government in Wulingyuan, Zhangjiajie, has not done enough in terms of vocational skills training. Over 54.58% of respondents reported not receiving any vocational training, while 22.92% indicated they had only attended one unhelpful session. The lack of specialized skills training has limited farmers' ability to improve their livelihoods, particularly as the tourism sector recovers and new job opportunities arise. The urgent need for training, especially in areas like hospitality and services, underscores the importance of L_4 as a major barrier to enhancing the resilience of farm households' livelihoods.

The second most significant barrier to livelihood resilience across all types of farm households is out-of-home labor (entrepreneurship) experience (S_4). The degree of impact on the livelihood resilience of traditional subsistence, tourism franchise, tourism-led, and balanced-income farm households was 12.22, 19.58, 18.60, and 16.36%, respectively, during the tourism normal phase (up to 2019); 14.95, 20.93, 27.16, and 18.64% during the epidemic disruption phase (2020–2022); and 17.33, 23.04, 27.55, and 18.19% during the tourism recovery phase (after 2023). The overall trend is an upward trajectory.

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TABLE 4 Obstacle factors and degrees (%) affecting the livelihood resilience of farmers with different livelihood strategies at different stages.

Stage	Type of farmers	Project	Criteria scheduling					
			1	2	3	4	5	6
Normal tourism stage	Traditional livelihood	Obstacle factors	L4	S4	B2	S2	L2	B1
		Obstacle degree	22.29	12.22	8.41	7.99	7.62	7.54
		Cumulative obstacle degree	22.29	34.50	42.92	50.91	58.53	66.07
	Tourism franchise	Obstacle factors	S4	L4	B2	L2	B1	S2
		Obstacle degree	19.58	14.73	12.38	9.67	9.15	6.71
		Cumulative obstacle degree	19.58	34.31	46.69	56.36	65.51	72.23
	Tourism-oriented	Obstacle factors	S4	L4	B1	L2	B2	B6
		Obstacle degree	18.60	17.89	9.18	8.72	8.44	6.19
		Cumulative obstacle degree	18.60	36.49	45.67	54.39	62.82	69.01
	Balanced	Obstacle factors	L4	S4	S2	B2	L2	B1
		Obstacle degree	19.99	16.36	8.74	7.62	7.15	6.99
		Cumulative obstacle degree	19.99	36.35	45.10	52.72	59.87	66.87
Epidemic disruption stage	Traditional livelihood	Obstacle factors	L4	S4	B2	B1	L2	S2
		Obstacle degree	26.70	14.95	7.25	7.11	7.00	6.90
		Cumulative obstacle degree	26.70	41.65	48.90	56.01	63.01	69.91
	Tourism franchise	Obstacle factors	L4	S4	B2	B1	L2	B5
		Obstacle degree	23.92	20.93	9.86	8.35	7.60	4.27
		Cumulative obstacle degree	23.92	44.84	54.71	63.06	70.65	74.93
	Tourism-oriented	Obstacle factors	S4	L4	B1	B2	L2	S2
		Obstacle degree	27.16	21.97	6.93	6.03	5.77	5.45
		Cumulative obstacle degree	27.16	49.13	56.06	62.09	67.86	73.30
	Balanced	Obstacle factors	L4	S4	B2	S2	L2	B1
		Obstacle degree	24.92	18.64	6.82	6.19	6.13	5.85
		Cumulative obstacle degree	24.92	43.55	50.37	56.56	62.69	68.54

(Continued)

TABLE 4 (Continued)

Stage	Type of farmers	Project	Criteria scheduling					
			1	2	3	4	5	6
Tourism recovery stage	Traditional livelihood	Obstacle factors	L4	S4	B1	S2	B2	L2
		Obstacle degree	24.80	17.33	8.06	7.61	7.35	7.24
		Cumulative obstacle degree	24.80	42.12	50.18	57.79	65.14	72.38
	Tourism franchise	Obstacle factors	S4	L4	B2	B1	L2	S2
		Obstacle degree	23.04	20.59	10.29	8.80	8.35	6.48
		Cumulative obstacle degree	23.04	43.64	53.93	62.73	71.08	77.56
	Tourism-oriented	Obstacle factors	S4	L4	B1	L2	B2	S2
		Obstacle degree	27.55	18.41	8.08	7.52	7.20	6.29
		Cumulative obstacle degree	27.55	45.96	54.04	61.56	68.77	75.05
	Balanced	Obstacle factors	L4	S4	S2	B2	B1	B6
		Obstacle degree	21.18	18.19	9.83	6.93	6.74	6.10
		Cumulative obstacle degree	21.18	39.37	49.20	56.13	62.87	68.97

The numbers 1–6 represent the ranking of the obstacle degrees of the corresponding indicators from small to large. The larger the value of the index, the greater the impact on livelihood resilience; B_1: per capita arable land area; B_2: per capita forest land area; B_5: Social interaction costs; B_6: the number of relatives of public officials; L_2: the closeness of contact with relevant organizations; L_4: Skills training opportunities; S_2: traffic convenience; S_4: Migrant work (entrepreneurship).

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Farmers who work or start businesses outside their homes typically generate higher income, which directly improves their family's economic situation. Moreover, through external work or entrepreneurship, farmers acquire new skills, industry knowledge, and technological expertise, broadening their horizons. Some migrant workers, after accumulating sufficient capital and experience, return to their hometowns to launch businesses, introducing advanced agricultural practices and management techniques. The pandemic, however, created barriers for many farmers who had been seeking such opportunities, especially for tourism-led and tourism-franchise farmers who were primarily dependent on tourism. Although tourism-related farmers were more directly impacted, traditional subsistence farmers, who depend on agriculture and home-based labor, experienced less disruption. As tourism gradually recovers, the need for tourism-related services such as catering and lodging is increasing, highlighting the importance of S_4 in the recovery phase.

Finally, both household cultivated land area per capita (B_1) and forested land area per capita (B_2) are key barriers to livelihood resilience for all types of farm households. The degree of impact on traditional subsistence, tourism franchise, tourism-led, and balanced-income farm households was 7.54, 9.15, 9.18, and 6.99%, respectively, during the tourism normal phase (up to 2019); 8.41, 12.38, 8.44, and 7.62% during the epidemic disruption phase (2020–2022); and 7.11, 8.35, 6.93, and 5.85% during the tourism recovery phase (after 2023). The trend fluctuates, showing a decline and then a slight increase. Stabilizing arable land and forest areas is essential for securing the livelihoods of farm households, as it directly influences their choice of agricultural practices and overall livelihood strategy. In the case of tourism development in the Wulingyuan Scenic Area, the purchase of large amounts of farmland and forested land by tourism operators has directly impacted farmers' basic needs and economic returns. During the pandemic, the importance of arable and forest land became even more apparent, especially for tourism-oriented farmers who were more vulnerable to the fluctuations caused by the epidemic. These farmers, particularly those with single income sources, experienced the most significant decline in livelihood resilience. On the other hand, non-tourism-oriented farmers, such as traditional subsistence and balanced-income earners, rely more on land for their livelihoods, providing a more stable income and making them less susceptible to the volatile effects of the epidemic.

4 Discussion

With the rapid development of global tourism, the tourism industry has become a strategic pillar of many national economies, and its high-quality development plays a significant role in promoting the transformation and upgrading of the sector (Wan et al., 2024). However, the outbreak of COVID-19 has brought about significant changes in the livelihoods of farmers, affecting their resilience to risks and, consequently, the evolution of their livelihood resilience (Tang et al., 2022).

The study found that the livelihood resilience of farm households in the Wulingyuan Scenic Area generally decreased under the impact of COVID-19, which aligns with the findings of Tang et al. (2022), Liu et al. (2024), and Li et al. (2024). Measuring the livelihood resilience across different types of farmers revealed that tourism-led farmers exhibited better resilience, supporting the conclusions of Zheng et al., who noted that the booming tourism industry has enhanced the incomes of tourism-dependent farmers, who are often more socially engaged. In the context of China's unique national conditions, traditional values, and social comparisons, individuals who are capable and adept at socializing enjoy higher social status, which in turn offers them more influence and greater opportunities (Zheng et al., 2023). The study also observed that different types of farm households were affected by COVID-19 in terms of family structures, production and lifestyle changes, and the types of livelihoods they depend on. These factors contributed to varying levels of resilience across the three dimensions of livelihood resilience. Tourism-led and tourism-focused farmers, for instance, saw a decline in patronage due to the pandemic-induced closures, making their livelihoods more vulnerable in the face of unexpected disruptions, such as COVID-19 (Jing et al., 2024; Li et al., 2015). In contrast, traditional and balanced-income farmers, who still rely on agriculture, were less affected, as their livelihoods remained more stable and resilient to the risks posed by the pandemic. There is a convergence of barrier factors affecting the livelihood resilience of farmers across different livelihood types in scenic areas, consistent with the findings of Wu J. L. et al. (2024), Wang and Wang (2024), and Felkner et al. (2022). The study shows that factors such as per capita forest land area (B_2), access to skill training opportunities (L_4), access to lending (S_3), and experience with migrant labor or entrepreneurship (S_4) are crucial to the resilience of farmers' livelihoods. Notably, the per capita forest land area (B_2) had a significant impact on farmers' livelihood resilience. Due to the rapid development of tourism in the Wulingyuan Scenic Area, large-scale expropriation of farmers' arable and forest land has led to the loss of their ability to accumulate capital, both familial and financial, and has contributed to the degradation and pollution of the natural environment. Based on our results, we propose the following strategic suggestions:

(1) Protect Farmland and Forest Land while Promoting a Thriving Tourism Industry: It is essential to safeguard the local farmland and forest areas while actively promoting the tourism industry. The region's unique natural landscapes, including mountains, rivers, forests, and fields, along with its favorable climate, should be fully explored and effectively utilized. Through policy guidance and support, the scale and quality of rural tourism and resort tourism should be enhanced, establishing a diversified tourism industry chain that strengthens competitiveness. This will attract more skilled and large-scale farmers to directly engage in the tourism sector, providing them with substantial economic benefits and employment opportunities. However, the tourism industry also faces serious challenges, such as ecological degradation, conflicts of interest with local communities, and limited farmer participation. Therefore, protecting farmland and forest resources is vital. This can be achieved through scientific and well-planned tourism development, where planning precedes construction, and all stakeholders are involved. As a result, farmers should be integrated into the rural tourism industry chain, increasing their participation in tourism initiatives and ultimately enhancing the resilience of their livelihoods.

(2) Provide Comprehensive Skills Training Opportunities for Local Farmers: The government should offer policy and financial support to facilitate diversified vocational training programs aimed at improving farmers' livelihoods and their capacity to respond to challenges. To make employment training more precise and effective, agricultural experts should visit rural areas to provide targeted guidance, introducing modern agricultural techniques, e-commerce, online marketing, and other emerging fields. This will help enhance the professional and technical abilities of farmers, particularly those involved in tourism and related industries, ultimately improving their overall skill set and increasing their opportunities for higher-paying jobs.

(3) Increase Employment Opportunities and Encourage Local Farmers to Start Their Own Businesses: Many scenic areas suffer from limited tourism products, a high degree of homogeneity, and an over-reliance on natural resources, which reduces employment opportunities. Consequently, many young adults in rural areas migrate for work, leaving behind the elderly, women, and children, with land cultivation being the primary source of livelihood. This makes the local economy vulnerable to disturbances, as the economic chain can easily break down. Tourism companies should recognize the strengths of local farmers and create a diversified tourism industry chain, providing more employment opportunities and supporting the rural tourism sector. Encouraging farmers to start their own businesses, while offering them employment and practical experience in local industries, can stimulate the local economy. Tourism development should focus on improving the livelihoods of farmers, fostering the growth of suitable industries to revitalize the local economy, reducing barriers to entry in tourism, and providing subsidies to farmers facing operational difficulties in the tourism sector.

5 Conclusion

We used survey data from 5 tourism villages and 364 farmers in the Wulingyuan Scenic Area and established an evaluation index system of farmers' livelihood resilience considering the buffering, learning, and self-organization abilities. The obstacle degree model was utilized to assess the evolution and influencing factors of farmers' livelihood resilience for different livelihood strategies in the normal tourism stage (before 2019), epidemic disruption stage (2020–2022), and the tourism recovery stage (after 2023). The conclusions are as follows:

(1) The livelihood resilience of farmers in the Wulingyuan Scenic Area fluctuated substantially in the three periods and decreased, followed by an increase. In the normal tourism stage (before 2019), tourism franchise and tourism-oriented farmers accounted for 48.35% of the sample size, indicating that participation in tourism development was the dominant livelihood strategy, and most farmers obtained their income from this source. In the epidemic disruption stage (2020–2022), tourism franchise and tourism-oriented farmers accounted for 34.62% of the sample size. The coronavirus epidemic adversely affected the tourism industry; thus, many tourism-based farmers had to change their livelihood, significantly decreasing the number of tourism franchise and tourism-oriented farmers. In the tourism recovery stage (after 2023), tourism franchise and tourism-oriented farmers accounted for 42.86% of the sample size. The economy and the tourism industry recovered after the coronavirus epidemic, increasing the number of tourism franchise and tourism-oriented farmers.

(2) The livelihood resilience of farmers with different livelihood strategies was compared. The ranking of the farmers based on livelihood resilience was tourism-oriented > traditional livelihood > tourism franchise > balanced. The buffering capacity was high, and the self-organizing and learning abilities were low. An imbalance was observed between the three dimensions of livelihood resilience. The livelihood resilience indices of the four types of farmers were generally low, with significant differences observed across farmers employing different livelihood strategies. These differences had a notable impact on their buffering, learning, and self-organizing capacities.

(3) The barrier factors affecting the livelihood resilience of different types of farm households in the Wulingyuan Scenic Area before and after the epidemic exhibited a convergence trend. Across all three periods, four common barriers to livelihood resilience were identified, ranked in descending order of impact as follows: skill training opportunities (L_4) > migrant work (entrepreneurship) (S_4) > per capita forest land area (B_2) > per capita arable land area (B_1). The degree of impact on the livelihood resilience of different types of farm households varied across the time periods. The cumulative barriers of these four factors to the livelihood resilience of the four types of farm households during different periods were 32.86, 36.85, 66.76, and 74.89% in the tourism normality phase (before 2019); 28.24, 29.96, 81.67, and 97.50% in the epidemic disruption phase (2020–2022); and 31.67, 31.78, 86.10, and 84.99% from 2023 onwards. It is evident that these four barrier factors played a critical role in shaping the livelihood resilience of farm households across the three phases.

Farmers' livelihood resilience is a dynamic process of sustainable development. Due to complex political and economic conditions in China and internationally, more influencing factors will affect farmers' livelihood resilience and change dynamically. There is a wide range of research methods and indicators used to assess farmers' livelihood resilience, but few studies have taken a microscale approach to the dynamic evaluation of livelihood resilience in rural landscapes or identified the obstacle factors at different stages. This paper examines the dynamic evolution and obstacles of farmers' livelihood resilience, offering valuable insights for enhancing resilience, managing external shocks such as epidemics, and implementing diversified livelihood strategies. However, we did not consider the diversity of spatial attributes of farmers' livelihood resilience. A future study will examine the regional differences in

farmers' livelihood resilience. In addition, we did not clarify the mechanism of farmers' livelihood resilience or predict future livelihood resilience. Follow-up research should analyze the impact mechanism of farmers livelihood resilience under different livelihood strategies and predict the evolution of farmers' livelihood resilience to optimize the livelihood strategies and improve tourism farmers' livelihood resilience.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Biomedical Ethics Committee of Jishou University, School of Civil Engineering and Architecture, Jishou University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

JW: Conceptualization, Data curation, Formal analysis, Writing – original draft. SL: Funding acquisition, Project administration, Supervision, Writing – review & editing. KX: Methodology, Data curation, Writing – review & editing. JZ: Data curation, Project administration, Writing – review & editing. LL: Formal analysis, Software, Writing – review & editing. DG: Conceptualization, Investigation, Writing – review & editing.

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Conflict of interest

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

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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