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Influence of Mental Models on Sustainable Wheat Seed Use: A Comparative Study in Western Iran

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Abstract

Understanding farmers' mental models (MM) is crucial for interpreting their behavior; however, these models, are shaped by technical, economic, and social factors, have often been overlooked. Using a case study from Kangavar County, Western Iran, this study investigates the MM of farmers and experts regarding wheat seed usage and proposes optimization strategies using a mixed-methods approach. Qualitatively, phenomenological analysis of interviews with 16 participants (selected via purposive and snowball sampling) identified five key factors shaping farmers' mental models (MM): work context, climate, experienced risks, available resources, and subjective norms. Experts' rationale for seed recommendations centered on three themes: academic knowledge, professional experience, and user characteristics. Quantitatively, a structured questionnaire administered to a separate sample of 255 farmers (stratified proportional sampling) and 50 experts (complete enumeration) revealed significant disparities. Independent samples t-tests revealed statistically significant differences ($p < 0.01$) across all major mental model (MM) domains. Responses were initially scored as percentages (0–100) based on item agreement, then standardized to a 100-point scale. Mean scores were substantially higher among farmers in experienced risks (74.02 vs. 15.80), subjective norms (66.24 vs. 18.93), and work context (65.67 vs. 35.30), indicating stronger perceived influence of experiential and social factors. Conversely, experts scored higher on academic knowledge (75.28 vs. 41.71), reflecting greater reliance on scientific evidence.The Delphi method identified and prioritized key strategies for optimizing seed use, with "preparing a suitable seedbed" (weighted average: 0.148) and "using certified seeds" (weighted average: 0.143) ranked highest. These findings underscore the critical gap between farmer and expert models and emphasize the need for targeted interventions that integrate experiential knowledge with scientific evidence to bridge this divide, fostering more sustainable seed usage practices.

Keywords: Cognitive decision-making, Delphi technique, Mental models, Mixed-methods, Phenomenological study, Sustainable wheat production

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Introduction

Achieving sustainable agricultural development hinges on optimizing the use of critical inputs, with seeds representing the biological cornerstone of crop production and global food security (Bist *et al.*, 2021). However, a persistent challenge in agricultural extension is the frequent divergence between scientifically recommended practices and the actual decisions made by farmers. This gap is often attributed not to a lack of information, but to the deeply held cognitive frameworks, or mental models, that guide farmers' perceptions and actions (Jones *et al.*, 2011; Moon *et al.*, 2019). These internal representations of reality, synthesized from personal experience, social norms, and contextual factors, form the lens through which farmers interpret risks, opportunities, and advice (Johnson-Laird, 2010). Despite their profound influence on farm management outcomes, the specific structure and content of farmers' mental models, particularly concerning input use like seeds, remain underexplored in research and poorly integrated into policy design (Olivier de Sardan, 2005; Levy *et al.*, 2018).

Seeds are crucial agricultural input where mental models play a pivotal role. Seeds are the biological foundation of global food security and directly affect human livelihoods (Bist *et al.*, 2021). The availability of suitable seeds and their correct usage are vital for optimizing agricultural performance per unit area (Zareyan *et al.*, 2011). Given the strategic importance of wheat, which is not only a major source of income but also a key factor in political and economic relations (Abolhassani *et al.*, 2018), understanding the MM related to wheat seed consumption is essential. Iran, which represents 1% of the world's population, consumes 2.5% of the world's wheat, with over 60% of the country's arable land dedicated to wheat cultivation. In the 2019-2020 agricultural year, Iran's cultivated crop area was approximately 12.192 million hectares, with 71% (8,658,095 hectares) allocated to grain crops, and wheat accounted for 69.3% of this area. Wheat also constitutes 58.6% of the total grain production (Statistical Center of Iran, 2021). In Kermanshah Province, western Iran, the recommended seed amount for rain fed wheat is 150 kg per hectare and for irrigated wheat, 200 to 250 kg (Haghparast, 2013). However, actual seed consumption often exceeds these recommendations, reaching 200–300 kg for rainfed wheat and 250–400 kg for irrigated wheat (Argha *et al.*, 2021). This overconsumption significantly impacts the agricultural economy, particularly in Kangavar County, where wheat cultivation covers 4,900 hectares of irrigated and 6,300 hectares of rainfed land. Excessive seed use could cost the agricultural sector between 40 and 70 billion Rials annually (Khazaei, 2021).

This study makes a novel contribution to the existing literature by focusing on the mental models that shape farmers' wheat seed consumption practices, an area that has received limited attention compared to technical aspects such as seed purity, germination, or varietal selection (Argha *et al.*, 2021). By employing a mixed-methods approach, we provide a comprehensive analysis of the cognitive frameworks of both farmers and agricultural experts in Kangavar County, Western Iran, and shedding light on the behavioral and psychological drivers of seed overconsumption. Furthermore, our study advances the field by identifying consensus-driven strategies to optimize wheat seed use, offering practical solutions to enhance agricultural sustainability and economic efficiency in regions heavily reliant on wheat production. This focus on mental models and actionable strategies addresses a critical gap in understanding how cognitive factors influence resource use in agriculture, contributing to both theoretical and applied dimensions of sustainable farming practices. This approach offers a novel perspective for developing targeted interventions to bridge the gap between recommended and actual seed use, a critical issue for sustainable wheat production. Given the strategic role of wheat in Iran's food security and its contribution to national development goals, optimizing seed use is crucial. With limitations in expanding production factors or implementing major technological changes, improving the efficiency of existing resources, especially seeds, is vital. Gathering comprehensive information on the factors affecting field coverage and understanding farmers' MM regarding seed consumption can lead to more accurate planting practices and significant economic savings. Therefore, this research presents a focused case study of Kangavar County, a key wheat-producing area in Kermanshah Province, Western Iran to identify the factors shaping farmers' MM and provide strategies to effectively reduce wheat seed consumption.

Literature review

Mental Models (MM) and Factors Influencing Their Formation

Mental models are cognitive representations that individuals construct to understand, interpret, and predict phenomena in their environment. These models consist of interconnected knowledge, experiences, beliefs, values, and assumptions that simplify complex realities and enable reasoning about unfamiliar situations (Moon *et al*., 2019). In agriculture, mental models profoundly influence farmers' decision-making processes by acting as filters for incoming information, shaping perceptions of risks and opportunities, and guiding behavioral responses to challenges such as resource allocation, climate variability, and input usage. For instance, farmers may rely on these models to evaluate trade-offs in seed consumption, prioritizing experiential heuristics over expert recommendations, which can lead to suboptimal practices if the models are misaligned with scientific evidence (Bartaburu *et al*., 2022).

Mental models are internal representations of reality that help individuals understand and reason about situations, even those they have not directly experienced (Jones *et al*., 2011). These models consist of deeply ingrained assumptions and generalizations that shape our perception of the world and guide our actions (Marques, 2014). However, these models are often based on generalizations that may not always be accurate, leading to widespread misunderstandings (Johnson-Laird, 2010). Two main approaches are used to study MM: one focuses on the knowledge and processes involved in reasoning within specific domains (Todorovikj *et al*., 2019), while the other views MM as constructs in working memory that support logical reasoning. Generally, people develop these models through interactions with their environment and others, which help them understand and predict various phenomena (Johnson-Laird, 2010). Mental models are crucial cognitive structures that influence reasoning processes. They act as a set of hierarchical rules that function competitively and cooperatively. However, individuals are often unaware of their MM and how these affect their performance and decision-making. Researchers study these models by analyzing behavior rather than asking direct questions, as MM often operate at a subconscious level. These cognitive structures, which include attitudes, emotions, and beliefs, serve as lenses through which individuals perceive the world and influence how they interpret and react to different situations. As a result, two people might perceive the same event differently based on their unique mental models (Lee & Webb, 2005; Suomala & Kauttonen, 2022; Holtrop *et al*., 2020). Overall, MM are essential for understanding how individuals make decisions and interact with their world. They are dynamic systems within the mind that process external information, leading to actions based on internal cognitive structures (Jones *et al*., 2011; Chermack, 2003; Capelo & Dias, 2009). Previous studies have employed a variety of methods to elicit and analyze mental models, including semi-structured interviews to capture farmers' cognitive frameworks through narrative responses (Eckert & Bell, 2005), questionnaires to quantify differences in perceptions across groups (Halbrendt *et al*., 2014), and behavioral analysis to infer models from observed decision-making patterns (Levy *et al*., 2018). More recent approaches have incorporated innovative techniques such as values-informed mental modeling, which integrates epistemic values into interviews and cognitive mapping to understand stakeholder perceptions of complex systems like water management (Afzal *et al*., 2025), and drawing-based elicitation methods to visualize and compare mental models of human-nature relationships in agricultural contexts (Morrison *et al*., 2024). More recently, behavioral analysis and experimental games have been used to infer mental models from observed actions rather than stated beliefs, helping to circumvent social desirability bias (Bartaburu *et al*., 2022). Recognizing that each method has limitations, a mixed-methods approach as adopted in this study is increasingly advocated. This approach leverages the depth of qualitative inquiry to ensure the relevant constructs are captured, followed by quantitative measures to validate and generalize findings, thereby providing a more comprehensive understanding (*Jones et al*., 2011; Levy *et al*., 2018).

Mechanisms Linking Contextual Factors to Mental Model Formation

Recently research has begun to delineate the precise cognitive mechanisms through which contextual factors shape farmers' mental models. These factors do not influence decisions directly but are filtered and interpreted through pre-existing cognitive frameworks, which are subsequently reinforced or updated (Moon *et al*., 2019; Lynam & Brown, 2011). For instance, climate-related experiences, particularly extreme events like drought, operate primarily through the mechanism of experiential learning and risk amplification (Gebrehiwot & Veen, 2020). Repeated exposure to crop loss from drought can lead to an overestimation of climatic risk, causing farmers to adopt defensive heuristics such as "more seeds equal more security" that become entrenched in their mental models (Kansiime *et al*., 2021; Guido *et al*., 2020). Similarly, limitations in facilities and equipment shape farmers' mental models through perceived affordances and constraints. When equipment is imprecise, farmers learn to compensate by overseeding in order to achieve acceptable plant density, a practice that gradually becomes a normalized "workaround" (Feola et al., 2015). Over time, this practical adaptation can evolve into a core belief about what is necessary, overshadowing knowledge of optimal seeding rates.Subjective norms exert their influence through the mechanism of social learning and normative conformity (Bandura, 1977; Ajzen, 1991). In close-knit agricultural communities, observing peers and adhering to traditional practices provides social validation and reduces perceived social risk. When a practice like high seed consumption is widespread, it creates a descriptive norm that individuals are cognitively motivated to follow, integrating it into their mental model as a "correct" way of farming (Hansson & Kokko, 2018; Hoppe *et al*., 2023). Understanding these mechanisms experiential learning, affordance-based adaptation, and social conformity helps explain not just what factors influence mental models, but how they become cognitively embedded and resistant to change.

Mental Models (MM) in Agriculture

When considering an agricultural system, it becomes evident that farming encompasses more than just plants, soil, and farm inputs. It also involves soil organisms, wildlife, water resources, runoff, and, crucially, the farmers themselves (Keating & McCown, 2001). However, the extent of farmers' engagement in environmental systems thinking and how this influences their on-farm decision-making and behaviors require further research (Azizi *et al*., 2022). Understanding these agricultural systems, including how factors and their relationships are defined, can be developed by exploring mental models, which are frameworks that people use to understand their world (Ghanbari *et al*., 2018). Mental models are utilized for everyday decision-making and are shaped by knowledge acquisition and experience (Grenier & Dudzinska-Przesmitzki, 2015).

For farmers, this knowledge often evolves over time through social learning processes, where information is shared with extension agents, scientists, and other industry partners during meetings, outreach events, and informal settings, such as farmer-to-farmer communication, all of which influence their decisions and preferences. Social learning processes may be key to sustainability in natural resource management, enabling the long-term sharing of perspectives among multiple stakeholders. An iterative process in which decisions are made, systems are impacted, and MM are consciously updated to reflect new perceptions of reality can help develop more sustainable systems (Levy *et al*., 2018; Moon *et al*., 2019). In agriculture, when farmers understand how a specific conservation practice or its components fit into the broader agricultural system, this awareness is reflected in their MM. External representations of these assumptions can enable farmers to make more informed decisions about how their agricultural practices might potentially affect social or environmental outcomes (Bardenhagen *et al*., 2020).

Mental models exert a profound effect on sustainable agricultural practices, including wheat seed use, by shaping how farmers interpret environmental cues, assess risks, and make decisions. For instance, inaccurate or outdated mental models may lead to overconsumption of seeds as a perceived safeguard against risks like drought or weed infestation, resulting in economic inefficiencies and reduced sustainability. Conversely, aligned mental models fostered through education and experience can promote optimal seed usage, enhancing resource efficiency, yield stability, and long-term food security. In this study, differences in mental models between farmers and experts highlight how these cognitive structures directly impact seed consumption behaviors, underscoring the need for interventions that refine farmers' models toward evidence-based practices.

Some research has revealed changes in farmers' MM based on their management styles (Cullen *et al*., 2022). Related studies by Eckert & Bell (2005) revealed that previous experience, values, beliefs, and knowledge influence a farmer's current MM. In turn, this MM serves as both a filter and guide for farmers' actions, decisions, and use of information, regardless of the type of farming operation, marketing practices, or agricultural approach (e.g. sustainable, organic, or conventional). Warner *et al*. (2016) compared the MM of scientists and local residents regarding flash floods and landslides, demonstrating that personal experience and observability of processes are two key factors explaining the content of MM. In relation to wheat productivity, it can be argued that observable factors such as the average age of the tenant, family labor, distance from home to farm, hired labor, distance from the farm to the irrigation source, number of irrigations, irrigation duration, availability of seeds, and access to and adoption of new, adaptable seed varieties influence the decision-making process. Less observable factors, such as water, fertilizer, and pesticides, may have a lesser impact.

Also a number of studies has begun to explicitly map farmers' mental models concerning specific agricultural inputs, with seeds being a critical focus. Table 1 shows the comparison between previous studies and the present study and identifies its innovation contribution. These studies reveal that seed-related decisions are not purely technical but are deeply embedded in cognitive frameworks shaped by experiential learning, risk perception, and social networks. For instance, Okello *et al*. (2018) applied means-end chain theory to analyze Kenyan farmers' mental models associated with quality seed potato use, revealing that perceived benefits like improved yields and disease resistance drive adoption behaviors. Similarly, Bulte *et al*. (2023) explored biased expectations in Ugandan farmers' mental models regarding improved seeds, showing how misinformation leads to under-adoption and suboptimal complementary input use. These findings underscore the role of mental models in seed-related decisions, aligning with our investigation into discrepancies between farmers' and experts' perceptions of optimal wheat seed quantities.Furthermore, Kansiime *et al*. (2021), highlighted how mental models concerning climate risk directly influence seed selection, with farmers opting for higher seeding rates as a buffer against perceived environmental uncertainties, a finding that resonates directly with the overconsumption problem addressed in the present study. By examining these seed-specific mental models, our study aims to contribute to this emerging body of literature, providing a granular understanding of the cognitive drivers behind wheat seed use in Western Iran.

Table 1- Comparative Analysis of Previous Studies and the Present Research

Aspect	Previous Studies	Present Study	Research Gap Addressed / Contribution
Focus	Often focused on technical aspects of seed use (e.g., purity, germination, varietal selection) or general farm decision-making. Some studies examined mental models in conservation or climate adaptation.	Explicitly focuses on mental models (MM) related to wheat seed consumption specifically overuse in a specific agro-economic context.	Addresses the cognitive and behavioral drivers behind seed overuse, a topic less explored compared to technical or agronomic factors.
Geographical Context	Diverse contexts: Sub-Saharan Africa (Bulte *et al*., 2023), Kenya (Okello *et al*., 2018), Uganda, Europe, and global models (e.g., Levy *et al*., 2018).	Western Iran (Kangavar County), a region with high wheat dependency and specific socio-climatic challenges.	Provides context-specific insights into Iranian farmers' decision-making, where wheat is vital for food security and economy.
Methodology	Varied: interviews (Eckert & Bell, 2005), surveys (Halbrendt *et al*., 2014), behavioral games (Bartaburu et al., 2022), values-informed modeling (Afzal *et al*., 2025), drawing-based methods (Morrison *et al*., 2024).	Mixed-methods: phenomenological interviews, quantitative surveys (t-tests), Delphi method, and Analytic Hierarchy Process (AHP) for strategy prioritization.	Combines qualitative depth with quantitative validation and systematic consensus-building to derive actionable strategies.
Key Factors Explored	Often focused on single domains: risk perception, social norms, or expert-farmer discrepancies. Some studies linked MM to climate or soil management.	Identifies five key MM domains: work context, climate, experienced risks, resources/equipment, and subjective norms. Also compares farmer vs. expert MMs quantitatively.	Offers a multi-dimensional framework that integrates experiential, normative, and contextual factors shaping seed use.
Strategy Development	Few studies progressed to developing and prioritizing actionable interventions based on MM findings.	Uses Delphi and AHP to identify and rank 9 consensus-based strategies (e.g., seedbed preparation, certified seeds).	Bridges the gap between theory and practice by translating MM insights into prioritized, implementable strategies.
Theoretical Integration	Often based on MM theory or behavioral models (e.g., TPB) in isolation.	Integrates Theory of Planned Behavior, Mental Model Theory, and agricultural decision-making frameworks into a unified conceptual model.	Provides a more holistic theoretical basis for understanding seed-use behavior.

Source: Research Findings

Conceptual Framework

Based on the literature, a conceptual framework was developed (see Fig. 1) to illustrate how mental models influence wheat seed consumption among farmers. The framework posits that farmers' mental models are shaped by a combination of experiential factors (e.g., past risks, climate experiences), socio-normative factors (e.g., subjective norms, traditions), and contextual factors (e.g., work conditions, resource availability). These mental models act as cognitive filters that influence farmers' risk perceptions, behavioral intentions, and ultimately, their seed-use practices. This model draws on elements from the Theory of Planned Behavior (Ajzen, 1991), Mental Model Theory (Johnson-Laird, 2010), and agricultural decision-making frameworks (Bartaburu *et al*., 2022; Moon *et al*., 2019).

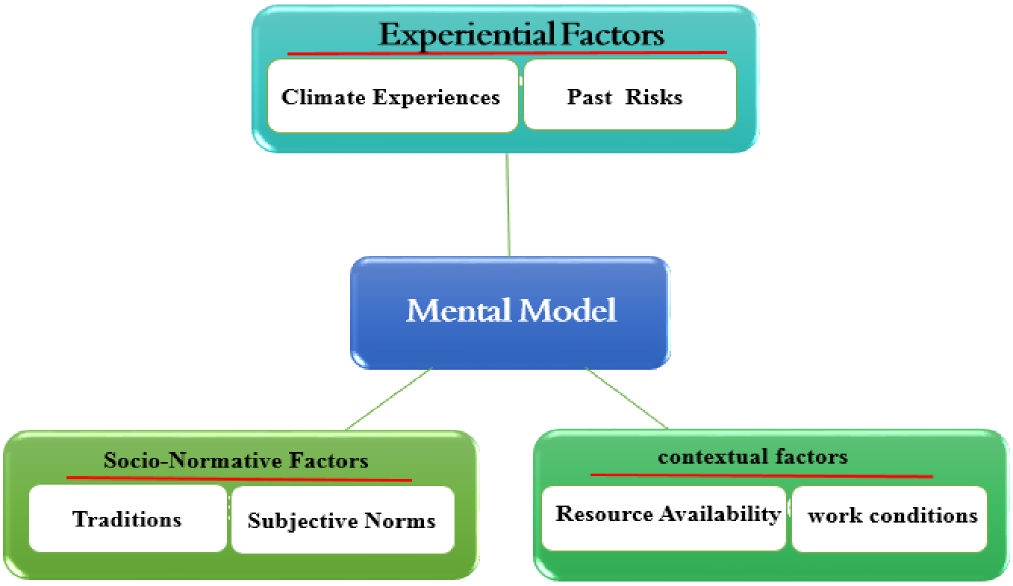

Figure 1- A conceptual model of mental models' influence on seed-consumption

Methodology

This study was conducted in three distinct stages to comprehensively understand and improve the wheat seed consumption practices of farmers in Kangavar County. Kangavar County was selected as a representative case study due to its significant wheat cultivation area and documented issues with seed overconsumption, providing a rich context for examining mental models. The stages included identifying and comparing mental models and developing actionable recommendations.

Stage One: Identifying Mental Models of Farmers and Experts

To elucidate and comprehend the mental models held by wheat farmers and agricultural experts regarding seed consumption practices, a qualitative, phenomenological approach was employed to explore and analyze participants' cognitive frameworks (Creswell, 2013). The study targeted wheat farmers and subject matter experts in Kermanshah County. The inclusion criteria for farmers required a minimum of five years of local wheat cultivation experience. Experts were selected based on a minimum of five years of professional experience in the field (Patton, 2015). Purposeful and snowball sampling techniques were used. The initial participants were selected based on specific criteria, and additional participants were recruited through referrals from these initial contacts (Marshall & Rossman, 2016). The final sample consisted of 16 individuals. We collected data through semi-structured interviews, direct observation, and field notes. These methods were chosen to gain a deep understanding of the participants' cognitive frameworks concerning wheat seed usage (Lincoln & Guba, 2018). The qualitative data were analyzed using a thematic analysis approach. Interview transcripts and field notes were coded inductively to identify significant statements related to seed usage. These codes were grouped into categories and further synthesized into thematic clusters representing key dimensions of farmers' and experts' mental models. This process ensured that the emergent themes were grounded in the participants' lived experiences and perspectives (Braun & Clarke, 2006).

Data were analyzed using Colaizzi's phenomenological method (Colaizzi, 1978), which involves a systematic process of extracting and interpreting participants' lived experiences. The analysis followed these steps:

- ✓ Familiarization: Researchers repeatedly read through all interview transcripts and field notes to gain an in-depth understanding of the data.

- ✓ Identification of Significant Statements: Sentences or phrases directly pertaining to wheat seed usage were extracted from the transcripts.
- ✓ Formulation of Meanings: Researchers interpreted the significant statements to uncover underlying meanings relevant to the research objective.
- ✓ Theme Development: The formulated meanings were grouped into clusters of themes, which were then organized into broader categories.
- ✓ Exhaustive Description: A detailed narrative was constructed to describe the phenomenon of interest comprehensively.
- ✓ Fundamental Structure: The essence of the participants' mental models was synthesized into a concise structural description.
- ✓ Member Checking: The findings were returned to participants for validation to ensure the accuracy and trustworthiness of the interpretations.

Credibility was established through member checking and through peer debriefing. Dependability was ensured by having multiple researchers independently code and review the data (Lincoln & Guba, 2018).

Stage Two: Comparing Mental Models (MM) of Farmers and Experts

To compare and contrast the MM of wheat farmers with those of experts regarding seed consumption. A mixed-methods approach was adopted, integrating qualitative findings from Stage One with quantitative analysis (Creswell, 2013). The population included 255 wheat farmers and 50 agricultural experts from Kangavar County. Stratified sampling with proportional allocation was used for the farmers (N= 740, n= 255) according Krejcie & Morgan (1970) sampling table. Owing to the small number of experts, a complete enumeration approach was applied (Bryman, 2016). A structured questionnaire, developed based on insights from Stage One, was used to assess differences in MM between farmers and experts (Dillman *et al*., 2014).

The structured questionnaire was structured into two main parts. The first part collected socio-demographic information from the participants (e.g., age, education level, farming experience, land size). The second part, which formed the core of the instrument, was designed to quantitatively capture the mental model domains identified in the qualitative stage (Stage One). It consisted of multiple Likert-scale questions (e.g., 1=Strongly Disagree to 5=Strongly Agree) for each domain. For instance, to measure 'Experienced Risks,' participants were asked to rate statements such as, 'Using a higher seed rate is an effective strategy to compensate for potential yield loss due to pests or drought.' Similarly, the 'Subjective Norms' domain included items like, 'Most farmers in my community believe that using more seeds leads to a better harvest.' The 'Academic Knowledge' domain for experts included items such as, 'Recommended seed rates should be primarily based on scientific research from seed institutes.' This approach allowed us to translate the qualitative themes into measurable variables for statistical comparison between the groups .Quantitative data were analyzed using independent samples t-tests to compare the mean scores of farmers and experts across the identified mental model domains. The t-test was chosen to assess the statistical significance of differences between the two groups, with a threshold of $p < 0.05$ indicating significance. This method allowed for a robust comparison of perceptual gaps between farmers and experts. Data analysis involved both descriptive and inferential statistics using the SPSS software (Field, 2013). The differences between the MM of farmers and experts were tested for statistical significance at the 1% and 5% levels.

Stage Three: Developing and Prioritizing Strategies for Optimizing Seed Use

To develop and prioritize strategies aimed at optimizing wheat seed usage among farmers in Kangavar County. This stage employed a mixed-methods approach, utilizing the Delphi method for strategy identification and the Analytic Hierarchy Process (AHP) for prioritization (Tzeng & Huang, 2011).

Delphi Method: The Delphi process was conducted in three rounds, following the established guidelines outlined by Keeney et al. (2006). A panel of 16 experts participated in an initial open-ended round that generated 21 strategies. In the second round, experts evaluated and prioritized these strategies using a 5-point Likert scale, resulting in a refined list of 14 items. The final consensus round employed binary Agree/Disagree responses, and strategies receiving more than 66% agreement were retained, yielding a final set of 9 strategies.

Round One: An open-ended questionnaire was distributed to a panel of 16 experts to gather potential strategies, resulting in 21 initial strategies (Linstone & Turoff, 2002).

- ✓ **Round Two:** A 5-point Likert scale questionnaire was used to assess and prioritize these strategies, leading to 14 strategies for further evaluation (Keeney et al., 2006).
- ✓ **Round Three:** A closed questionnaire with binary response options (Agree/Disagree) was employed to finalize the top 9 strategies based on expert consensus (Dalkey & Helmer, 1963).

The Delphi technique was employed to achieve expert consensus through iterative rounds of feedback. In the first round, experts generated open-ended suggestions. These were synthesized and rated in the second round using a Likert scale. The final round used binary agree/disagree responses to finalize strategies. This iterative process ensured reliability and collective validation of the strategies (Hsu & Sandford, 2007). The Analytic Hierarchy Process (AHP) was then used to prioritize the strategies based on pairwise comparisons, with consistency ratios maintained below 0.1 to ensure logical consistency.

The Analytic Hierarchy Process was applied to rank the final strategies. Pairwise comparisons were conducted and analyzed using the Expert Choice software. The strategies were ranked based on weighted average scores, with an inconsistency rate maintained below 0.1 to ensure accurate and reliable judgments (Saaty, 1980). The prioritized strategies were designed to optimize wheat seed use, with the potential to improve agricultural practices and enhance the livelihoods of farmers in Kangavar County.

Results

To achieve the research objectives, the researcher aimed to extract the underlying mental frameworks of small-scale farmers regarding seed usage by asking what, how, and why. Data collected from the in-depth interviews and field observations were compiled and organized into a database. Transcriptions and field notes were repeatedly reviewed to gain a comprehensive view of the collected information. Key phrases related to the mental framework of farmers regarding seed consumption were identified, and after eliminating redundant items, 33 key codes (themes) were identified. These were then consolidated into 15 meaningful categories (Table 2). The extracted phrases were grouped into five main thematic clusters: work context, climate, experienced risks, facilities and equipment, and subjective norms.

To identify the underlying reasoning of experts regarding the recommended seed quantity for farmers, key statements related to the research topic (the underlying mental models of farmers concerning wheat seed consumption) were identified after the initial analyses. After eliminating duplicates and merging similar statements, 11 key codes (themes) were identified. The researchers then attempted to consolidate similar items and formulate the extracted statements into meaningful expression. Five formulated meanings were derived at this stage. Subsequently, the statements related to the experts' reasoning regarding recommended seed amounts for farmers were categorized into three main subjects (categories): Academic Knowledge, Professional Experience, and Farmer Characteristics (Table 3).

Table 2- Primary Codes, Concepts, and Categories Extracted from Interviews (Farmers' Mental Models)

Concepts	Categories	Subcategories (Initial Codes)
Work Context	**Soil Structure and Texture**	**Presence of clods in the field**
		Rocky soil
		Heavy soil texture
		Soil fertility
	Land shape	Marginal lands
		Sloped lands
		Irregular land shapes
	Land fragmentation and dispersion	Small plot sizes
		High number of plots
		Inappropriate soil tillage
Climate	Rainfall	Drought
		Decrease in precipitation
		Heavy rainfall
	Air temperature	Cold weather
Experienced Risks	Managing natural risks	Controlling weeds
		Reducing crop pest damage
	Managing financial risks	Preventing yield reduction
		Preventing income loss
Resources and Equipment	Lack of required tools	Lack of tractors
		Lack of proper seed drills
	Inadequate equipment	Use of inappropriate combines
		Use of improper fertilizer spreaders
	Locally made equipment	Inaccuracy of local equipment
	Lack of production inputs	High plowing costs (labor shortages)
		Use of homegrown seeds
		Lack of access to water
		Lack of access to irrigation systems
Subjective Norms	Individual attitudes	Rivalry and competition
	Beliefs and values	Mindset and way of thinking
		Following ancestral traditions

Source: Research Findings

Table 3- Primary codes, concepts, and categories extracted from interviews (Experts' Mental models)

Category	Concept	Theme
Academic knowledge	University resources	Academic textbooks
		Scientific articles
	Information sources	Seed research center
		Scientific and practical standards
		Meteorological center data
Experience	Professional experience	Climatic experience
		Work experience
Farmer characteristics	Personal farmer conditions	Older farmers
		Younger farmers
	Professional farmer conditions	Awareness of farmer conditions
		Type of farmer management

Source: Research Findings

Differences in Mental Models (MM), Between Farmers and Agricultural Promoters and Experts Regarding Seed Usage

An examination was conducted using the t-test to identify differences in MM between farmers and agricultural promoters and experts concerning seed usage. The results showed significant differences at the 1% and 5% levels in the context of working conditions (t = 10.703, Sig. = 0.000), awareness (t = 4.204, Sig. = 0.000), climate (t = 8.184, Sig. = 0.000), experienced risks (t = 17.101, Sig. = 0.000), facilities and equipment (t = 10.615, Sig. = 0.000), and mental norms (t = 12.780, Sig. = 0.000). However, there was no significant difference in the operators' characteristics (t = -0.733, Sig. = 0.464) (Table 4).

To facilitate comparison of the mental models between farmers and experts, Fig. 2 presents a bar chart illustrating the mean scores for each category, with statistically significant differences ($p < 0.01$).

Table 4- Comparison of mental models between farmers and agricultural promoters and experts regarding seed usage

Variable	Groups	Mean	Std	t	Sig
Work context	Farmers	65.67	22.325	10.703	0.000
	Experts	35.30	16.764		
Climate	Farmers	48.43	22.314	8.184	0.000
	Experts	20.00	20.763		
Experienced risks	Farmers	74.02	21.542	17.101	0.000
	Experts	15.80	21.768		
Facilities and equipment	Farmers	64.10	19.470	10.615	0.000
	Experts	31.96	18.021		
Subjective norms	Farmers	66.24	19.826	12.780	0.000
	Experts	18.93	24.276		
Academic knowledge	Farmers	41.71	36.239	-8.392	0.000
	Experts	75.28	21.908		
Professional experience	Farmers	66.71	23.784	9.178	0.000
	Experts	22.60	31.852		
Operator characteristics	Farmers	51.51	21.238	-0.733	0.464
	Experts	53.90	18.043		

**Significance at the 1% level is indicated by **

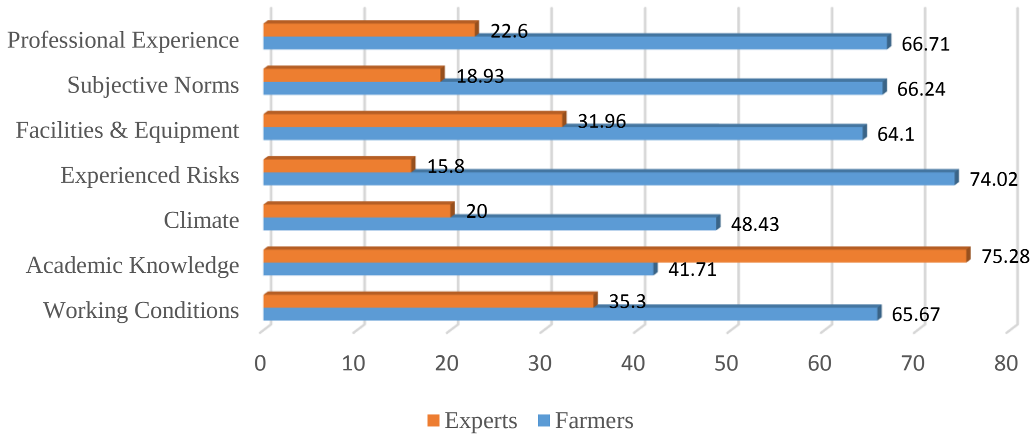

Figure 2- Comparison of mental models between farmers and experts across key categories
Note: ** indicates statistical significance at the 1% level ($p < 0.01$)

Identifying Strategies to Adjust Wheat Seed Usage among Farmers in Western Iran

The first round of the Delphi method was conducted to identify strategies and suggestions for adjusting seed usage among farmers in Kangavar County, located in western Iran. In this round, 21 strategies were identified and retained. Some of these strategies include preparing a suitable seedbed, plowing before planting (breaking the soil) and leveling the land before planting (frequency of 4), preparing a suitable seedbed (tillage in appropriate moisture, using suitable tillage equipment, managing plant residues) (frequency of 2), increasing beneficial organisms after initial plowing (bacteria that dissolve and provide essential nutrients for the plant in the soil) and restoring soil structure (frequency of 2), replacing old planting equipment with new and modern technology (frequency of 2), and using appropriate seeds (certified and parent seeds) (frequency of 5).

In the second round, items with an average of 3.5 and above were selected, and the others were eliminated. At the end of this stage, seven items were eliminated, and 14 items remained.

The remaining strategies at the end of the second stage were preparing a suitable seedbed, plowing before planting (breaking the soil) and leveling the land before planting (average of 5), training farmers on new sciences such as no-till planting or conservation agriculture (average of 4.82), and appropriate depth, density, and uniform distribution of plants per unit area (average of 4.71).

In the third and final round of the Delphi method (consensus phase), items that gained over 66% agreement from experts were accepted, and those that did not reach 66% were eliminated. Ultimately, 5 items were removed, and 9 items were finalized as strategies to adjust seed usage among farmers in Kangavar County, located in western Iran. Some of the selected strategies in this phase included "preparing a suitable seedbed (tillage in appropriate moisture, using suitable tillage equipment, and managing plant residues)" with 93.8% agreement, "using appropriate seeds (certified and parent seeds)" with 87.5% agreement, and "appropriate depth, density, and uniform distribution of plants per unit area" with 81.2% agreement (Table 5).

Table 5- Strategies for adjusting wheat seed usage after third round data analysis

Strategies	Agree (%)	Disagree (%)
Preparing a suitable seedbed (tillage in appropriate moisture, using suitable tillage equipment, managing plant residues)	93.8	6.2
Using appropriate seeds (certified and parent seeds)	87.5	12.5
Appropriate depth, density, and uniform distribution of plants per unit area	81.2	18.8
Planting at the appropriate time and adhering to planting dates	93.8	6.2
Recommending seed rates for each region based on climate, soil, and individual farmer conditions	87.5	12.5
Using suitable planting equipment (calibrated planters equipped with markers)	93.8	6.2
Training farmers in new sciences such as no-till planting or conservation agriculture	81.2	18.8
Encouraging and motivating leading farmers to use less seed and providing incentives for these farmers, creating competition between leading and regular farmers	87.5	12.5
Using treated seeds (soaking seeds in water or spraying zinc compounds on seeds)	93.8	6.2

Source: Research Findings

Prioritization of Strategies to Adjust Wheat Seed Usage among Farmers in Kangavar County, Western Iran

Based on the results presented in Fig. 3, it can be seen that among the identified strategies, the most important and suitable strategies for adjusting seed usage among farmers in western Iran are "preparing a suitable seedbed (tillage in appropriate moisture, using suitable tillage equipment, managing plant residues)" with a weighted average of 0.148, "using appropriate seeds (certified and parent seeds)" with a weighted average of 0.143, and "appropriate depth, density, and uniform distribution of plants per unit area" with a weighted average of 0.131. Strategies with lesser importance included "training farmers in new sciences such as no-till planting or conservation agriculture" with a weighted average of 0.089, "encouraging and motivating leading farmers to use less seed and providing incentives for these farmers, creating competition between leading and regular farmers" with a weighted average of 0.087, and "using treated seeds (soaking seeds in water or spraying zinc compounds on seeds)" with a weighted average of 0.075.

Discussion

Based on the findings, six key categories were identified as influential in shaping farmers' MM regarding wheat seed consumption: working conditions, awareness, climate, experienced risks, facilities and equipment, and mental health norms. The 'working conditions' category, including soil structure, land shape, and fragmentation, shapes mental models through the mechanism of practical constraint and adaptation. Farmers operating on sloped or fragmented lands may perceive a higher risk of uneven plant establishment. This perception, rooted in the affordances of their land, leads to adaptive decisions like increasing seed rates to compensate for perceived inefficiencies, a finding consistent with other studies (Mersha *et* *al*., 2022; Feola *et al*., 2015), and social and physical factors (Xie & Huang, 2021) are significant determinants of farmers' decision-making processes. Peltonen-Sainio *et al*. (2018) further suggested that land shape and slope are hidden factors affecting farmers' decisions.

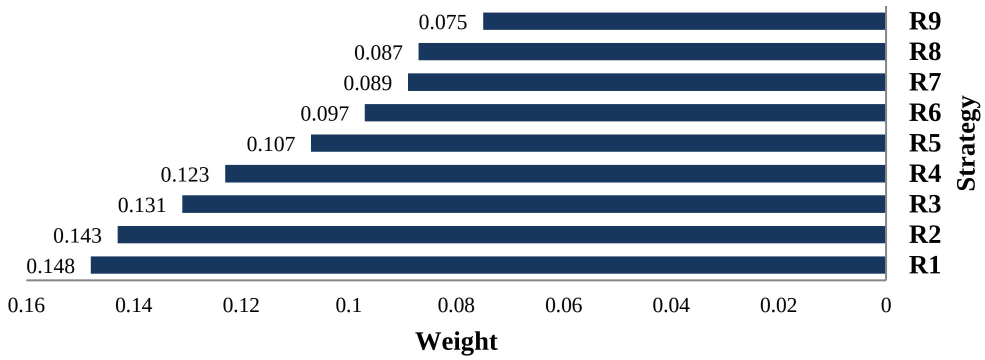

Figure 3- Prioritization of strategies to adjust wheat seed usage Inconsistency rate: 0.07

The findings indicate that climate change is a critical factor influencing farmers' MM of wheat seed consumption. Ellis & Albrecht (2017) also highlighted how climate change intensifies farmers' concerns about weather conditions, weakens their sense of identity, and potentially impacts their mental well-being and subsequent actions. Edwards *et al*. (2015) argue that drought negatively affects farmers' and workers' mental states, especially when drought reduces farm productivity to its lowest levels. Similarly, Gebrehiwot & Veen (2020) add that drought experiences significantly impact farmers' decisions regarding adaptation measures, vulnerability perception, self-efficacy, and the effectiveness of their responses. Harik *et al*. (2023) emphasize the significant role of climate and social factors in influencing farmers' decisions. Azizi *et al*. (2021) also confirm that climate conditions (temperature, rainfall, extreme cold and heat events, and drought) considerably affect farmers' decision-making processes. Based on this, it can be inferred that the farmers studied may have increased their wheat seed consumption owing to the severe drought impacts. In line with this, Taylor *et al*. (1988) confirmed that experiencing climate changes, such as drought, can influence farmers' definitions, memories, and expectations, potentially leading to inadequate responses to environmental risks. Supporting this analysis, Guido *et al*. (2020) found that farmers' expectations regarding future seasonal rainfall play a crucial role in their farm decision-making processes.

The results also revealed that the risks experienced by farmers can shape their MM and ultimately lead to higher wheat seed consumption levels. In this regard, research by Kolb *et al*. (2012), Lemerle *et al*. (2004), and Hasam *et al*. (2021) shows that higher wheat seeding rates (at least 200 plants per square meter) are an effective method for managing weeds, reducing weed biomass, and improving grain yield in low-rainfall environments. Kumari & Kataria (2023) confirmed that a seeding rate of 140 kg/ha in wheat significantly increased both biological and grain yields compared to a rate of 100 kg/ha. Thus, although the farmers studied appear to have shaped their MM based on the risks they have experienced to efficiently manage these risks, their seed consumption rates are well above 140 kg/ha.

The "facilities and equipment" category includes four key concepts: lack of necessary tools, inappropriate tools, and shortages in production inputs, all of which can influence farmers' MM of wheat seed consumption. Feola *et al*. (2015) also confirm that understanding farmer behavior requires addressing decision-making models, short-term pressures, cross-level interactions, and dynamic factors over time.

According to the findings, mental norms (individual attitudes, beliefs, and values) significantly influence the shaping of farmers' MM. In this regard, Ajzen (1991) demonstrated that attitudes and beliefs play crucial roles in forming mental behavior. Ajzen & Fishbein (2000) further noted that attitudes automatically follow accessible beliefs stored in memory and guide relevant behaviors. Highlighting the importance of this factor, Hansson & Kokko (2018) showed that farmers often associate wetland restoration with negative impacts on their fields, with their changing MM influenced by personal values. Additionally, Hoppe *et al.* (2023) found that collective factors, such as in-group identification and norms, directly and indirectly influence individuals' conservation actions. Furthermore, Grob (1995) revealed that personal-philosophical values and emotions have the strongest influence on environmental behavior, explaining 39% of the variance in such behavior. Gatersleben *et al.* (2014) also argue that values and identities are strong predictors of pro-environmental behavior, with identities explaining these behaviors more than specific attitudes.

The analysis showed that experts recommend wheat seed rates based on three main factors: academic knowledge, practical experience, and the farmer's personal and professional characteristics. The academic knowledge category consists of two components—university resources (such as academic books and scientific papers) and informational resources (including seed research centers, scientific and practical standards, and meteorological data).In this regard, Ulrich *et al.* (2022) found that academic education enhances the integration of scientific concepts into experiential brain systems and mental frameworks.

The experience category includes concepts such as climatic and work experience. Rajabali Baglou *et al.* (2019) stated that experience, training, and professional background significantly influence the formation of individuals' MM. Eckert & Bell (2005) also highlighted values and prior knowledge as key factors influencing respondents' mindset and decision-making. According to the findings, from the experts' perspective, the personal and professional traits of the farmer play a determining role in the seed amount they recommend. Therefore, the experts' reasoning and mental frameworks are influenced by these farmer-specific traits.

A comparison of the mental frameworks of experts and farmers revealed a significant difference in reasoning between the two groups, except regarding farmer characteristics. To further elucidate the magnitude of this gap, the percentage difference in mean scores was calculated. The most striking disparity was in 'Experienced Risks,' where farmers' scores were 368% higher than those of experts (74.02 vs. 15.80). Similarly, large differences were observed for 'Subjective Norms' (250% higher for farmers) and 'Facilities and Equipment' (100% higher). In contrast, experts' scores for 'Academic Knowledge' were 80% higher than farmers'. These percentages underscore a profound divergence in perspective. Halbrendt *et al.* (2014) explained that the gap between expert and farmer perspectives can be attributed to the MM each group holds. Our qualitative data provide concrete examples of this divergence. For instance, regarding 'Experienced Risks,' a farmer explained their high seeding rate by stating: "I saw my neighbor's field fail due to poor germination after a dry spell. I always add extra seed as insurance against such losses". This contrasts sharply with an expert's rationale, which was rooted in academic knowledge. *"Our trials show that beyond 150 kg/ha, the law of diminishing returns applies, and excessive seeding can even promote disease"*. Similarly, the influence of Subjective Norms was evident in farmer interviews, with one noting: "everyone in our village plants this much. If I use less and my yield is lower, I will be blamed for not following the tradition". These examples illustrate how the quantitative disparities are manifestations of deeply rooted cognitive frameworks based on lived experience versus scientific training. Eitzinger *et al.* (2018) argued that these two groups perceive risks differently, which influences their mental behavior. Rios-Gonzalez *et al*. (2013) further noted that this difference in perception arises from the distinct roles of men and women in the agricultural process rather than a lack of knowledgeThe Delphi method was employed to reduce this gap in reasoning and to identify common solutions for optimizing seed consumption. The results indicated that the most effective strategies include: preparing an appropriate seedbed (such as tilling under suitable moisture conditions, using proper tillage implements, and managing crop residues), using high-quality seeds (including parent and certified seeds), and ensuring proper sowing depth, plant density, and uniform seed distribution per unit area. These strategies were identified as the most important and optimal approaches for improving wheat seed consumption among the farmers studied. Less important solutions included educating farmers on new technologies such as no-till farming or conservation agriculture, encouraging and incentivizing leading farmers to use less seed, creating competition between leading and average farmers, and using seed treatments (soaking seeds in water or spraying them with zinc compounds). These solutions were agreed upon by both experts and farmers, aligning with the reasoning of both groups. Therefore, it is expected that by implementing these solutions, wheat seed consumption will significantly decrease.

Conclusion and Limitation

Mental models form the foundation of an individual's decision-making and behavior. By examining reasoning processes, we can identify the root causes of behavioral patterns and avoid unnecessary expenditures of time and resources in altering behaviors. In other words, understanding reasoning enables us to accurately grasp the factors behind farmers' unstable behaviors and implement appropriate solutions to address them. The qualitative and quantitative phases of this study provided an opportunity to explore the reasons for the differences in seed usage logic between farmers and experts. The findings also showed that, through consensus-driven solutions, it is possible to bridge the gap between farmers' and experts' reasoning, thereby creating the conditions necessary to optimize seed consumption.

While this study provides valuable insights into the mental models influencing wheat seed consumption among farmers in Kangavar County, several limitations should be noted to contextualize the findings. Geographically, the research is confined to a specific region in western Iran (Kangavar County). As a case study focused on Kangavar County, the findings are not statistically generalizable to all of Western Iran. The unique climatic, soil, and socio-economic conditions of the region mean that the specific weightings of mental model factors may differ in other areas. For instance, the emphasis on drought-related risks in farmers' mental models may be amplified here due to regional arid conditions, potentially less relevant in wetter climates. Sampling constraints also apply. The qualitative phase relied on purposeful and snowball sampling, which, while effective for in-depth exploration, may introduce selection bias by favoring more accessible or networked participants. The quantitative phase used stratified sampling for farmers (n=255) and complete enumeration for experts (n=50), but the relatively small expert sample size could limit the robustness of comparisons. Additionally, data collection methods, such as interviews and questionnaires, depend on self-reported information, which may be subject to recall bias or social desirability effects. Future research could mitigate these limitations by expanding to multi-regional samples, incorporating longitudinal designs to track changes in mental models over time, or integrating objective measures (e.g., field audits of seed usage) alongside subjective assessments. Despite these constraints, the study's mixed-methods approach offers a solid foundation for understanding farmer-expert discrepancies in this context. Future research could benefit from a longitudinal design and include a more geographically diverse population to enhance the external validity of the findings.

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تأثیر مدل‌های ذهنی بر مصرف پایدار بذر گندم: مطالعه تطبیقی در غرب ایران

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چکیده

درک مدل‌های ذهنی (MM) کشاورزان برای فهم رفتار آن‌ها ضروری است؛ با این حال، این مدل‌ها که از عوامل فنی، اقتصادی و اجتماعی تأثیر می‌پذیرند، اغلب مورد غفلت قرار گرفته‌اند. در پژوهش حاضر سعی شد با استفاده از مطالعه موردی در شهرستان کنگاور (واقع در غرب ایران)، به بررسی مدل‌های ذهنی کشاورزان و کارشناسان در زمینه مصرف بذر گندم در مزارع پرداخته شود و سپس با رویکرد ترکیبی، راهکارهایی برای بهینه‌سازی مصرف آن پیشنهاد شود. در بخش کیفی، به تحلیل پدیدارشناسی تجربیات کشاورزان و کارشناسان در زمینه بذر مصرفی پرداخته شد. مصاحبه با ۱۶ شرکت‌کننده (انتخاب‌شده با نمونه‌گیری هدفمند و گلوله‌برفی) منجر به شناسایی پنج عامل کلیدی شکل‌دهنده مدل‌های ذهنی در کشاورزان (بستر کاری، آب‌وهوا، ریسک‌های تجربه‌شده، منابع در دسترس و هنجارهای ذهنی) و سه مدل ذهنی در کارشناسان (دانش آکادمیک، تجربه حرفه‌ای و ویژگی‌های کاربر) شد. در بخش کمی، پرسشنامه ساختاریافته بر روی نمونه جداگانه‌ای شامل ۲۵۵ کشاورز (نمونه‌گیری طبقه‌ای متناسب) و ۵۰ کارشناس (سرشماری کامل) اجرا شد و اختلافات قابل توجهی را آشکار نمود. آزمون t مستقل، تفاوت‌های آماری معنادار ($p < 0.1$) را در همه حوزه‌های اصلی مدل‌های ذهنی تأیید نمود. پاسخ‌ها ابتدا به‌صورت درصد (۰—۱۰۰) بر اساس میزان توافق با گویه‌ها امتیازدهی و سپس به مقیاس استاندارد ۱۰۰ امتیازی تبدیل شدند. میانگین امتیاز کشاورزان در ریسک‌های تجربه‌شده (۷۴,۰۲ در برابر ۱۵,۸۰)، هنجارهای ذهنی (۶۶,۲۴ در برابر ۱۸,۹۳) و زمینه کاری (۶۵,۶۷ در برابر ۳۵,۳۰) به مراتب بالاتر بود که نشان‌دهنده تأثیر قوی‌تر عوامل تجربی و اجتماعی است. در مقابل، کارشناسان در دانش آکادمیک امتیاز بیشتری کسب کردند (۷۵,۲۸ در برابر ۴۱,۷۱) که بیانگر اتکای بیشتر به شواهد علمی است. روش دلفی، راهکارهای کلیدی را شناسایی و اولویت‌بندی کرد؛ به‌طوری‌که «آماده‌سازی بستر بذر مناسب» (میانگین وزنی: ۰,۱۴۸) و «استفاده از بذرهای گواهی‌شده» (میانگین وزنی: ۰,۱۴۳) در صدر قرار گرفتند. این یافته‌ها بر شکاف عمیق میان مدل‌های ذهنی کشاورزان و کارشناسان تأکید دارند و بر ضرورت مداخلات هدفمند برای پیوند دانش تجربی با شواهد علمی به منظور کاهش این شکاف و ترویج مصرف پایدارتر بذر دلالت می‌کنند.

واژه‌های کلیدی: تولید پایدار گندم، تصمیم‌گیری شناختی، تکنیک دلفی، روش ترکیبی، مدل‌های ذهنی، مطالعه پدیدارشناختی

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