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Beekeepers' intentions to adopt resilience strategies for climate change: a comparative and integrated approach using the theory of planned behavior and protection motivation theory

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Beekeeping plays a vital role in global food security, contributing to the pollination of up to 30% of global food production and ensuring the sustainability of food supplies worldwide. However, climate change has significantly impacted beekeeping in recent years, affecting honeybees, pollination, and honey harvesting. Due to the effects of climate variability, which impose environmental strain on bees and beekeepers, modifications in management strategies and agricultural practices are essential to enhance biodiversity, guarantee agricultural sustainability, and ensure food security. This study aims to investigate the factors influencing beekeepers' intentions to adopt resilience strategies in response to climate change using protection motivation theory (PMT), the theory of planned behavior (TPB), and an extended PMT model. The study uses data obtained from a survey of 120 Tunisian beekeepers. The findings from the partial least squares analysis highlight the value and complementarity of the three models (TPB, PMT, and extended PMT), with the extended model offering superior explanatory and predictive power. The TPB model reveals the significant influence of perceived behavioral control and attitudes toward climate change resilience strategies on the intention to adopt them. The PMT model emphasizes the roles of self-efficacy, coping appraisal, and the perception of climate change occurrence in shaping adoption intentions, with self-efficacy being the most impactful factor. The extended PMT model further demonstrates that self-efficacy strongly influences perceived behavioral control. Overall, all three models show a positive and significant impact of intention on the selection of specific resilience strategies.

KEYWORDS

beekeeping, climate change, resilience strategies, structural equation models, theory of planned behavior (TPB), protection motivation theory (PMT)

1 Introduction

Beekeeping plays a crucial role in food and nutrition security by pollinating up to 30% of global food production (Fikadu, 2019), making it essential for the sustainability of global food supplies. However, climate change currently poses a serious threat to honeybees. Additionally, climate change, along with other natural hazards, represents a significant concern for beekeepers (Varalan and Çevrimli, 2024) and is seen as deeply interlinked with broader ecological challenges rather than isolated occurrences (Remotti et al., 2024). There is a shared understanding among beekeepers that climate change is an integral part of the set of challenges threatening the long-term viability of their livelihoods. It has the potential to intensify interconnected issues, including the spread of diseases, the growing presence of parasites, predators, and parasitoids, and shifts in both the effects and application patterns of pesticides. These challenges significantly affect the behavior, physiology, and distribution of honeybees, indirectly impacting the availability of essential food sources for colony survival and growth. Warmer temperatures and direct sunlight, in particular, can directly impact bee population dynamics, altering survival, life cycle, fertility, and dispersal. Climate change has been reported to negatively impact pollinating bees, reducing their pollination activity and efficiency, which leads to a significant decline in bee populations and biodiversity (Pătruică et al., 2021; Vercelli et al., 2021). In fact, heavy rainfall and prolonged droughts negatively affect nectar production and the foraging behavior of bee colonies. Moreover, temperature fluctuations can alter both the quantity and quality of nectar produced by honey plants. Furthermore, climate change poses a significant threat to pollinators, and some researchers suggest a strong link between climate change and colony collapse disorder in bees (Pătruică et al., 2021; Neumann and Straub, 2023; Switanek et al., 2017). Consequently, climate change is imposing unprecedented environmental stress on bees and the beekeeping sector. This strongly reinforces the need for beekeepers to implement adaptation strategies to mitigate the negative effects of climate change on bee productivity (Di Falco et al., 2011; Rahman et al., 2023). An increasing body of scientific research concludes that coping management and practices are crucial for maintaining the health of honeybee colonies, ensuring successful overwintering, and sustaining productivity. Without the implementation of adaptation strategies, climate change will continue to drive the decline in agricultural yields (Neumann and Straub, 2023; Van Oort and Zwart, 2018). Although adaptation strategies can significantly improve resilience, boost productivity, and aid in mitigation efforts, their adoption among farmers, in particular smallholders, remains relatively low (Tanimonure and Naziri, 2021; Gashure, 2024).

Resilience to climate change refers to the capacity of ecological, social, and economic systems to absorb disturbances, adapt to changing conditions, and maintain core functions (Dzvene et al., 2025; Elgendy et al., 2024). Adaptation strategies involve practical responses aimed at reducing vulnerability and managing climate risks, such as climate-smart agriculture, water resource management, early warning systems, and nature-based solutions. However, the effectiveness of these strategies often depends on institutional capacity, access to financial and technical resources, and coherent policy frameworks. Common barriers include limited funding, poor governance, and gaps in climate data and local engagement (Takal and Amfo, 2025; Elgendy et al., 2024). The implementation of adaptation and resilience strategies by farmers is further influenced by socio-economic factors including age, education, and off-farm income (Gashure, 2024; Purwanti et al., 2023; Asrat and Simane, 2018; Bedeke et al., 2018). Moreover, psychological factors related to perceived risk, beliefs in the reality of climate change, and adaptive capacity have been identified as determinants of the intention to adopt adaptation strategies (Purwanti et al., 2023; Dang et al., 2014; Van Gameren et al., 2014). Additionally, factors such as the cost, complexity, and effectiveness of implementing resilience strategies are critical determinants of their adoption (Lin et al., 2024; Westcott et al., 2017; Aldrighetti et al., 2021).

Although studies on adaptation strategies to climate change in the agricultural sector have been conducted extensively, little attention has been given to the beekeeping sector. Furthermore, research carried out by Neumann and Straub (2023) concluded that the effects of climate change and the measures to mitigate them are currently not well-understood in the context of beekeeping. There is still a lack of a comprehensive strategy to effectively address the challenges posed by global climate change within the beekeeping sector.

Along the same line, several researchers have adopted diverse approaches to explore beekeeping practices, honey production, and the challenges facing the beekeeping value chain while also contributing to the establishment of a social-ecological systems framework. The research of Vercelli et al. (2021), based on focus groups in the Italian context, reveals that beekeepers need to implement new practices and strategies to sustain the strength and profitability of their bee colonies in the face of climate change. These include sugar supplementation to offset nectar shortages, adopting more effective and sustainable methods for controlling varroa, such as queen caging and complete brood removal, practicing intensive transhumance, and enhancing core production, among others. Likewise, Landaverde et al. (2023) studied beekeepers' perceptions of climate change and their adaptation strategies. Adaptation measures include adjustments to traditional hive structures, the use of pollen traps, increasing the amount of pollen in local flora, providing additional food sources, and choosing the apiary location. In 2023, Van Espen et al. conducted a mixed-methods study on the beekeeping sector in Europe, examining the perceived impacts of climate change and the need for adaptation from the perspectives of stakeholders and beekeepers. While this research offers a descriptive quantitative analysis of European beekeepers' perceptions of climate change, it does not assess their intentions to adopt resilience strategies or the factors influencing their choices of adaptation strategies and practices.

While climate adaptation in agriculture has been extensively studied, the beekeeping sector remains significantly unexplored, with current research focusing mainly on adaptation strategies rather than the psychological and behavioral determinants influencing beekeepers' intentions (Vercelli et al., 2021; Neumann and Straub, 2023; Landaverde et al., 2023; Van Espen et al., 2023). This study is the first to apply Structural Equation Modeling to explore the determinants influencing beekeepers' intentions to adopt resilience strategies. There is a clear gap in research on the factors driving resilience adoption among beekeepers, especially in Tunisia.

Several behavioral models have been used to guide beekeepers' climate adaptation studies, yet each presents certain limitations. The theory of reasoned action (TRA) emphasizes attitudes and norms but neglects perceived behavioral control, a gap addressed by the theory of planned behavior (TPB) (Ajzen, 1991). The health belief model (HBM) focuses on individual threat perceptions but fails to account for social norms and collective efficacy (Janz and Becker, 1984). Similarly, the norm activation model (NAM) and value–belief–norm (VBN) theory focus on moral motivations but often underestimate self-efficacy and practical barriers (Schwartz, 1977; Stern et al., 1999). While the social cognitive theory (SCT) stresses self-efficacy and learning, it remains underutilized in the context of agricultural climate adaptation (Bandura, 1986). None of these models, however, integrate perceived control, social influence, and threat appraisal as comprehensively as the combined TPB and PMT approach. This study therefore seeks to advance the literature by integrating the theory of planned behavior (TPB) and protection motivation theory (PMT) to achieve three key objectives: (1) clarify the often-confused relationship between self-efficacy and perceived behavioral control (Parkinson et al., 2017; Yap and Lee, 2013; Trafimow et al., 2002), (2) assess the influence of climate risk perception on attitudes toward resilience strategies, and (3) demonstrate the improved explanatory power of combining TPB and PMT in predicting farmers' adaptation intentions (Wang et al., 2019; Badsar et al., 2023).

The remainder of this article is organized into six sections as follows. Section 2 presents the theoretical framework and research hypotheses. Section 3 contains a broad exposition of the methodology used. Section 4 presents the results. Section 5 discusses the results, followed by the conclusion and implications of the findings in Section 6.

2 Theoretical framework and research hypotheses

Many social psychology theories have been employed to understand the factors influencing farmers‘ intentions and behaviors, such as the theory of planned behavior, the theory of reasoned action (TRA), and protection motivation theory (PMT) (Kim et al., 2013; Daxini et al., 2019; Kahramanoglu, 2020). The following section will present a review of the literature on theoretical models used to analyze and understand farmers' adaptation intentions for coping with climate change.

2.1 Using protection motivation theory to explain farmers' climate change adaptation decisions

Protection motivation theory (PMT), developed by Rogers (1975), explains how individuals are motivated to protect themselves from threats by assessing perceived severity, vulnerability, response efficacy, and self-efficacy (Sutton, 2001). Rooted in expectancy-value theory, PMT emphasizes both threat and coping appraisals while acknowledging the influence of environmental and cognitive factors, including response costs and stimulus duration. In agricultural research, PMT has been widely applied to study farmers' adaptation to climate change. For instance, Bagagnan et al. (2019) found that both risk and coping appraisals positively influenced adaptation behaviors among Gambian farmers. Similarly, Martin et al. (2007) and Bryan et al. (2009) reported that self-efficacy, perceived severity, and financial barriers shape adaptation decisions. Purwanti et al. (2023) observed that perceived risk and adaptation assessment significantly influenced Indonesian farmers' adaptation intentions, a finding echoed by Hasibuan et al. (2023), Singh (2020), and Abid et al. (2019) in South Asia. Additionally, Villamor et al. (2023) showed that New Zealand forest growers with high threat perception and self-efficacy were more likely to adopt protective measures. In Ethiopia, Regasa and Abera (2019) demonstrated that severity, susceptibility, efficacy beliefs, and perceived costs significantly predicted farmers' climate responses. Although PMT has been extensively applied in agricultural and forestry contexts for studying climate adaptation, its application in apiculture remains largely unexplored in existing research.

2.2 The theory of planned behavior: explaining farmers' adaptation to climate change

The theory of planned behavior (TPB), proposed by Ajzen (1991), is widely used to analyze farmers' behavior (Zhang and Wang, 2024; Dessart et al., 2019). TPB identifies attitudes, subjective norms, and perceived behavioral control as key predictors of behavioral intentions. Subjective norms involve perceived social expectations, perceived behavioral control reflects the ease or difficulty of performing the behavior, and attitudes relate to positive or negative feelings about the action. Behavioral intention indicates the willingness to perform the behavior, which is linked to actual behavior. Studies applying TPB to climate-related behaviors show mixed results: Asrari et al. (2022) found that attitudes and subjective norms positively influenced resilience intentions, but perceived control had no significant effect. Ofoegbu and Speranza (2017) reported strong positive effects of attitudes and subjective norms on sustainable forest management intentions, with perceived control showing a negative correlation. Meanwhile, Hounnou et al. (2023) observed that all three TPB factors positively influenced farmers' intentions to use climate information in decision-making.

2.3 Extending the protection motivation theory to assess farmers' intentions to adapt to climate change

A growing body of research has explored the determinants of climate change adaptation intentions using the protection motivation theory (PMT), either independently or in combination with other theoretical frameworks. For instance, Luu et al. (2019) used an extended protection motivation theory (PMT) to study farmers' adaptation intentions in Vietnam's Red River Delta, finding that perceived risks to health, finances, production, social ties, and mental wellbeing increased adaptation intentions, while denial and fatalism reduced them. In a comparative study, Kim et al. (2013) combined the Theory of Reasoned Action (TRA) and PMT to show that attitudes, perceived severity, response efficacy, and self-efficacy predict pro-environmental intentions among American and Korean students. Lin et al. (2024) found that vulnerability, self-efficacy, response efficacy, and subjective norms significantly affect forest tourists' attitudes and revisit intentions, while severity had no significant effect. Supporting the value of integrated models, Badsar and Karami (2021) demonstrated that combining TPB and PMT better explains farmers' sustainable behavior, with PMT variables playing a crucial role. Similarly, Cai et al. (2024) highlighted that climate experience strongly influences adaptation behavior within an integrated TPB-PMT framework. Collectively, these studies support PMT's relevance for understanding climate adaptation intentions and suggest that integrating TPB improves explanatory power. Nevertheless, while research on climate adaptation in agriculture is expanding, quantitative studies specifically examining the factors influencing beekeepers' adaptation intentions remain scarce, emphasizing the need for further empirical investigation in this sector.

2.4 In a combined model using PMT and TPB, are perceived behavioral control and self-efficacy different constructs?

A review of studies using PMT, TPB, or both reveals ongoing debate about whether self-efficacy (S-E) and perceived behavioral control (PBC) are distinct. Some research treats them interchangeably (Lin et al., 2024; Droms and Craciun, 2014), while others clearly differentiate the two (Yap and Lee, 2013; Badsar et al., 2023; Rhodes and Courneya, 2003). Manstead and Eekelen (1998) define PBC as the perceived ease or difficulty of performing a behavior, whereas self-efficacy reflects belief in one's ability to achieve desired outcomes, viewing challenges as opportunities rather than threats. Tavousi et al. (2009) further support this distinction, defining S-E as the assessment of task difficulty and PBC as perceived control over behavior. Nonetheless, Lin et al. (2024) note that TPB and PMT treat PBC and S-E as similar constructs, highlighting their conceptual overlap.

2.5 Suggested conceptual model for evaluating farmers' intentions to adapt to climate change and research hypothesis

This study aims to assess the core frameworks of protection motivation theory (PMT) and theory of planned behavior (TPB) models, along with an extended PMT model, to examine the determinants affecting beekeepers' intentions to implement resilience strategies in response to the recognized impacts of climate change. This research highlights the differences and relative significance of self-efficacy and behavioral control variables, as well as the impact of risk perception on attitudes toward resilience practices, as detailed in the extended version of the model. The empirical focus is placed on the beekeeping sector in Tunisia, acknowledging that adaptation strategies may differ significantly depending on the specific context. Furthermore, the study evaluates the added value of extending the PMT model through the inclusion of supplementary variables that may enhance its explanatory power.

The first six hypotheses formulated are based on the protection motivation theory (PMT) model (Figure 1). Risk perception is a fundamental predictor of the behavioral coping strategies

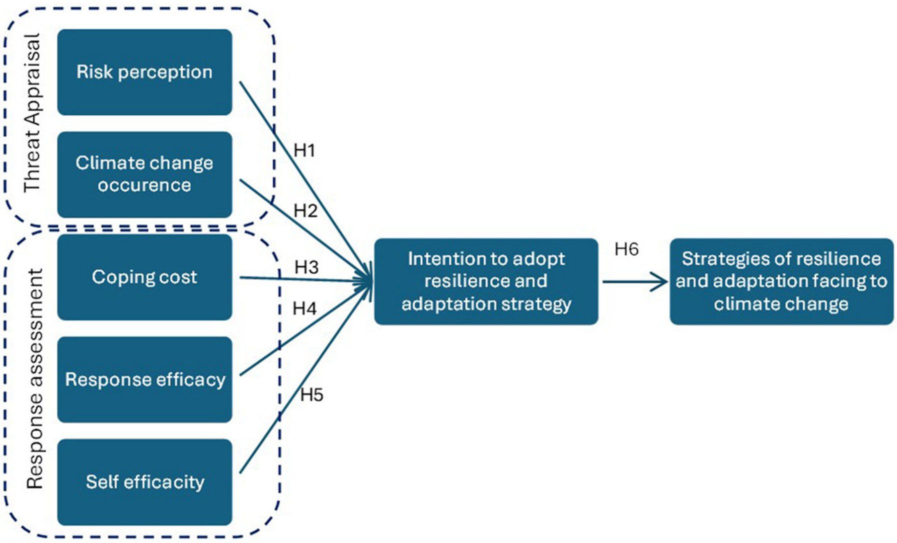

FIGURE 1
Proposed theoretical research framework based on a PMT model.

that individuals use to deal with risk (Lee and Lin, 2022). The protection motivation model suggests that two pathways explain human behavior: threat appraisal and coping appraisal (Badsar et al., 2023; Chen, 2020). Threat appraisal involves assessing how individuals perceive a specific behavioral threat, specifically the perceived severity and vulnerability of climate change issues. On the other hand, perceived severity reflects the extent to which individuals emotionally evaluate the seriousness of potential negative consequences associated with a given threat (Badsar and Karami, 2021). The perception of severity pertains to how farmers evaluate the effects of climatic changes. Perceived vulnerability refers to an individual's assessment of the likelihood of experiencing climate change. Based on the above literature review, both constructs, "perceived severity" and "perceived vulnerability," positively and significantly influence the behavioral intention to adopt resilience and adaptation strategies to face climate change. Therefore, it could be argued that:

Hypothesis (H1). The perceived risk of climate change positively and significantly influences the behavioral intention to adopt resilience and adaptation strategies to face climate change.

Hypothesis (H2). The perception of the occurrence of climate change positively and significantly influences the behavioral intention to adopt resilience and adaptation strategies to face climate change.

Lin et al. (2024) confirmed that response assessment significantly influences individuals' risk moderation behavior, especially regarding climate change risks. Response assessment includes factors such as response efficacy, self-efficacy, and response cost.

Self-efficacy reflects an individual's confidence in their ability to address specific problems, which affects their decision to engage in risk-reducing behaviors (Shafiei and Maleksaeidi, 2020). In this study, self-efficacy refers to farmers' perceived ability to implement adaptation and resilience strategies. Response efficacy pertains to the perceived effectiveness of specific risk prevention behaviors, which relates to how well farmers are adopting resilience practices. Response cost represents the expense associated with implementing recommended behaviors, influencing the intention to adopt resilience strategies in response to climate change. Based on this, the following hypotheses are established:

Hypothesis (H3). Response cost negatively impacts farmers' intention to adopt resilience strategies to address climate change.

Hypothesis (H4). Response efficacy (copying appraisal) positively impacts farmers' intention to adopt resilience strategies to address climate change.

Hypothesis (H5). Self-efficacy positively impacts farmers' intention to adopt resilience strategies to address climate change.

Behavioral intention is defined as the motivational drive that compels an individual to undertake a specific behavior, according to Arendt et al. (2013). Similarly, Badsar et al. (2023) identified farmers' behavioral intentions as a major predictor of their sustainable environmental practices. However, Hou and Hou (2019), Fishbein and Ajzen (1975), and Josef (2013) pointed out that behavioral intention determines actual behavior. Based on this, the following hypothesis is proposed:

Hypothesis (H6). Behavioral intention to adopt resilience and adaptation strategies positively and significantly influences the adoption of these strategies by beekeepers.

The next three hypotheses formulated are based on the Theory of Planned Behavior (TPB) (Figure 2). According to the TPB, perceived behavioral control is shaped by beliefs regarding factors that either facilitate or hinder the execution of a behavior (Asrari et al., 2022; Hounnou et al., 2023). This control significantly impacts disaster management. Thus, the following hypothesis is proposed:

Hypothesis (H7). Positive perceived behavioral control has a significant and positive influence on the intention to adopt resilience and adaptation practices to address climate change.

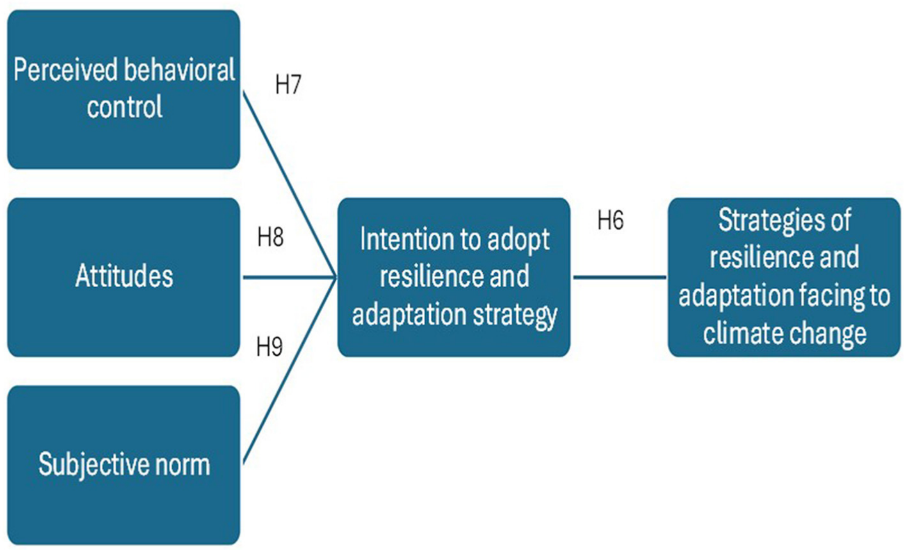

FIGURE 2
Proposed theoretical research framework based on a TPB model.

Attitudes toward behavior are shaped by perceived benefits or drawbacks, influencing emotions and ultimately behavioral intentions (Lin et al., 2024). Cai et al. (2024) also confirmed that positive attitudes significantly affect herdsmen's motivation to adopt climate adaptation strategies. Based on this, we propose the following hypothesis:

Hypothesis (H8). Attitudes toward coping strategies have a significant and positive impact on beekeepers' intention to adopt these resilience and adaptation strategies and practices to face climate change.

Subjective norms refer to an individual's understanding of what others consider important and the expectations surrounding their behavior (Asrari et al., 2022; Ofoegbu and Speranza, 2017). These norms have a positive, direct, and significant influence on the intention to adopt resilient behaviors, while perceived behavioral control did not demonstrate a significant effect. Therefore, we propose the following hypothesis:

Hypothesis (H9). Subjective norms have a significant and positive impact on beekeepers' intention to adopt resilience and adaptation strategies and practices to face climate change.

In response to climate change, research has increasingly emphasized the relationship between climate risk perception and pro-environmental attitudes. Shen et al. (2024) demonstrate that climate risk perception has a significant positive impact on pro-environmental attitudes, highlighting a strong correlation between the two constructs. Similarly, Bradley et al. (2020) suggest that risk perception can indirectly forecast environmental behaviors. Moreover, Carducci et al. (2021) found that attitudes toward pro-environmental behaviors are positively associated with risk perception. Therefore, we advance the following hypothesis (Figure 3):

Hypothesis (H10). Risk perception has a significant and positive impact on attitudes toward adopting pro-environmental practices and developing coping strategies to address climate change.

Building on the work of Yap and Lee (2013), Trafimow et al. (2002), Ajzen (2002), Rhodes and Courneya (2003), and Manstead and Eekelen (1998), self-efficacy is identified as an internal factor, while perceived behavioral control (PBC) encompasses both internal and external influences. Ajzen (2002), along with Bandura (1997) and Armitage and Conner (2001), emphasizes that self-efficacy is a core component of PBC. Although commonly treated as a subdimension within PBC, self-efficacy can also be modeled as an independent (exogenous) latent variable that significantly influences PBC. Conceptually, PBC consists of two elements: self-efficacy, reflecting an individual's belief in their capability to perform a behavior, and controllability, referring to the perceived influence of external constraints or enablers. In this framework, self-efficacy has a direct impact on perceived behavioral control, which subsequently shapes behavioral intention and, ultimately, actual behavior. This how Li et al. (2023) explored, through SEM modeling, the effects of cotton farmers' self-efficacy, access to resources, and technological assistance on their perceived behavioral control regarding the adoption of smart agricultural technologies. Therefore, we assert that:

Hypothesis (H11). Self-efficacy positively impacts farmers perceived behavioral control to face climate change.

Wang et al. (2019) and Badsar et al. (2023) found that integrating the theory of planned behavior (TPB) and protection motivation theory (PMT) enhances the explanatory power of behavioral intention models in agriculture. Their results showed that the combined model provides a better fit and higher R^2 values compared to using either theory alone. Similarly, Xiang and Guo

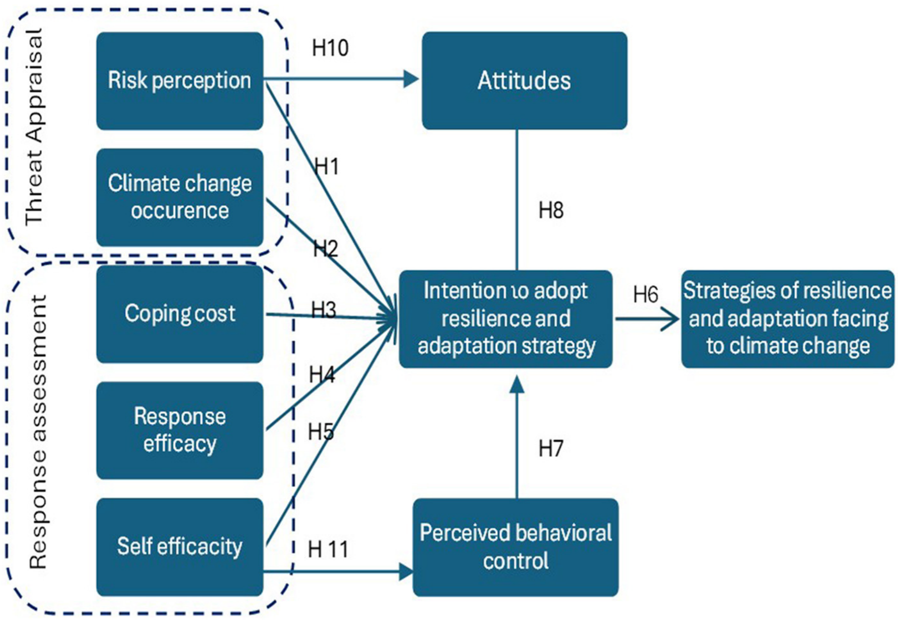

FIGURE 3
Proposed theoretical research framework based on an extended PMT model.

(2023) confirmed the superiority of the integrated approach in predicting farmers' adoption of green pest and disease control techniques. Consequently, we can conclude that:

Hypothesis (H12). The integrated model combining PMT and TPB has better predictability than the separate models.

3 Research methodology

3.1 Study area: beekeeping sector in Tunisia

The research was conducted in Tunisia. According to a report from the World Bank (2024), Tunisia is considered highly vulnerable to climate change and is expected to experience adverse impacts from increased temperatures, increased aridity, reduced precipitation, and rising sea levels. Furthermore, socio-economic and environmental implications will particularly affect water resources, agriculture, and livestock. In this context, climate change is threatening the beekeeping sector and honey production. The beekeeping sector in Tunisia contributes 0.1% to the national GDP and 1% to the agricultural GDP. Over the years, beekeeping in Tunisia has grown in significance. Sixty-five percent of beekeepers operate with fewer than 50 hives. Only 21.1% of beekeepers, those with more than 100 hives, are considered professionals (Jmal et al., 2024). In 2021, the average annual honey production was estimated at 2,360 tons, marking a 57% increase since 2011. However, fluctuations in the number of hives and honey production have been observed in recent years due to climatic conditions and decreasing honey resources [Office d'Elevage et de Pâturage (OEP), 2023]. In Tunisia, beekeepers estimate that colony losses can exceed 40%, with ∼20% occurring during periods of extreme heat and another 20% during colder temperatures (Debbabi et al., 2024).

3.2 Data collection

Data were collected based on a survey conducted between May and June 2024, involving a sample of 120 beekeepers across Tunisia. Given the absence of a recent national census of farmers, particularly beekeepers, and the limited availability of data on the structure of beekeeping operations and beekeeper characteristics, a purposive sampling method was used. This approach allowed for the inclusion of a wide range of beekeeper profiles (in terms of training, age, region, gender, main activity, years of experience, etc.) and types of operations (size, legal status, practices, etc.). A questionnaire was designed based on a literature review to collect both quantitative and qualitative data about beekeepers' strategies for addressing climate change and/or their intention to adopt such strategies, along with the factors influencing their choice of a particular resilience strategy. The questionnaire is organized into five sections: (1) s-economic variables of the beekeepers, (2) identification of beekeeping activities, (3) problems and threats in beekeeping, (4) perception of the impact of crises and risks encountered, and (5) strategies for resilience and adaptation to climate change, including the factors that determine the beekeeper's intention to adopt resilience strategies and their choice among these strategies[1]. The questionnaire incorporates both closed-ended questions and five-point Likert scale questions to gauge attitudes toward climate change, resilience strategies, and the various factors influencing beekeepers' intention to adopt resilience strategies and their choice of strategies, based on the conceptual model and the literature review. Table 1 shows the specific questionnaire items used for the fifth section and their reference sources.

3.3 Data analysis

Descriptive data analysis was carried out using SPSS 26, while modeling with structural equations was performed using Smart PLS software (version 4.0.9.6). This study used the partial least squares structural equation model (PLS-SEM), a multivariate analysis technique used for estimating variance-based structural equation models. It is regarded as having a predictive approach to Structural Equation Modeling (SEM), as it emphasizes the explanation of different variations. Additionally, it is favored among analytical tools due to its minimal requirements for observations and measurements and its ability to identify potential relationships that may warrant further investigation in other experiments or studies (Xiang and Guo, 2023).

The measurement model was used to investigate the relationship between measurement indicators and constructs, while the structural model was utilized to analyze the relationships between exogenous and endogenous constructs.

The estimation of the measurement model involves three types of analyses (Roussel et al., 2005): the reliability of each construct (latent variable), the validity of the constructs, and the degree of fit of the measurement model (Hair et al., 2017, 2019, 2021, 2011).

According to Anto et al. (2023) and Mutyasira et al. (2018), reliability is interpreted based on the obtained alpha values: an alpha >0.90 indicates perfect reliability, between 0.70 and 0.90 indicates high reliability, between 0.50 and 0.70 indicates moderate reliability, and below 0.50 indicates low reliability. Additionally, unlike Cronbach's alpha, composite reliability does not assume that all indicators are equally reliable, making it more appropriate for PLS-SEM, which prioritizes indicators based on their reliability during model estimation. Composite reliability values between 0.60 and 0.70 are considered satisfactory in exploratory research, while values from 0.70 to 0.90 are deemed acceptable in more advanced stages of research (Anto et al., 2023).

In assessing construct validity, discriminant validity is commonly evaluated using two key criteria: the Fornell–Larcker

1 While the behavioral indicators (SRA_CC) reflect strategies already adopted and the intention to adopt (IA_SRA) was measured at the time of the interview, our analysis is grounded in the widely accepted theoretical premise that behavioral intention is a key predictor of behavior, as established in both the theory of planned behavior (TPB) and protection motivation theory (PMT). In cross-sectional studies, it is common to assess the consistency between current intentions and reported behaviors to infer alignment and motivational patterns, especially when longitudinal data is not available. Moreover, the intention items in our questionnaire were explicitly framed in a future-oriented manner (e.g., "I plan to implement…."), allowing us to interpret the relationship as indicative of ongoing behavioral commitment.

TABLE 1 Questionnaire items and scale sources.

Variables constructs	Measurement items or indicators	Symbols	Sources
SRA _CC Strategies of resilience adaptation to face climate change	I have diversified my activities to diversify multiply my sources of income	SRA_CC1	Erdoğan, 2023; Barroca and Serre, 2013; Yohana, 2021
	I have taken out insurance for my beekeeping activity	SRA _CC2	
	I have diversified honey crops.	SRA _CC3	
	I have adapted my beekeeping practices (techniques of management of the colonies transhumance feeding).	SRA _CC4	
	I have implemented pest disease control techniques.	SRA _CC5	
	I have diversified my markets	SRA _CC6	
	I have valued my beekeeping products	SRA _CC7	
	I made transparent communication about the quality benefits of my honey	SRA _CC8	
	I have provided capacity building for myself my employees on climate-smart production techniques to support adaptation to climate change	SRA _CC9	
	I have been networking collaborating with local partners	SRA_CC10	
	I have managed my financial resources carefully	SRA _CC11	
	I have sought additional funding assistance	SRA _CC12	
	I used innovative technologies like blockchain	SRA _CC13	
	I have installed Precision Beekeeping / Smart Beekeeping (connected hives)	SRA _CC14	
	I moved my hives to new beehives.	SRA _CC15	
	I imported bee breeds that I am not used to.	SRA _CC16	
	I increased the number of transhumances	SRA _CC17	
IA_SRA Intention to adopt strategy of resilience adaptation	I plan to implement strategies in the future to adapt my beekeeping activities to climate change.	IA_SRA1	Hounnou et al., 2023; Asrari et al., 2022
	I intend to establish continuous strategies for adjusting my beekeeping practices to climate change.	IA_SRA2	
	I will put additional effort into adopting strategies for adapting my beekeeping activities to climate change.	IA_SRA3	
	I plan to adapt to climate change in the upcoming bee season by introducing new beekeeping practices.	IA_SRA4	
ATT Attitude toward resilience strategies	I believe that adapting to climate change is crucial for the long-term success of beekeeping.	ATT1	Hounnou et al., 2023; Asrari et al., 2022
	I think the uncertainty surrounding climate change impacts justifies making changes to beekeeping practices strategies.	ATT2	
	Various climate change adaptation strategies enable beekeepers to enhance both the quantity quality of honey produced.	ATT3	
	Diverse strategies for adapting to climate change assist beekeepers in exploring new markets boosting their profitability.	ATT4	
PBC Perceived behavior control	I have enough facilities money to adopt climate change resilience strategies	PBC1	Hounnou et al., 2023; Asrari et al., 2022
	I am fully confident that I can overcome the obstacles challenges preventing me from implementing a strategy to adapt my beekeeping activities to climate change.	PBC2	
	I am still working on adopting strategies to adapt my beekeeping activities to climate change.	PBC3	
	I am confident in my ability to adopt strategies for adapting my beekeeping activities to climate change.	PBC4	
RP Risk perception	Health crises such as bee diseases have reduced the productivity of bee colonies.	RP1	Ghanian et al., 2020; Raza et al., 2019
	Health crises including bee diseases affecting hives have raised the costs of treatment management.	RP2	
	Climate change has resulted in shifts in harvest seasons with some occurring earlier than usual.	RP3	
	Climate change has altered bee habitats environmental conditions.	RP4	

(Continued)

TABLE 1 (Continued)

Variables constructs	Measurement items or indicators	Symbols	Sources
CCO Climate change occurrence	Overall climate change is evident through rising temperatures.	CCO1	Ghanian et al., 2020; Raza et al., 2019
	Seasonal changes are associated with climate change.	CCO2	
	Man has a responsibility for the current climate change	CCO3	
	The occurrence of climate change is scientifically established.	CCO4	
	Climate change has changed my lifestyle how my project works.	CCO5	
	The main causes of climate change are human activities	CCO6	
Copping appraisal cost CA_C	Inflation hinders the adoption of climate resilience strategies.	CA_C1	Ghanian et al., 2020; Raza et al., 2019
	The costs of certain innovative resilience strategies are obstructing their implementation in the beekeeping sector.	CA_C2	
CA Copping appraisal	I can readily adopt various climate change adaptation strategies due to my knowledge skills abilities.	CA1	Ghanian et al., 2020; Raza et al., 2019
	Adopting climate change adaptation strategies will be straightforward for me given my financial physical human resources.	CA2	
	It would be easy for me to adopt climate change adaptation strategies because I can manage my time.	CA3	
SE Self-efficacity	I possess the motivation energy needed to address all climate change-related challenges.	SE1	Ghanian et al., 2020; Raza et al., 2019
	I have sufficient funds resources to implement climate change adaptation strategies.	SE2	
	I believe I have the skills required to manage the risks associated with climate change.	SE3	

criterion and the heterotrait–monotrait ratio (HTMT). Among these, the HTMT ratio is especially important, as relying solely on the Fornell–Larcker criterion may not adequately confirm the distinctiveness of the constructs. As suggested by Henseler et al. (2014), the HTMT value should not exceed the threshold of 0.85 to confirm discriminant validity.

The variance inflation factor (VIF) is commonly used to assess collinearity among formative indicators. Higher VIF values indicate greater collinearity, with values of 5 or above signaling potential collinearity issues among predictor constructs. However, according to Hair et al. (2017), the VIF should ideally be around 3 or less to ensure acceptable levels of multicollinearity.

The overall fit of a structural equation model can be evaluated using fit indices such as the standardized root mean square residual (SRMR) and the normed fit index (NFI). According to Hu and Bentler (1998), an SRMR value below 0.08 indicates a good fit, reflecting a small average difference between observed and predicted correlations. The NFI, recommended by Lohmöller (1989), measures how well the proposed model fits relative to a null model, with values >0.50 considered acceptable.

To assess and compare the performance of the PMT, TPB, and extended PMT models, several evaluation criteria can be applied, including the coefficient of determination (R^2), predictive relevance (Q^2), root-mean-square error (RMSE), and the Bayesian Information Criterion (BIC) (Hair et al., 2017, 2021; Sharma et al., 2019; Schwarz, 1978). The R^2 value reflects the proportion of variance in the dependent variable that is explained by the independent variables (Hair et al., 2017, 2019). A higher R^2 value indicates better predictive capacity. In turn, the Q^2 statistic evaluates the model's predictive relevance, with values greater than zero signifying that the model has meaningful predictive power (Hair et al., 2017, 2019; Cohen, 1988).

For model comparison, the Bayesian Information Criterion (BIC) is valuable, as it balances model fit and predictive accuracy, especially in contexts with small sample sizes typical in PLS-SEM analyses. Sharma et al. (2021, 2019) support the use of BIC, noting that the model with the lowest BIC value is preferred for selection.

4 Results

4.1 Descriptive sample information

Table 2 shows that the beekeepers surveyed include women (27.5%) and men (72.5%). The variable "age" divides the sample into three categories, with a predominance of individuals aged 36–65 years, accounting for 60.8%. Those under 35 years of age represent 35.8%, and only 3.4% of surveyed beekeepers are over

TABLE 2 Sample description ($n = 120$ beekeepers).

Variable	Category	%
Age	≤35 years	35.8
	36–65 years	60.8
	>65 years	3.4
Gender	Male	72.5
	Female	27.5
Education level	Illiterate	2.5
	Elementary education	25.8
	Secondary education	30
	University /High school	41.7

65 years of age. Among the 120 beekeepers surveyed, 65.8% are married. The average household size is 3.46, with the most common household size being 2 people. There are four identified levels of education in our sample: secondary education accounts for 30%, university education for 41.7%, primary education for 25.8%, and illiteracy affects ∼2.5%.

The survey results indicate that only 20% of beekeepers are members of a professional organization, such as an association or agricultural development group.

4.2 Perceived adverse effects of climate change on the beekeeping sector in Tunisia

Environmental crises have profound and diverse effects on beekeeping, as indicated by beekeeper testimonies. Consistent with the findings of Makamane et al. (2025) in South Africa's Eastern Cape Province, a significant majority of respondents (93.3%) perceive variations in harvest seasons, while 92.5% report that global warming is impacting bee activities. Furthermore, 85.8% of beekeepers indicate that high temperatures reduce colony fertility, and 84.2% observe that higher temperatures lead to premature flowering. Additionally, 75% cite laying failures due to water shortages, a direct result of high temperatures. Pollen and nectar collection and colony development are affected for 76.7% of beekeepers, and 65.8% notice changes in bee habitats. Moreover, 60.8% report an increase in certain diseases, and 5.8% note a rise in invasive species.

These findings (Figure 4) underscore the urgent need for action to mitigate the effects of environmental crises on beekeeping. This includes promoting sustainable agricultural practices, protecting bee habitats, and enhancing colony resilience to climate change.

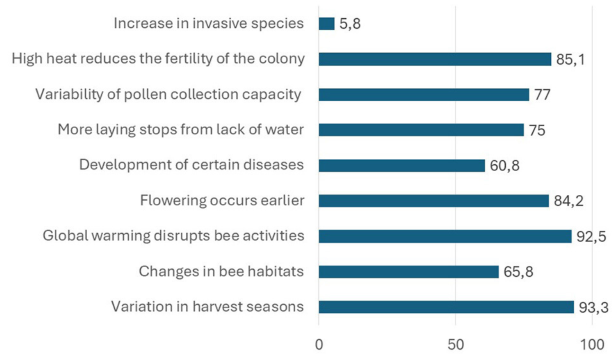

FIGURE 4
Perceived impacts of climate change (%).

4.3 Structural equation modeling identifying the determinants influencing the adaptive behavior of beekeepers in response to climate change

4.3.1 Assessment of the measurement model reliability and validity test

Table 3 presents the model's reliability and the validity of the indicators. All indicators with a factor loading below 0.7 were excluded from the final model due to their insufficient variance relative to the variable.

Then, composite reliability (CR $\geq$ 0.7) and the average variance extracted (AVE $\geq$ 0.5) were checked. All latent variables exceeded the threshold, indicating that all constructs are valid. Although the Cronbach's alpha value of the construct "coping appraisal cost (CA-C)" was low, we decided to keep it given its importance in diagnosing the determinants of adaptation and resilience strategies among beekeepers.

Compared to the acceptability thresholds specified in the methodology, the results indicate that both Cronbach's alpha and composite reliability, which are alternative measures of internal consistency, demonstrate high internal consistency across all constructs. In addition, the results of the discriminant validity test for reliability are shown in Appendices A–C for the three models. The values for each model fall within the acceptable range, further confirming that the constructs are reliable and valid.

4.3.2 Assessment of the structural model

The assessment of the structural model initially involves examining collinearity and the validity of the proposed relationships between the latent variables, specifically testing the validity of the formulated research hypotheses. The structural model is subsequently assessed based on the predictive usefulness of the latent variables. In our study, all VIF values are ideally <3, except for the PBC in the extended PMT model, which remains at an acceptable level (Table 4).

Table 5 displays the estimates for the three structural models. In the PMT model, the path analysis revealed that most hypotheses (H2, H4, H5, and H6) were statistically significant, except for the paths associated with risk perception and coping appraisal cost to behavioral intention.

The results of the analysis show that the occurrence of climate change ($\beta = 0.329$, $p < 0.05$), the response efficacy of coping appraisal ($\beta = 0.245$, $p < 0.05$), and self-efficacy ($\beta = 0.487$, $p < 0.001$) have a positive and significant influence on beekeepers' intentions to adopt resilience strategies. Additionally, their intention to implement resilience and adaptation practices in response to climate change significantly impacts their choice of specific practices ($\beta = 0.424$, $p < 0.001$).

With respect to the TPB model, the path analysis indicated that most hypotheses (H6, H7, H8) were statistically significant, except for the path connecting subjective norms to behavioral intention. Specifically, perceived behavioral control ($\beta = 0.480$, $p < 0.001$) and attitude ($\beta = 0.313$, $p < 0.01$) positively and significantly influence beekeepers' intentions to adopt resilience strategies. Furthermore, their intention to implement resilience and adaptation practices in response to climate change significantly affects their choice of specific practices ($\beta = 0.424$, $p < 0.001$).

In the extended PMT model, the path analysis showed that most hypotheses (H2, H5, H6, H8, H10, and H11) were statistically significant, except for the paths involving risk perception and the cost of coping appraisal to behavioral intention. Climate change

TABLE 3 Reliability and convergent validity result of PMT and extended PMT models.

Constructs	Items	Mean	S.D.	PMT model			TPB model			Extended PMT model		
				Loadings	C.R	AVE	loadings	C.R	AVE	Loadings	C.R	AVE
ATT	**ATT1**	4.400	0.907				0.937	0.942	0.803	0.935	0.942	0.803
	ATT2	4.217	1.018				0.780			0.789		
	ATT3	4.358	0.938				0.948			0.946		
	ATT4	4.333	1.011				0.909			0.907		
CA-C	**CA-C-1**	3.992	0.917	0.823	0.804	0.672				0.823	0.804	0.672
	CA-C-4	3.450	1.407	0.817						0.817		
CA	**CA1**	3.758	1.049	0.938	0.912	0.838				0.938	0.912	0.838
	CA2	3.350	1.005	0.892						0.892		
CCO	**CCO1**	4.608	0.849	0.949	0.950	0.864				0.949	0.950	0.864
	CCO2	4.683	0.796	0.959						0.959		
	CCO4	4.617	0.787	0.880						0.880		
IA SRA	**IA SR2**	4.025	1.004	0.960	0.972	0.896	0.960	0.972	0.897	0.960	0.972	0.896
	IA SR3	4.092	1.008	0.968			0.968			0.968		
	IA SR4	4.033	1.024	0.925			0.923			0.923		
	IA SRA1	3.983	1.088	0.934			0.936			0.936		
PBC	**PBC2**	3.875	1.005				0.930	0.967	0.906	0.934	0.967	0.906
	PBC3	4.008	1.021				0.955			0.952		
	PBC4	3.992	1.012				0.970			0.969		
RP	**RP1**	4.358	0.990	0.871	0.918	0.736				0.867	0.917	0.736
	RP2	4.308	1.039	0.821						0.819		
	RP3	4.625	0.764	0.865						0.865		
	RP4	4.583	0.812	0.874						0.879		
SE	**SE1**	3.850	1.100	0.916	0.930	0.817				0.910	0.931	0.818
	SE2	3.808	1.019	0.941						0.937		
	SE3	3.583	1.085	0.852						0.866		
SRA CC	**SRA CC3**	3.892	1.264	0.851	0.894	0.739	0.851	0.894	0.739	0.851	0.894	0.739
	SRA CC4	3.908	1.183	0.936			0.936			0.936		
	SRA CC5	3.608	1.337	0.785			0.785			0.785		
SN	**SN2**	3.733	1.499				1.000					

occurrence ($\beta = 0.259$, $p = 0.05$) and self-efficacy ($\beta = 0.337$, $p < 0.01$) have a positive and significant impact on beekeepers' intentions to adopt resilience strategies. Risk perception positively impacts attitudes toward resilience strategies ($\beta = 0.353$, $p < 0.01$), which, in turn, positively and significantly impacts beekeepers' intentions to adopt resilience strategies ($\beta = 0.273$, $p < 0.01$), revealing an indirect effect of risk perception on behavioral intention. Additionally, the results reveal a positive and significant impact of self-efficacy on perceived behavioral control ($\beta = 0.779$, $p < 0.001$). In addition, behavioral intention has a positive and significant impact on the implementation and choice of these adaptation strategies and practices ($\beta = 0.424$, $p < 0.01$).

The overall model fit was evaluated to determine the validity and explanatory strength of the model by examining the standardized root mean square residual (SRMR) and the normed fit index (NFI). The SRMR values for the PMT model, TPB, and the extended PMT model are 0.072, 0.061, and 0.069, respectively, indicating a good fit (<0.080). The NFI values for these models are 0.724, 0.827, and 0.699, respectively, which are deemed acceptable (Table 6).

In this study, based on the R^2 values (see Table 7), the PMT model shows that beekeepers' intentions to adopt resilience strategies are explained by their perceptions of climate change occurrence, coping appraisal efficacy, and self-efficacy, accounting for 61.5%. This is considered satisfactory, as it exceeds the 0.26 threshold suggested by Cohen (1988). The final endogenous variable, "implementation and choice of resilient behaviors by beekeepers in response to climate change," is

TABLE 4 Collinearity statistics (variance inflation factor; VIF): inner model.

Hypothesis	PMT model	TPB	Extended PMT
ATT -> IA SRA		1.823	1.922
CA -> IA SRA	1.930		2.259
CA-C -> IA SRA	1.443		1.543
CCO -> IA SRA	2.208		2.306
IA SRA -> SRA CC	1.000	1.000	1.000
PBC -> IA SRA		1.717	3.802
RP -> ATT			1.000
RP -> IA SRA	2.498		2.496
SE -> IA SRA	1.998		2.852
SE -> PBC			1.000
SN -> IA SRA		1.155	

explained by 18% of the behavioral intention. In the TPB model, beekeepers' intentions to adopt resilience strategies are explained by perceived behavioral control and attitudes toward adaptation and resilience strategies, reaching 56.3%. The resilient behavior of beekeepers in response to climate change is explained by 17.9% of the behavioral intention. In the extended PMT model, perceptions of climate change occurrence, self-efficacy, and attitudes toward resilience strategies explain 66.6% of their intention to adopt resilient practices, while the beekeepers' resilient behavior in response to climate change is again explained by 17.9% of the behavioral intention. Additionally, our results for the three models demonstrate that the Q^2 values for beekeepers' intentions to adopt resilience strategies and the implementation of these strategies are greater than zero, signifying predictive relevance.

Figures 5–7 show the SEM determining the factors affecting the adaptive behavior of beekeepers facing climate change based

TABLE 5 Assessment of the structural models and significance testing results.

Hypothesis		PMT model		TPB model		Extended PMT model	
		β	t-values	β	t-values	β	t-values
H1	**RP -> IA SRA**	−0.229	1.545			−0.208	1.563
H2	**CCO -> IA SRA**	0.329*	2.431			0.259*	2.244
H3	**CA-C -> IA SRA**	0.142	1.418			0.075	0.782
H4	**CA -> IA SRA**	0.245*	2.132			0.197	1.656
H5	**SE -> IA SRA**	0.487***	4.337			0.337**	2.938
H6	**IA SRA -> SRA CC**	0.424***	4.264	0.424***	4.255	0.424***	4.258
H7	**PBC -> IA SRA**			0.480***	3.670	0.089	0.479
H8	**ATT -> IA SRA**			0.313**	2.863	0.273**	2.895
H9	**SN -> IA SRA**			0.071	1.376		
H10	**RP -> ATT**					0.353**	2.769
H11	**SE -> PBC**					0.779***	13.400

Significance level of beta coefficient: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 6 Models fit.

Fit indices	PMT	TPB	Extended PMT	Minimum Cut-Off	Recommended by
SRMR	0.072	0.061	0.069	<0.08	Hu and Bentler, 1998
NFI	0.724	0.827	0.699	>0.50	Lohmöller, 1989

TABLE 7 Comparison of PMT, TPB and extended PMT models.

Constructs	R-square			BIC		
	PMT	TPB	Extended PMT	PMT	TPB	Extended PMT
ATT			0.125			−7.413
IA SRA	0.615	0.563	0.666	−86.819	−81.159	−94.348
PBC			0.607			−103.594
SRA CC	0.180	0.179	0.179	−15.203	−15.152	−15.162

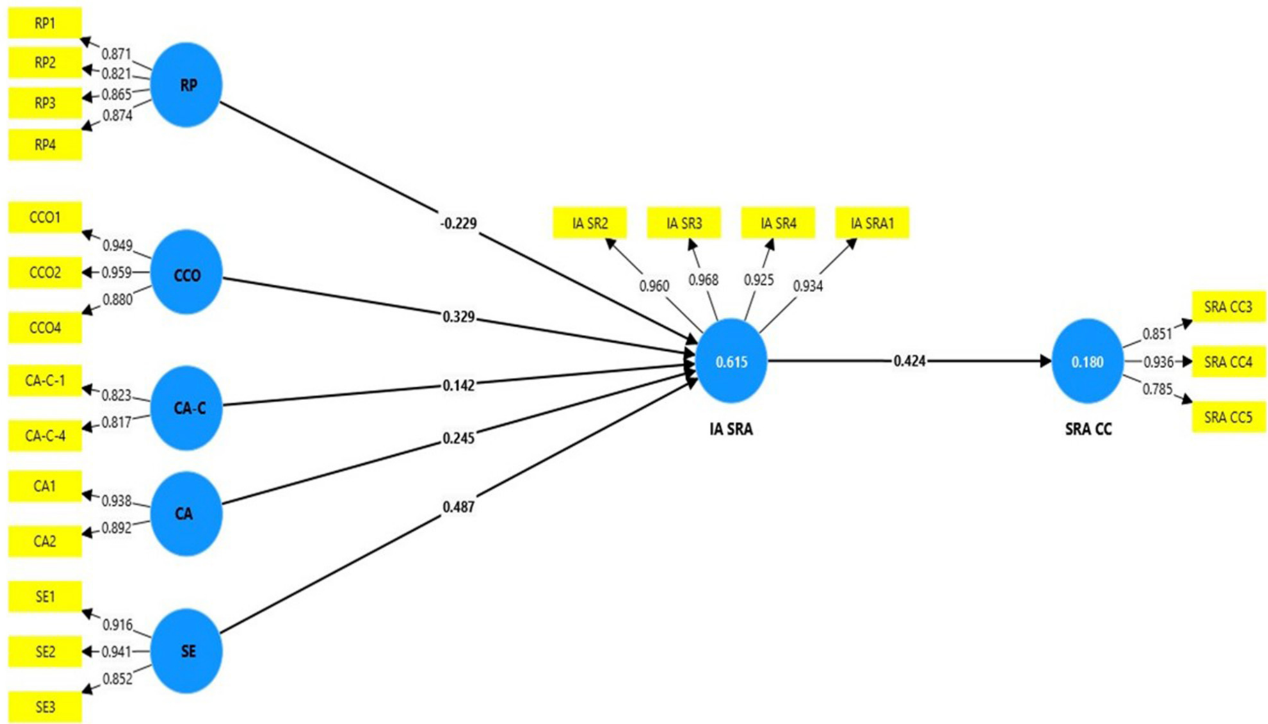

FIGURE 5
SEM for determining the factors affecting the adaptive behavior of beekeepers facing climate change based on PMT.

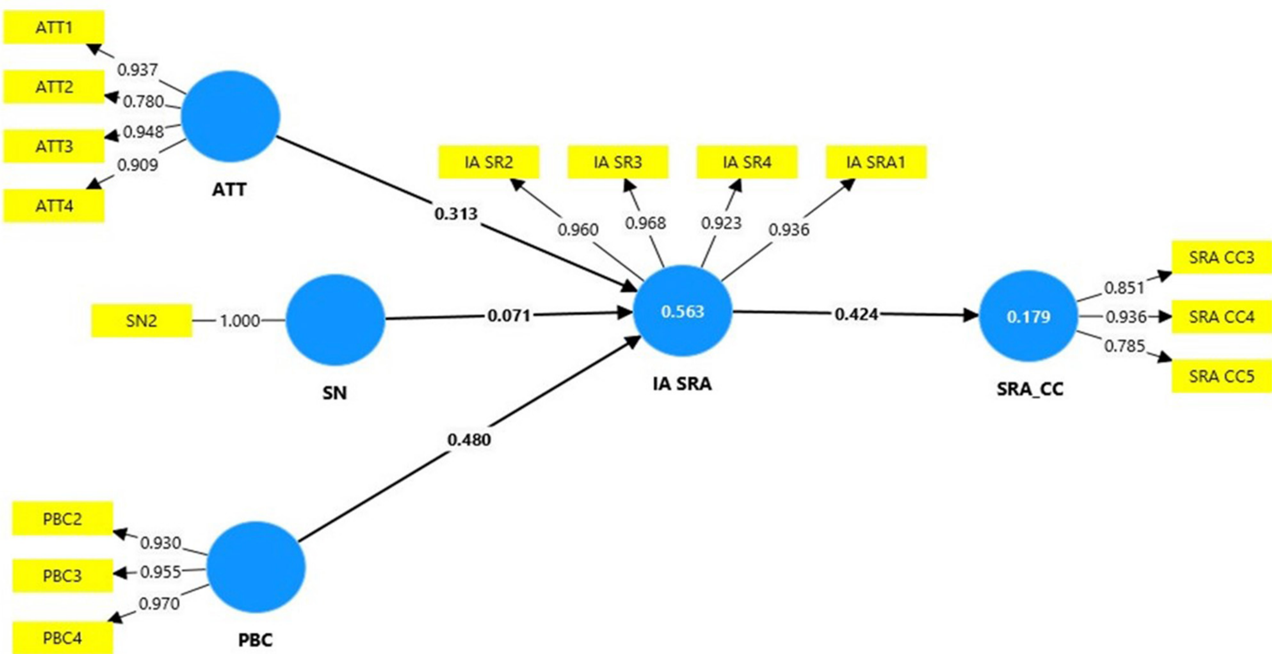

FIGURE 6
SEM for determining the factors affecting the adaptive behavior of beekeepers facing climate change based on TPB.

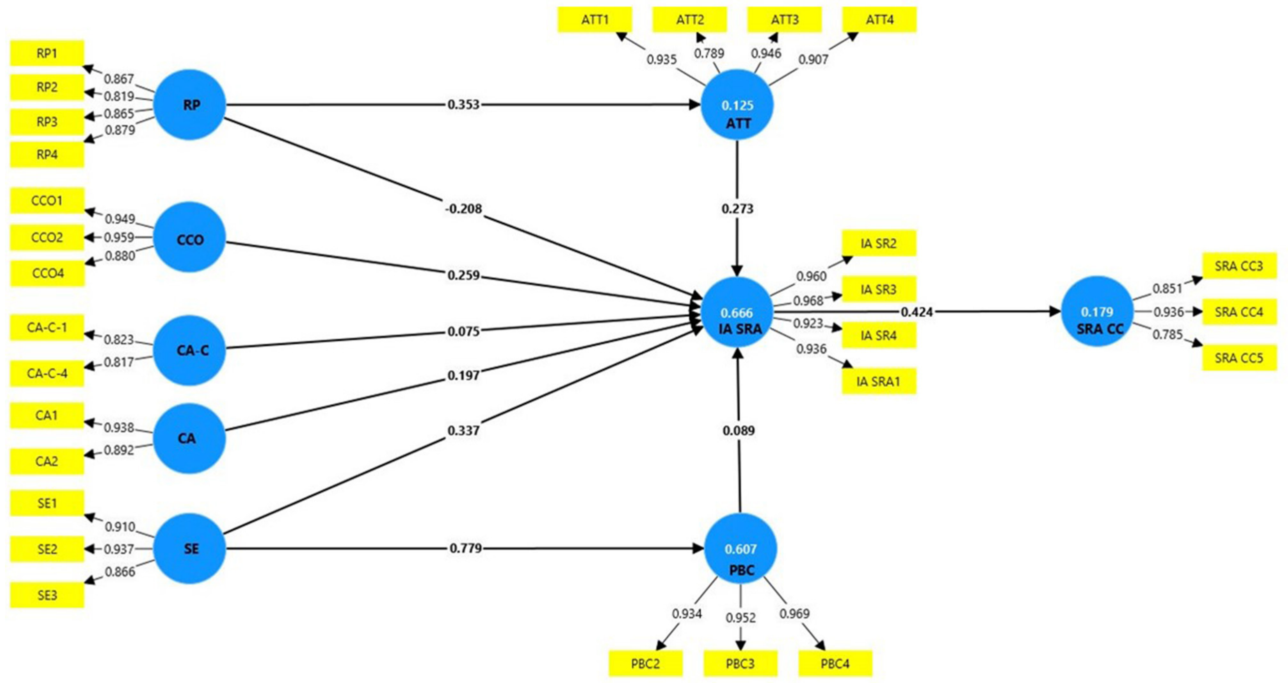

FIGURE 7
SEM for determining the factors affecting the adaptive behavior of beekeepers facing climate change based on the extended PMT.

on PMT, TPB, and the extended PMT. The PMT model initially comprised 7 constructs and 21 indicators. The TPB model initially comprised 5 constructs and 15 indicators. The extended PMT model was enhanced by 2 constructs and 7 indicators.

4.4 Models' comparison

As suggested by Sok et al. (2020), we initially focused on analyzing the TPB and PMT models in their basic, original forms by examining the direct effects of various factors. This approach paved the way for the development of the extended PMT model, which was then tested for potential mediation effects between factors (Borau et al., 2015). This approach allowed us to demonstrate that the model extension enhances the understanding and fit of the behaviors exhibited by beekeepers. Specifically, starting with the original TPB model, we found that, unlike subjective norms, factors such as attitudes and perceived behavioral control significantly influenced the intention to adopt mitigation strategies. In turn, this intention significantly impacted the adoption of resilience strategies. In the original PMT model, three out of five explanatory variables had a substantial effect on the intention to adapt to climate change. The two factors that were not found to be significant were the perceived cost of adaptation and the perception of climate change risks. Furthermore, intention played a key role in influencing the adoption of adaptation strategies (Table 6).

In the extended PMT model with proposed mediation effects, the attitude variable mediated the relationship between risk perception and adaptation intent, whereas risk perception did not have a significant direct effect on adaptation intent in the original PMT model. Additionally, the direct effect of self-efficacy on adaptation intent, observed in the original PMT model, remained significant in the extended PMT model. Notably, self-efficacy was shown to have a significant impact on perceived behavioral control, aligning with our hypotheses. These findings emphasize the added value of the extended PMT model, even though the sample size was relatively small. In fact, as highlighted by Sok et al. (2020), larger sample sizes are necessary to better detect significant mediation and moderation effects in extended structural equation models.

In addition, as outlined in the methodological approach of our study, the three-model comparison is based on R^2 and BIC (see Table 7). The extended PMT model accounts for 66.6% of the variation in the beekeeper's intention to adopt resilient behaviors in response to climate change. This value significantly surpasses those of the other two models, indicating that the extended model is more explanatory. Consequently, the extended PMT model demonstrates the best in-sample predictive capability. Comparing BIC values, the results reveal that the integrated PMT model (BIC $= -94.348$) significantly outperforms both the PMT model (BIC $= -86.819$) and the TPB model (BIC $= -81.159$) in predicting beekeepers' intentions to adopt resilient strategies for climate change. Our hypothesis H12 is thus validated (Sharma et al., 2019, 2021).

The three models—extended PMT, PMT, and TPB—account for ~18% of the variance in resilient behaviors and adaptation strategy choices, demonstrating acceptable explanatory power close to the 20% threshold typically expected in behavioral studies (Hair et al., 2010). The BIC values for all three models are similar, indicating comparable predictive accuracy for beekeepers' resilient behaviors.

5 Discussion

First, the findings of this study highlight a positive and significant impact of perceived climate change manifestations on beekeepers' intention to adopt resilient strategies. This means that when farmers perceive that climate change is genuinely occurring in different forms, they are more likely to express an intention to adopt adaptation strategies. Similar findings are reported by Badsar and Karami (2021) and Getu et al. (2025), who concluded that the perception of climate change occurrence (perceived severity and perceived impacts) influences the behavioral intention to adopt resilience and adaptation strategies to face climate change.

Second, in contrast to previous research in other agricultural sectors suggesting that the high risks associated with climate change significantly influence the intention to adopt resilience strategies (Martin et al., 2007; Villamor et al., 2023; Karrer, 2012), the results of this study indicate that perceived risk does not have a significant direct impact on beekeepers' intention to adopt resilience strategies. However, the extended PMT model demonstrates a positive and significant indirect effect of risk perception on beekeepers' intention to adapt, mediated by their attitudes toward adaptation strategies. These results align with those of Purwanti et al. (2023), which show that perceived risk indirectly but significantly affects adaptation intentions. Indeed, our descriptive analysis of the issues and challenges faced by beekeepers in Tunisia, particularly their perception of the negative impacts of climate change, shows that they are quite aware of the challenges and climatic conditions affecting their beekeeping activities. They also associate specific strategies with each issue. This understanding contributes to the significant positive impact of risk perception on their favorable attitudes toward the adaptation strategies they intend to implement. The positive attitude toward resilience strategies significantly influences beekeepers' intention to adopt these strategies, as evidenced by both the TPB model and the extended PMT model. This result confirms the findings of Asrari et al. (2022), Ofoegbu and Speranza (2017), Hounnou et al. (2023), and Badsar et al. (2023), who reported similar results. Consequently, it is advisable for beekeepers to be informed about the benefits of adopting resilience strategies to enhance their activities in the face of climate change, as this can raise their awareness and shape their attitudes and intentions to adopt.

Meanwhile, the cost of adaptation measures has been recognized as a barrier to adapting to climate change in previous research by Bryan et al. (2009); Ndamani and Watanabe (2015); Purwanti et al. (2023), and Regasa and Abera (2019). However, the results of this study do not show a significant impact of response costs on beekeepers' intention to adapt to climate change. This may be attributed to their awareness of the benefits of resilience practices and their experience in implementing adaptation strategies, particularly as we identified a significant influence of beekeepers' coping appraisal.

Moreover, the PMT and extended PMT models indicate that beekeepers' perception of self-efficacy has a direct and significant positive impact on their intention to adapt to climate change, as well as on their perception of behavioral control. The findings of Getu et al. (2025), Villamor et al. (2023), and Regasa and Abera (2019) also suggest that higher self-efficacy leads to a stronger intention to adopt adaptive measures. For instance, Yap and Lee (2013) characterized self-efficacy as an internal factor influencing perceived behavioral control (PBC), highlighting that self-efficacy is often a more reliable predictor of behavior and intentions than PBC, which encompasses both internal and external factors.

Our results from the TPB model contrast with previous research that demonstrated that the variable of subjective norms had a positive, direct, and significant impact on the intention to adopt resilient behaviors, whereas perceived behavioral control did not show a significant effect (Asrari et al., 2022; Ofoegbu and Speranza, 2017; Hounnou et al., 2023). This may be attributed to the fact that beekeepers in Tunisia are not particularly influenced by the opinions and experiences of their colleagues, relatives, or their environment. Instead, they rely on their own attitudes, experiences, and personal judgments. Our PMT model supports this, showing a positive and significant impact of their perception of their current level of adaptation and their experiences with resilience strategies, as demonstrated by a significant positive impact of coping appraisal on adaptation intent, which confirms the results of Bagagnan et al. (2019).

Our outcomes showed a positive and significant impact of PBC on beekeepers' intention to adopt resilient behavior within the TPB model, contrasting with a non-significant impact via the extended PMT model. This is particularly evident, as previous case studies revealed no consensus on the impact of perceived behavioral control. The difference in the significance of PBC between the TPB and extended PMT models may also arise from how the construct is measured. In the TPB model, PBC is often captured with well-defined items reflecting both internal and external control, enabling it to strongly predict intention. However, in the extended PMT model, similar items may overlap conceptually with constructs like self-efficacy, which is modeled separately. This overlap reduces the distinctiveness and explanatory power of PBC, possibly leading to statistical insignificance. Compared to other studies, findings from Hounnou et al. (2023) demonstrated that PBC positively impacted the intention to use climate forecasts in agricultural decision-making. However, conclusions from previous research demonstrated that perceived behavioral control did not show a significant effect on the intention to adopt resilient behaviors (Asrari et al., 2022). Additionally, perceived behavioral control was negatively correlated with intention according to Ofoegbu and Speranza (2017).

In all three models analyzed, the intention to adopt resilience strategies significantly influences actual adoption among Tunisian beekeepers. These findings are consistent with those outlined in our literature review (Badsar et al., 2023; Hou and Hou, 2019; Arendt et al., 2013).

Furthermore, the results reveal that the integrated PMT model significantly outperforms both the PMT model and the TPB model. These findings are consistent with those of Xiang and Guo (2023), who found that an integrated model was more effective in predicting farmers' intentions to adopt green pest and disease control techniques compared to individual theoretical models. Similarly, Sharifzadeh et al. (2017) and Rezaei et al. (2020) argued that integrated models provide a more comprehensive understanding of behavioral intentions than any single theory. Cai et al. (2024) also highlighted the importance of an integrated framework in studying herders' perceptions and adaptations to climate change, incorporating the theory of planned behavior (TPB), protection motivation theory (PMT), and climate experience. Badsar et al. (2023) reinforced this view, emphasizing the value of an extended model.

6 Conclusions and implications

This research investigates beekeepers' intentions to implement resilience strategies for mitigating climate change problems by comparing three models: TPB, PMT, and an extended PMT model. It employs a structural equation model to test a comprehensive framework, incorporating variables from both TPB and PMT, and explores the interrelations between constructs such as perceived climate change risk and attitudes toward resilience strategies, as well as between self-efficacy and perceived behavioral control.

Empirically, the study identifies both direct and indirect determinants with significant effects on beekeepers' adoption of resilience strategies, particularly in the Tunisian context. These findings offer valuable insights into the psychological mechanisms behind resilience adoption, which can guide policymakers and stakeholders in developing targeted interventions to promote the adoption of resilience strategies.

This study's findings highlight the significance of the three chosen models in assessing beekeepers' intentions to implement coping strategies for climate change issues. However, the extended PMT model offers a broader and more comprehensive scope, aligning with findings from numerous prior studies in the field. Specifically, the TPB model reveals the substantial influence of perceived behavioral control, attitudes toward climate change resilience strategies, and practices on the intention to adopt them. This intention, in turn, significantly affects the choice of strategy to implement. The PMT model highlights the important roles of self-efficacy, coping appraisal, and the perception of climate change occurrence in shaping the intent to adopt resilience strategies, with self-efficacy emerging as the most impactful factor. Furthermore, the intention to adopt these measures plays a decisive role in selecting specific strategies.

Building on both models, the extended PMT model further confirms the significant influence of climate change perception, self-efficacy, and attitude on beekeepers' adaptation intentions. Notably, self-efficacy has a dominant effect and also strongly influences perceived behavioral control. The extended model also validates the significant role of adaptation intention in determining the choice of resilience strategies and practices.

Our findings underscore the beneficial connection between the TPB and PMT models, along with the significant interactions among variables. Specifically, perceptions of climate change risk notably affect attitudes toward resilience strategies, which, in turn, influence adaptation intentions, demonstrating significant mediating effects. Additionally, self-efficacy plays a crucial role in shaping an individual's perceived behavioral control, thereby impacting their intention to adapt. This highlights the theoretical contribution of our research.

The research underscores the necessity for effective communication regarding the onset of climate change, which presents an urgent challenge requiring prompt action from all stakeholders in the agri-food system, especially beekeepers, to improve their adaptation strategies and implement resilience measures. Beekeepers must be educated on how climate change impacts both bees and apiculture practices. It's important for them to understand how climate variability creates specific challenges for bees and affects flower availability, bee migration patterns, diseases, and more. Tailored workshops, training, and extension services can be highly beneficial in providing this information.

Additionally, raising awareness of the risks associated with climate change would strengthen beekeepers' attitudes toward innovative resilience strategies and measures, such as precision beekeeping, connected hives, and the use of advanced technologies like blockchain, which are viewed as critical for resilience and positively influence their intention to adopt climate change resilience strategies. Beekeepers are more inclined to adopt resilience strategies when they perceive climate change as an immediate threat to their livelihoods, fostering a sense of urgency for adaptation. Highlighting local case studies of beekeepers who have faced climate-related risks such as nectar deficiency or decreased nectar production and who have successfully implemented resilience practices can serve as an effective communication tool. In fact, beekeepers often place more trust in advice from their peers than in guidance from external experts. However, it's crucial to consider regional differences by focusing on the specific risks beekeepers face in their area. It's also important to emphasize the additional benefits of adopting climate resilience strategies, such as increased productivity, reduced costs, and improved honey quality, to improve beekeepers' attitudes toward mitigation strategies.

Moreover, self-efficacy perception and perceived behavioral control are crucial in beekeepers' decision-making. In this case, training sessions, mentoring, and demonstrating that resilience measures are both practical and achievable will be of great use.

Furthermore, the perceived effectiveness of these strategies in responding to climate change could further reinforce adaptation intentions among beekeepers. Therefore, it is essential to provide beekeepers with tools for evaluating and monitoring the environmental, social, and economic impacts of selected resilience strategies, highlighting the crucial role of support institutions in this process.

As a political implication, it is essential to establish a supportive policy and incentive framework that encourages climate adaptation among beekeepers, given the sector's critical role in food security. Government-supported training programs, subsidies for new technologies, and the promotion of peer networks can motivate beekeepers to adopt these practices.

Despite the valuable results and both theoretical and practical implications, this study has some limitations. It primarily focuses on Tunisia, which may limit the ability to generalize the findings to other regions due to differences in socio-cultural, economic, and climatic factors. Additionally, the sample size may not be sufficient to capture local variations in beekeepers' perceptions and coping strategies. A larger sample could offer greater insight into the factors influencing a complex theoretical model like the extended PMT. Therefore, this research opens up several avenues for further exploration, such as studying other contexts and exploring different methodological approaches and theoretical frameworks. Considering the limitations of cross-sectional data, particularly the difficulty in establishing causality, future research should focus on validating and gaining a deeper understanding of the relationship between intentions and behaviors. A valuable approach would be to undertake longitudinal studies that follow individuals over time to determine if their stated intentions lead to real actions.

Author's note

The content of this article reflects only the authors' views, and the European Union Agency is not responsible for any use that may be made of the information it contains.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

EO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. YE: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. LA: Methodology, Writing – review & editing. TD: Funding acquisition, Writing – review & editing. SO: Writing – review & editing. ZK: Funding acquisition, 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.

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

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References

Abid, M., Scheffran, J., Schneider, U. A., and Elahi, E. (2019). Farmer perceptions of climate change observed trends and adaptation of agriculture in Pakistan. *Environ. Manag.* 63, 110–123. doi: 10.1007/s00267-018-1113-7

Ajzen, I. (1991). The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* 50, 179–211. doi: 10.1016/0749-5978(91)90020-T

Ajzen, I. (2002). Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J. Appl. Soc. Psychol.* 32, 665–683. doi: 10.1111/j.1559-1816.2002.tb00236.x

Aldrighetti, R., Battini, D., Ivanov, D., and Zennaro, I. (2021). Costs of resilience and disruptions in supply chain network design models: a review and future research directions. *Int. J. Prod. Econ.* 235:108103. doi: 10.1016/j.ijpe.2021.108103

Anto, A., Sugiyanto, S., Yuliati, Y., and Kustanti, A. (2023). Validity and reliability of the adoption questionnaire of agricultural mechanization in the food estate area of central Kalimantan Indonesia. *Int. J. Sci. Technol. Manag.* 4, 736–741. doi: 10.46729/ijstm.v4i4.855

Arendt, S. W., Paez, P., and Strohbehn, C. (2013). Food safety practices and managers' perceptions: a qualitative study in Hospitality. *Int. J. Contemp. Hosp. Manag.* 25, 124–139. doi: 10.1108/09596111311290255

Armitage, C. J., and Conner, M. (2001). Efficacy of the theory of planned behaviour: a meta-analytic review. *Br. J. Soc. Psychol.* 40, 471–499. doi: 10.1348/014466601164939

Asrari, A., Najafabadi, M. O., and Hosseini, J. F. (2022). Modeling resilience behavior against climate change with food security approach. *J. Environ. Stud. Sci.* 12, 547–565. doi: 10.1007/s13412-022-00763-z

Asrat, P., and Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecol. Process* 7, 1–13. doi: 10.1186/s13717-018-0118-8

Badsar, M., and Karami, R. (2021). Understanding farmers' response to renewable energy: an application of protection motivation theory. *J. Agric. Sci. Technol.* 23, 987–1000. Available online at: http://jast.modares.ac.ir/article-23-42761-en.html

Badsar, M., Moghim, M., and Ghasemi, M. (2023). Analysis of factors influencing farmers' sustainable environmental behavior in agriculture activities: integration of the planned behavior and the protection motivation theories. *Environ. Dev. Sust.* 25, 9903–9934. doi: 10.1007/s10668-022-02468-3

Bagagnan, A. R., Ouedraogo, I., Fonta, W. M., Sowe, M., and Wallis, A. (2019). Can protection motivation theory explain farmers' adaptation to climate change decision making in the Gambia? *Climate* 7:13. doi: 10.3390/cli7010013

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control.* New York, NY: W H Freeman/Times Books/ Henry Holt & Co. Available online at: https://www.academia.

edu/28274869/Albert_Bandura_Self_Efficacy_The_Exercise_of_Control_W_H_Freeman_and_Co_1997_pdf

Barroca, B., and Serre, D. (2013). *Behind the Barriers: A Resilience Conceptual Model, S.A.P.I.EN.S Surveys and Perspectives Integrating Environment and Society 6.1. Vol. 6*. Paris: Resilient Cities. by Institut Veolia Environnement.

Bedeke, S., Vanhove, W., Gezahegn, M., Natarajan, K., and Van Damme, P. (2018). Adoption of climate change adaptation strategies by maize-dependent stallholders in Ethiopia. *NJAS Wageningen J. Life Sci.* 88, 96–104. doi: 10.1016/j.njas.2018.09.001

Borau, S., El Akremi, A., Elgaaied-Gambier, L., Hamdi-Kidar, L., and Ranchoux, C. (2015). L'analyse des effets de mediation moderee: applications en marketing. *Rech. Applic. Market.* 30. doi: 10.1177/0767370115585307

Bradley, G., Babutsidze, Z., Chai, A., and Reser, J. P. (2020). The role of climate change risk perception, response efficacy, and psychological adaptation in pro-environmental behavior: a two-nation study. *J. Environ. Psychol.* 68:101410. doi: 10.1016/j.jenvp.2020.101410

Bryan, E., Deressa, T. T., Gbetibouo, G. A., and Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: OPTIONS and constraints. *Environ. Sci. Policy* 12, 413–426. doi: 10.1016/j.envsci.2008.11.002

Cai, Y., Zhao, M., Khan, A., and Shi, Y. (2024). Understanding herder's perception and adaptation to climate change: an integrated framework. *Environ. Dev. Sust.* 26. doi: 10.1007/s10668-024-04907-9

Carducci, A., Fiore, M., Azara, A., Bonaccorsi, G., Bortoletto, M., Caggiano, G., et al. (2021). Pro-Environmental behaviors: déterminants and obstacles among Italian university students. *Int. J. Environ. Res. Public Health* 18:3306. doi: 10.3390/ijerph18063306

Chen, M. F. (2020). Moral extension of the protection motivation theory model to predict climate change mitigation behavioral intentions in Taiwan. *Environ. Sci. Pollut. Res.* 27, 13714–13725. doi: 10.1007/s11356-020-07963-6

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Science, 2nd Edn*. Hillsdale, NJ: Laurence Erlbaum Associates.

Dang, H. L., Li, E., Nuberg, I., and Bruwer, J. (2014). Understanding farmers' adaptation intention to climate change: a structural equation modelling study in the Mekong Delta, Vietnam. *Environ. Sci. Policy* 41, 11–22. doi: 10.1016/j.envsci.2014.04.002

Daxini, A., Ryan, M., O'Donoghue, C., and Barnes, A. (2019). Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behavior. *Land Use Policy* 85, 428–437. doi: 10.1016/j.landusepol.2019.04.002

Debbabi, H., Ben Ismail, H., and Jmal, S. (2024). *Handbook Mediterranean Challenges for Food Safety and Authenticity of Honey*. doi: 10.5281/zenodo.10216020

Dessart, F. J., Barreiro-Hurlé, J., and Van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. *Eur. Rev. Agric. Econ.* 46, 417–471. doi: 10.1093/erae/jbz019

Di Falco, S., Veronesi, M., and Yesuf, M. (2011). Does Adaptation to climate change provide food security? A micro-perspective from Ethiopia. *Am. J. Agric. Econ.* 93, 825–842. doi: 10.1093/ajae/aar006

Droms, C. M., and Craciun, G. (2014). The impact of attitudinal ambivalence on weight loss decisions: consequences and mitigating factors. *J. Cons. Behav.* 13, 303–315. doi: 10.1002/cb.1475

Dzvene, A. R., Zhou, L., Slayi, M., and Dirwai, T. L. (2025). A scoping review on challenges and measures for climate change in arid and semi-arid agri-food systems. *Discov. Sust.* 6:151. doi: 10.1007/s43621-025-00945-z

Elgendy, M., Hassini, S., and Coulibaly, P. (2024). Review of climate change adaptation strategies in water management. *J. Hydrol. Eng.* 29. doi: 10.1061/JHYEFF.HEENG-6014

Erdoğan, Y. (2023). "Climate change and beekeeping," in *Current Issues in Agriculture* (Ankara: İksad Yayınevi). doi: 10.5281/zenodo.10392176

Fikadu, Z. (2019). The contribution of managed honey bees to crop pollination, food security, and economic stability: case of Ethiopia. *Open Agric. J.* 13, 175–181. doi: 10.2174/1874331501913010175

Fishbein, M., and Ajzen, I. (1975). *Belief Attitude Intention and Behavior: An Introduction to Theory and Research*. Reading, MA: Addison-Welsey.

Gashure, S. (2024). Adaptation strategies of smallholder farmers to climate variability and change in Konso, Ethiopia. *Sci. Rep.* 14:19203. doi: 10.1038/s41598-024-70047-9

Getu, E., Ayenew, B., Singh, K., and Worku M, A. (2025). Factors influencing urban farmers' intention to adapt to climate change in Addis Ababa, Ethiopia: a protection motivation theory. *Front. Clim.* 7:1541228. doi: 10.3389/fclim.2025.1541228

Ghanian, M., Ghoochani, O. M., Dehghanpour, M., Taqipour, M., Taheri, F., and Cotton, M. (2020). Understanding farmers' climate adaptation intention in Iran: a protection-motivation extended model. *Land Use Policy* 94, 1–13. doi: 10.1016/j.landusepol.2020.104553

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2010). *Multivariate Data Analysis, 7th Edn*. New York, NY: Pearson.

Hair, J. F., Hult, G. T. M., Ringle, C. M., and Sarstedt, M. (2017). *A Primer on Partial Least Squares Structural Equations Modeling (PLS-SEM)*. Thousand Oaks, CA: SAGE.

Hair, J. F., Ringle, C. M., and Sarstedt, M. (2011). PLS-SEM: indeed a silver bullet. *J. Market. Theory Pract.* 19, 139–152. doi: 10.2753/MTP1069-6679190202

Hair, J. F., Risher, J. J., Sarstedt, M., and Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *Eur. Business Rev.* 31, 2–24. doi: 10.1108/EBR-11-2018-0203

Hair, J. F. Jr., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., and Ray, S. (2021). *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook, 1st Edn*. Cham: Springer International Publishing. doi: 10.1007/978-3-030-80519-7_1

Hasibuan, A. M., Wulandari, S., Ardana, I. K., Saefudin, and Wahyudi, A. (2023). Understanding climate adaptation practices among small-scale sugarcane farmers in Indonesia: the role of climate risk behaviors, farmers' support systems, and crop-cattle integration. *Resour. Environ. Sust.* 13:100129. doi: 10.1016/j.resenv.2023.100129

Henseler, J., Dijkstra, T., Sarstedt, M., Ringle, C., Diamantopoulos, A., and Straub, D. (2014). Common beliefs and reality about partial least squares: comments on Rönkkö and Evermann. *Organ. Res. Methods* 17, 182–209. doi: 10.1177/1094428114526928

Hou, J., and Hou, B. (2019). Farmers' adoption of low-carbon agriculture in China: an extended theory of the planned behavior model. *Sustainability* 11:1399. doi: 10.3390/su11051399

Hounnou, F. E., Omotayo, A. O., Houessou, A. M., and Dedehouanou, H. (2023). Smallholder farmers' intention to use climate forecast services in the Benin Republic, West Africa. *Clim. Dev.* 15, 850–863. doi: 10.1080/17565529.2023.2172314

Hu, L. T., and Bentler, P. M. (1998). Fit indices in covariance structure modeling: sensitivity to under parameterized model misspecification. *Psychol. Methods* 3, 424–424. doi: 10.1037//1082-989X.3.4.424

Janz, N. K., and Becker, M. H. (1984). The Health Belief Model: a decade later. *Health Educ. Q.* 11, 1–47. doi: 10.1177/109019818401100101

Jmal, S., Ben Ismail, H., Hamzaoui, M., Ben Salem, H., and Hajer Debbabi, H. (2024). Analysis of Tunisian beekeepers' perceptions in honey bee diseases and pests management. *Egypt. J. Agric. Sci.* 75, 48–59 doi: 10.21608/ejarc.2024.345965

Josef, M. (2013). Study on agriculture decision-makers behavior on sustainable energy utilization. *J. Agric. Environ.* 26, 679–689. doi: 10.1007/s10806-012-9423-x

Kahramanoglu, I. (2020). Reasons behind the farmers' behaviour about the implementation of sustainable farming practices. *J. Sociol. Soc. Anthropol.* 11, 67–77. doi: 10.31901/24566764.2020/11.1-3.344

Karrer, S. L. (2012). *Swiss Farmers' Perception of and Response to Climate Change* (Thesis for: Ph.D.). ETH Zurich: Zürich, Switzerland. Advisor: Bernard Lehmann; Michael Siegrist.

Kim, S., Jeong, S. H., and Hwang, Y. (2013). Predictors of pro-environmental behaviors of American and Korean Students: the application of the theory of reasoned action and protection motivation theory. *Sci. Commun.* 35, 168–188. doi: 10.1177/1075547012441692

Landaverde, R., Rodriguez, M. T., and Parrella, J. A. (2023). Honey production and climate change: beekeepers' perceptions, farm adaptation strategies, and information needs. *Insects* 14:493. doi: 10.3390/insects14060493

Lee, Y. J., and Lin, S. Y. (2022). Effects of perceptions of climate change and flood risk on coping behavior: a case study of Taipei, Taiwan. *Sustainability* 14:289. doi: 10.3390/su14010289

Li, J., Liu, G., Chen, Y., and Li, R. (2023). Study on the influence mechanism of adoption of smart agriculture technology behavior. *Sci. Rep.* 13:8554. doi: 10.1038/s41598-023-35091-x

Lin, W. H., Lin, Q., Tang, D., and Yan, Y. (2024). A study on the factors influencing the intention to revisit forest tourism based on PMT-TPB? *Curr. Psychol.* 43, 11841–11853 doi: 10.1007/s12144-023-05278-6

Lohmöller, J. B. (1989). "Predictive vs. structural modeling: PLS vs. ML," in *Latent Variable Path Modeling with Partial Least Squares* (Heidelberg: Physica), 199–226. doi: 10.1007/978-3-642-52512-4_5

Luu, T. A., Nguyen, A. T., Trinh, Q. A., Pham, V. T., Le, B. B., Nguyen, D. T., et al. (2019). Farmers' intention to climate change adaptation in agriculture in the Red River Delta Biosphere Reserve (Vietnam): a combination of Structural Equation Modeling (SEM) and Protection Motivation Theory (PMT). *Sustainability* 11:2993. doi: 10.3390/su11102993

Makamane, A., Loki, O., Swanepoel, J., Zenda, M., and Van Niekerk, J. (2025). Farmers' perceptions on the capacity of extension practitioners on climate change in the Eastern Cape Province of South Africa. *Front. Clim.* 7:1534254. doi: 10.3389/fclim.2025.1534254

Manstead, A. S., and Eekelen, S. A. (1998). Distinguishing between perceived behavioral control and self-efficacy in the domain of academic achievement intentions and behaviors. *J. Appl. Soc. Psychol.* 28, 1375–1392. doi: 10.1111/j.1559-1816.1998.tb01682.x

Martin, I. M., Bender, H., and Raish, C. (2007). What motivates individuals to protect themselves from risks: the case of wildland fires. *Risk Anal.* 27, 887–900. doi: 10.1111/j.1539-6924.2007.00930.x

Mutyasira, V., Hoag, D., and Pendell, D. (2018). The adoption of sustainable agricultural practices by smallholder farmers in Ethiopian highlands: an integrative approach. *Cogent Food Agric.* 4:1552439, doi: 10.1080/23311932.2018.1552439

Ndamani, F., and Watanabe, T. (2015). Farmers' perceptions about adaptation practices to climate change and barriers to adaptation: a micro-level study in ghana. *Water* 7, 4593–4604. doi: 10.3390/w7094593

Neumann, P., and Straub, L. (2023). Beekeeping under climate change. *J. Apic. Res.* 62, 963–968. doi: 10.1080/00218839.2023.2247115

Office d'Elevage et de Pâturage (OEP) (2023). *Official Statistics.* Tunisia: OEP.

Ofoegbu, C., and Speranza, S. I. (2017). Assessing rural peoples' intention to adopt sustainable forest use and management practices in South Africa. *J. Sust. Forestry* 36, 729–746. doi: 10.1080/10549811.2017.1365612

Parkinson, J., David, P., and Rundle-Thiele, S. (2017). Self-efficacy or perceived behavioural control: which influences consumers' physical activity and healthful eating behaviour maintenance? *J. Cons. Behav*. 16, 413–423. doi: 10.1002/cb.1641

Pătruică, S., Peţ, I., and Simiz, E. (2021). Beekeeping in the context of climate change. *Sci Papers Ser. D Anim. Sci*. LXIV, 277–280.

Purwanti, T. S., Syafrial, S., Huan, W. S., Hartono, B., Rahman, M. S., and Putritamara, J. A. (2023). Understanding farmers' adaptation to climate change: a protection motivation theory application. *Cogent Soc. Sci.* 9:2282210. doi: 10.1080/23311886.2023.2282210

Rahman, M. S., Huang, W., Toiba, H., Putritamara, J. A., Nugroho, T. W., and Saeri, M. (2023). Climate change adaptation and fishers' subjective well-being in Indonesia: is there a link?. *Reg. Stud. Mar. Sci.* 63:103030. doi: 10.1016/j.rsma.2023.103030

Raza, M. H., Abid, M., Yan, T., Naqvi, S. A. A., Akthar, V. S., and Faisal, M. (2019). Understanding farmers' intentions to adopt sustainable crop residue management practices: a structural equation modeling approach. *J. Clean. Prod.* 227, 613–623. doi: 10.1016/j.jclepro.2019.04.244

Regasa, D. T., and Abera, N. (2019). Determinants of climate change mitigation and adaptation strategies: an application of protection motivation theory in Konta District, South Western Ethiopia. *Eur. Rev. Appl. Sociol.* 12, 49–73. doi: 10.1515/eras-2019-0010

Remotti, F., Mattalia, G., Porporato, M., Cevasco, R., and Pieroni, A. (2024). 'The rules of nature are changing; every year is unpredictable': perceptions of climate change by beekeepers of Liguria, NW Italy. *Reg. Environ. Change* 24:79. doi: 10.1007/s10113-024-02242-3

Rezaei, R., Safa, L., and Ganjkhanloo, M. M. (2020). Understanding farmers' ecological conservation behavior regarding the use of integrated pest management-an application of the technology acceptance model. *Glob. Ecol. Conserv*. 22:e00941. doi: 10.1016/j.gecco.2020.e00941

Rhodes, R. E., and Courneya, K. S. (2003). Investigating multiple components of attitude, subjective norm, and perceived control: an examination of the theory of planned behaviour in the exercise domain. *Br. J. Soc. Psychol.* 42, 129–146. doi: 10.1348/014466603763276162

Rogers, R. W. (1975). A protection motivation theory of fear appeals and attitude change. *J. Psychol.* 91, 93–114. doi: 10.1080/00223980.1975.9915803

Roussel, P., Durrieu, F., Campoy, E., and El Akremi, A. (2005). "Analyse des effets linéaires par modèle d'équations structurelles," in *Management des Ressources Humaines* (Louvain-la-Neuve: De Boeck Supérieur), 297–324. doi: 10.3917/dbu.rouss.2005.01.0297

Schwartz, S. H. (1977). "Normative influence on altruism," in *Advances in Experimental Social Psychology, Vol. 10*, ed. L. Berkowitz (New York, NY: Academic Press), 221–279. doi: 10.1016/S0065-2601(08)60358-5

Schwarz, G. (1978). Estimating the dimension of a model. *Ann. Statist*. 6, 461–464. doi: 10.1214/aos/1176344136

Shafiei, A., and Maleksaeidi, H. (2020). Pro-environmental behavior of university students: application of protection motivation theory. *Glob. Ecol. Conserv*. 22:e00908. doi: 10.1016/j.gecco.2020.e00908

Sharifzadeh, M. S., Damalas, C. A., Abdollahzadeh, G., and Ahmadi-Gorgi, H. (2017). Predicting adoption of biological control among Iranian rice farmers: an application of the extended technology acceptance model (TAM2). *Crop. Prot*. 96, 88–96. doi: 10.1016/j.cropro.2017.01.014

Sharma, P. N., Sarstedt, M., Shmueli, G., Kim, K. H., and Thiele, K. O. (2019). PLS-based model selection: the role of alternative explanations in information systems research. *J. Assoc. Inform. Syst.* 40, 346–397. doi: 10.17705/1jais.00538

Sharma, P. N., Shmueli, G., Sarstedt, M., Danks, N., Ray, S. (2021). Prediction-oriented model selection in partial least squares path modeling. *Decis. Sci.* 52, 567–607. doi: 10.1111/deci.12329

Shen, T., Rasdi, I. B., Ezani, N. E. B., and San, O. T. (2024). The mediating role of pro-environmental attitude and intention on the translation from climate change health risk perception to pro-environmental behavior. *Sci. Rep. Nat.* 14:9831. doi: 10.1038/s41598-024-60418-7

Singh, S. (2020). Farmers' perception of climate change and adaptation decisions: micro-level evidence from Bundelkhand region, India. *Ecol. Indic.* 116:106475. doi: 10.1016/j.ecolind.2020.106475

Sok, J., Borges Joao, R., Schmidt, P., and Ajzen, I. (2020). Farmer behaviour as reasoned action: a critical review of research with the theory of planned behaviour. *J. Agric. Econ.* 72, 388–412. doi: 10.1111/1477-9552.12408

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., and Kalof, L. (1999). A value-belief-norm theory of support for social movements: the case of environmentalism. *Hum. Ecol. Rev.* 6, 81–97.

Sutton, S. (2001). "Health behaviour: psychosocial theories," in *International Encyclopedia of Social and Behavioural Sciences*, eds. N. J. Smelser and B. Baltes (Oxford: Elsevier), 6499–6506. doi: 10.1016/B0-08-043076-7/03872-9

Switanek, M., Crailsheim, K., Truhetz, H., and Brodschneider, R. (2017). Modelling seasonal effects of temperature and precipitation on honey bee winter mortality in a temperate climate. *Sci. Total Environ.* 579, 1581–1587. doi: 10.1016/j.scitotenv.2016.11.178

Takal, T. U., and Amfo, S. (2025). Enhancing resilience to climate change: a comprehensive PRISMA review of agricultural and non-agricultural adaptation strategies for Ghana. *Cogent Soc. Sci.* 11:2453905. doi: 10.1080/23311886.2025.2453905

Tanimonure, V. A., and Naziri, D. (2021). Impact of climate adaptation strategies on the net farm revenue of underutilised indigenous vegetables' (UIVs) production in Southwest Nigeria. *Resour. Environ. Sust.* 5:100029. doi: 10.1016/j.resenv.2021.100029

Tavousi, M., Hidarnia, A. R., Montazeri, A., Hajizadeh, E., Taremain, F., and Ghofranipour, F. (2009). Are perceived behavioral control and self-efficacy distinct constructs? *Eur. J. Scie. Res.* 30, 146–152.

Trafimow, D., Sheeran, P., Conner, M., and Finlay, K. A. (2002). Evidence that perceived behavioural control is a multidimensional construct: perceived control and perceived difficulty. *Br. J. Soc. Psychol.* 41, 101–121. doi: 10.1348/014466602165081

Van Espen, M., Williams, J. H., Alves, F., Hung, Y., de Graaf, D. C., and Verbeke, W. (2023). Beekeeping in Europe facing climate change: a mixed methods study on perceived impacts and the need to adapt according to stakeholders and beekeepers. *Sci. Total Environ*. 888:164255. doi: 10.1016/j.scitotenv.2023.164255

Van Gameren, V., Weikmans, R., and Zaccaï, E. (2014). *L'adaptation au changement climatique. Volume/Séries: Repères (No. 634).* Paris: Éditions La Découverte, 128. doi: 10.3917/dec.gamer.2014.01

Van Oort, P. A., and Zwart, S. J. (2018). Impacts of climate change on rice production in Africa and causes of simulated yield changes. *Glob. Chang. Biol.* 24, 1029–1045. doi: 10.1111/gcb.13967

Varalan, A., and Çevrimli, M. B. (2024). Determination of risk factors in beekeeping enterprises producing geographically indicated Kars honey. *Acta Vet. Eurasia* 50, 141–150. doi: 10.5152/actavet.2024.23099

Vercelli, M., Novelli, S., Ferrazzi, P., Lentini, G., and Ferracini, C. (2021). A qualitative analysis of beekeepers' perceptions and farm management adaptations to the impact of climate change on honey bees. *Insects* 12:228. doi: 10.3390/insects12030228

Villamor, G. B., Wakelin, S. J., Dunningham, A., and Clinton, P. W. (2023). Climate change adaptation behaviour of forest growers in New Zealand: an application of protection motivation theory. *Clim. Change* 176:3. doi: 10.1007/s10584-022-03469-x

Wang, Y., Liang, J., Yang, J., Ma, X., Li, X., Wu, J., et al. (2019). Analysis of the environmental behavior of farmers for non-point source pollution control and management: an integration of the theory of planned behavior and the protection motivation theory. *J. Environ. Manag.* 237, 15–23. doi: 10.1016/j.jenvman.2019.02.070

Westcott, R., Ronan, K., Bambrick, H., and Taylor, M. (2017). Expanding protection motivation theory: investigating an application to animal owners and emergency responders in bushfire emergencies. *BMC Psychol.* 5:13. doi: 10.1186/s40359-017-0182-3

World Bank (2024). Available online at: https://climateknowledgeportal.worldbank.org/country/Tunisia (Accessed December 10, 2024).

Xiang, P., and Guo, J. (2023). Understanding farmers' intentions to adopt pest and disease green control techniques: comparison and integration based on multiple models. *Sustainability* 15:10822. doi: 10.3390/su151410822

Yap, S. F., and Lee, C. K. C. (2013). Does personality matter in exercise participation? *J. Cons. Behav.* 12, 401–411. doi: 10.1002/cb.1442

Yohana, Z. E. (2021). *Assessment of Beekeeping as an Adaptation Strategy Against Impacts of Climate Change in Iramba District* (A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in environmental studies department of environmental studies the open university of Tanzania). The Open University of Tanzania. Tanzania. doi: 10.61538/huria.v27i1.874

Zhang, M., and Wang, H. (2024). Exploring the factors affecting farmers' willingness to cultivate eco-agriculture in the Qilian Mountain National Park based on an extended TPB model. *Land* 13:334. doi: 10.3390/land13030334