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Technical knowledge acquisition modes and environmental sustainability in Spanish organic farms

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ABSTRACT

Understanding technical knowledge acquisition modes in organic farming (i.e., how organic farmers learn about the means and methods underpinning the practice of organic agriculture) and how such learning modes and subsequent knowledge affect environmental sustainability constitutes a necessary condition to develop a more sustainable type of agriculture. Using survey data from 358 organically certified Spanish farms, this paper analyzes the role of educational and research institutions, advisory organizations, and sectoral organizations when it comes to promoting different types of knowledge acquisition pathways among organic farmers, as well as the degree of effectiveness of such learning alternatives and the acquired technical knowledge vis-à-vis environmental sustainability. The results obtained show that sectoral organizations are the most relevant actor and that a balance is needed between social interaction-based and codification-grounded learning pathways to facilitate the acquisition of technical knowledge by organic farmers and thus contribute to environmental sustainability.

1. Introduction

According to the Geneva Environment Network (2003), today, food production systems (i.e., the constellation of activities involved in producing, processing, transporting, and consuming food) are responsible for 60% of biodiversity loss on land, 33% of degraded soils, 24% of global greenhouse gas emissions, and 20% of overexploitation of the world's aquifers. To overcome these negative consequences, organic farming has emerged as a farm management and food production system that encourages responsible usage of energy and natural resources; maintenance of biodiversity; preservation of regional ecological balances; enhancement of soil fertility; maintenance of water quality; and high standards of animal welfare (European Commission, 2023).

To fulfill the above mission, enabling farmers to acquire technical knowledge regarding the means and methods underpinning the practice of organic agriculture—i.e., agroecological production techniques, agricultural machinery, and information and communication technology (ICT)-based applications for farm management—constitutes a necessary condition. As pointed out by Šūmane et al. (2018), to practice more sustainable agriculture, farmers may need to relearn and change their mindsets to overcome the productivist approach which has been dominant for a long time and has been internalized in many farmers' thinking and practices. Indeed, as expressed by Toffolini et al. (2019), agricultural modernization has emphasized optimization with the aim to obtain "the maximum productivity permitted by the genetic potential" (Toffolini et al., 2019:3). Thus, increasing productivity has been a primary goal over the last few decades.

Under these circumstances, research is needed to understand the learning modes (i.e., the specific manners in which learning occurs) that best facilitate the acquisition of technical knowledge by farmers, and to help develop learning ecosystems that facilitate access to the right knowledge at the right time and in the most effective and efficient way. Within such learning ecosystems, special attention should be paid to those actors that could play a relevant role (i.e., education and research institutions, advisory organizations, and sectoral organizations), and to the different kinds of knowledge acquisition pathways (i.e., specific formats for knowledge delivery) that they could promote. Beyond the provision of formal education (which can only be offered by educational institutions), they could propose continuous education programs and facilitate ICT-based and social interaction-based learning processes. A few studies exist that address social interaction-based learning in organic farming (e.g., Kroma, 2006; Strauss, 2016; Šūmane et al., 2018;

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Tran et al., 2018), ICT-based learning (e.g., Soulignac et al., 2012; Thanopoulos et al., 2012; Guiné et al., 2015), and educational programs (e.g., Francis, 2009; Polat, 2015). However, to the best of our knowledge there are no studies that comparatively address the role of educational and research institutions, advisory organizations, and sectoral organizations in promoting various learning pathways in organic farming, and that evaluate the effectiveness of these pathways and the technical knowledge acquired in relation to environmental sustainability.

Indeed, each learning pathway involves a distinct combination of learning modes, each of which is associated with a different type of knowledge. On one hand, there is codified or explicit knowledge regarding the scientific principles of organic agriculture and the specifications and procedures to perform specific tasks, solve problems, and use different tools and equipment. This type of knowledge can be effectively conveyed through systematic and structured means, such as textbooks, manuals, or other documented resources (Nonaka and Takeuchi, 1995). On the other hand, there is context-dependent tacit knowledge, which involves the ability to diagnose problems, interpret complex situations, and make informed decisions. This form of knowledge relies on personal experiences, intuitions, skills, and insights, making it challenging to communicate and formalize (Nonaka and Takeuchi, 1995). According to Jensen et al. (2016), while explicit knowledge derived from scientific sources would demand a 'Science, Technology, and Innovation' (STI) learning mode, context-dependent tacit knowledge would require a 'Doing, Using, and Interacting' (DUI) learning mode.

In the STI learning mode, knowledge transfer and learning mechanisms are primarily related to knowledge sharing among actors through conferences, scientific publications, or academic activities (Apanasovich, 2016; Parrilli and Alcalde-Heras, 2016; Santos et al., 2022). Meanwhile, the DUI learning mode focuses on face-to-face knowledge sharing leveraging state-of-the-art practices and experienced human capital in daily problem-solving, using trial-and-error mechanisms (Parrilli and Alcalde-Heras, 2016; Santos et al., 2022). Each of these modes could play a crucial role in the acquisition of knowledge for organic agriculture, and effective learning pathways should consider how to facilitate the acquisition of both codified and tacit knowledge to empower organic farmers and enhance environmental sustainability.

While educational programs are primarily focused on the transmission of codified knowledge (i.e., they mainly involve an STI learning mode), social interaction with different types of actors is better suited for the transmission of context-dependent tacit knowledge (i.e., it aligns with the DUI learning mode). This contextuality aspect (i.e., the dependence of knowledge on the specific characteristics of the local context) is specially exacerbated in the case of organic farming (see Šūmane et al., 2018), where only natural inputs and processes are used, thus making the outcomes of a specific technique greatly dependent on local conditions such as climate, altitude, soil characteristics, water sources, insect population, etc. As a result, a balanced combination of codified and tacit knowledge-oriented learning pathways should be applied to facilitate the acquisition of technical knowledge conducive to environmental sustainability. In this regard, ICT-based learning offers the possibility to integrate both types of learning modes effectively. First, it provides access to extensive sets of documented (codified or explicit) knowledge available on various websites, blogs, and specialized portals. Second, social networks, virtual meeting software, and image and video sharing platforms facilitate the transmission of tacit knowledge through interactions and discussions among farmers, researchers, advisers, and other stakeholders (e.g., Slimi et al., 2023).

Hence, using large-scale survey data from a set of 358 family-owned organic farms in Spain, this paper aims to analyze the role of educational and research institutions, advisory organizations, and sectoral organizations when it comes to promoting different learning pathways in organic farming, as well as the degree of effectiveness of such pathways and the acquired technical knowledge vis-à-vis environmental sustainability. In so doing, this paper will contribute to the knowledge management and rural sociology literatures by highlighting the combined role of codified and tacit knowledge-oriented learning resources in organic agriculture, which exemplifies a context in which the application of technical knowledge is highly affected by local characteristics. By elucidating how different learning alternatives contribute to the acquisition of technical knowledge and sustainability improvements, and by identifying the key actors facilitating them, this study can propose intervention strategies aimed at enhancing access to the right knowledge at the right time, in the most effective and efficient manner. Furthermore, understanding the extent of organic farmers' engagement in various learning pathways and their effectiveness can help pinpoint priority areas for action.

2. Theoretical background and hypothesis development

2.1. Learning modes

This paper revolves around how different learning modes inherent to different learning pathways (educational programs, ICT-based learning, and social interaction with different types of actors) can contribute to technical knowledge acquisition by organic farmers and thus to enhanced environmental sustainability. Therefore, the notion of 'learning mode' is central to our work. By learning mode, we refer to the approach used to acquire knowledge, or, conversely, the specific manner in which learning occurs.

Jensen et al. (2016) formulated a taxonomy of learning modes grounded in the conceptual framework put forth by Lundvall and Johnson (1994) concerning learning processes and the premise that diverse knowledge bases yield distinct outcomes. Their taxonomy not only acknowledges the paramount role of science and technology but also underscores the significance of experiential learning and interactions within the learning process. The authors delineate two distinctive modes of learning: 'Science, Technology, and Innovation' (STI), which draws upon explicit and codified knowledge derived from scientific sources, and learning rooted in 'Doing, Using, and Interacting' (DUI), which relies on tacit knowledge acquired through practical experience.

The STI learning mode is primarily driven by the demand for technical and scientific knowledge encompassing the 'know-what' and 'know-why' aspects. Scientific knowledge necessitates expression in explicit and codified terms, facilitating its global accessibility and utilization by anyone well-versed in the specific codified language (Isaksen and Karlsen, 2010). However, the STI mode does not dismiss the importance of tacit knowledge. Often, a blend of scientific theory and practical application is essential for experimentation and result interpretation (Jensen et al., 2016; Aslesen et al., 2012). Specialized research organizations, such as research centers, R&D departments, and universities, are instrumental in the production of scientific-based knowledge. Consequently, firms relying on this type of knowledge often engage in interactions with these scientific institutions (Parrilli and Elola, 2012; Fitjar and Rodríguez-Pose, 2013; Apanasovich, 2016). The underlying conceptual driver of the STI mode is the linear model of innovation, where technological knowledge emerges within scientific organizations and subsequently undergoes transfer to firms for commercialization (Isaksen and Karlsen, 2010).

In contrast, the DUI learning mode relies on tacit, experiential knowledge to drive innovative outcomes. Tacit knowledge is considered strategically vital for organizations and is predominantly acquired through day-to-day activities and problem-solving situations in the workplace (Asheim and Coenen, 2006; Guo et al., 2010; Aslesen et al., 2012). Within the DUI learning mode, two core components are emphasized: 'know-how' (i.e., knowing how to do something effectively and/or efficiently) and 'know-who' (i.e., knowing the right people to help solve a problem). 'Learning-by-doing' posits that repetitive workplace tasks enable experimentation with new organizational approaches, ultimately enhancing efficiency and performance (Arrow, 1962; Amara et al., 2008). ‘Learning-by-using’ involves leveraging feedback from user experiences to inform iterative product design, thereby improving the productivity of production methods (Rosenberg, 1982). This knowledge also contributes to the development of both general and specialized worker skills and competencies (Jensen et al., 2016). Given its nature, tacit knowledge tends to be highly localized. Much of it is acquired through direct observation and communication within the workplace, followed by subsequent assimilation and practice. Moreover, interactions with clients, suppliers, and competitors further augment experiential knowledge (González-Pernía et al., 2015; Apanasovich, 2016; Parrilli and Alcalde-Heras, 2016).

Numerous studies conducted across different industries and geographic regions (Amara et al., 2008; Isaksen and Karlsen, 2010; Trippl and Maier, 2011; Aslesen et al., 2012; Fitjar and Rodríguez-Pose, 2013; Apanasovich, 2016; Parrilli and Alcalde-Heras, 2016) have aimed to determine the most effective learning mode. However, their findings have been diverse. Generally, the STI learning mode contributes to the generation of advanced scientific and technological knowledge. This mode is often associated with analytical processes focused on identifying natural principles and mechanisms applicable to various industries, particularly in fields such as chemicals, pharmaceuticals, biotechnology, and nanomaterials. In contrast, the DUI approach encompasses learning-by-doing, learning-by-using, and learning-by-interacting. These elements facilitate the translation of scientific and analytical knowledge inputs into practical, synthetic knowledge. This synthetic knowledge is more readily applicable in engineering-based businesses and industries, including machine-tools, automotive, shipbuilding, and traditional manufacturing sectors (Asheim and Coenen, 2006). Parrilli and Alcalde-Heras (2016) suggest that these variations can be attributed to sector-specific factors, which encompass various forms of capital. These include financial resources, such as R&D investments, human capital levels, particularly the presence of scientifically trained individuals, and social and relational capital, which pertains to the quality of relationships among producers, suppliers, and users.

However, as highlighted by Girard (2015), the agricultural domain has received limited attention in the knowledge management literature. Consequently, there is a dearth of research aimed at comprehending how traditional business learning modes accommodate the diverse learning practices and strategies within this field. In agriculture, knowledge is generated, translated, discussed, and shared through inter-organizational processes that bridge the realms of science and communities. Similarly, Doloreux et al. (2023) underscore the importance of considering the rural context of farming. The distinct characteristics of knowledge bases in agriculture are deeply rooted in rural environments, and these areas may also face geographic isolation. Such isolation can potentially impact their capacity to engage in interactive learning activities and subsequently affect the effectiveness of various learning modes. This warrants further exploration and investigation.

Based on these research gaps and the theoretical background previously outlined, this study proposes a research model organized into three blocks:

1. The role of educational and research institutions, advisory organizations, and sectoral organizations in promoting different learning pathways in organic farming, specifically continuous education, ICT-based learning, and social interaction with key actors in the agricultural value creation system (hypotheses H1, H2, and H3).
2. The contribution of different learning pathways to the acquisition of technical knowledge in organic farming, including formal education, continuous education, ICT-based learning, social interaction with key actors in the agricultural value creation system, social interaction with family and friends, and social interaction with technical staff from educational and research institutions, advisory organizations, and sectoral organizations (hypotheses H4, H5, H6, H7, H8, and H9).
3. The relationship between technical knowledge and environmental sustainability (hypothesis H10).

Fig. 1 summarizes the research model.

2.2. The role of educational and research institutions, advisory organizations, and sectoral organizations in the promotion of learning in organic farming

Röling (1990) stressed the significance of knowledge in the agricultural sector and introduced the concept of ‘Agricultural Knowledge and Information System’ (AKI). This term encompasses the network of organizations and individuals who collaborate in generating, preserving, disseminating, and applying knowledge to make decisions, solve problems, and drive innovation within agriculture. Traditional components of AKIs, such as educational and research institutions, and advisory organizations (FAO and World Bank, 2000; Davis and Sulaiman V, 2018), have long played pivotal roles. Additionally, recent developments have seen the incorporation of farmers’ organizations and other members of the value chain into AKIs (Sutherland et al., 2017).

Given their inherent characteristics and expertise, educational and research institutions are ideally positioned to play a central role in facilitating the acquisition of technical knowledge. Beyond formal education, vocational centers and universities can offer ongoing educational programs related to organic agriculture and other pertinent subjects. Additionally, both educational and research institutions can organize short courses, workshops, and conferences to disseminate the findings of their research projects and innovative solutions. They can also provide valuable information on advancements in organic farming techniques through their websites, social media platforms, blogs, and newsletters. Moreover, these dissemination events can serve as platforms to foster social interaction among diverse actors within the agricultural value creation system.

Based on these considerations, we propose the following hypothesis:

H1. The greater the extent to which farmers rely on educational and research institutions, the stronger (a) the participation in continuous education programs, (b) the utilization of ICT-based mechanisms, and (c) social interaction with key actors in the agricultural value creation system, including customers and/or consumers, suppliers, and other producers.

Beyond educational and research institutions, agricultural advisory organizations and farmers’ organizations (encompassing unions, professional associations, sectoral groups, and agrarian social movements), constitute crucial stakeholders in the agricultural development process. They serve four primary purposes: 1) facilitating technology transfer; 2) fostering human capital development, with a particular emphasis on technical skills and knowledge; 3) creating social capital; and 4) educating farmers in sustainable resource management (Swanson 2008).

Specifically, agricultural advisory services encompass a range of institutions from the public, private, and third sectors (the latter have been excluded from this research), which provide farmers with knowledge, expertise, and information to address problems and enhance their economic well-being (Birner et al., 2009). These organizations usually promote knowledge creation and dissemination among farmers and various stakeholders through diverse means. They offer educational and training programs for farmers in various formats, including curriculum-based training such as courses, seminars, and workshops, as well as field guidance (Pang and Zhang, 2018). Additionally, they leverage ICT-based tools like weblogs to provide valuable information (Zakaria and Nagata, 2010). While these tools primarily facilitate the sharing of codified or explicit knowledge, advisory agencies also actively encourage collaboration between farmers and promote face-to-face interactions, facilitating the exchange of tacit knowledge (Zakaria and Nagata, 2010).

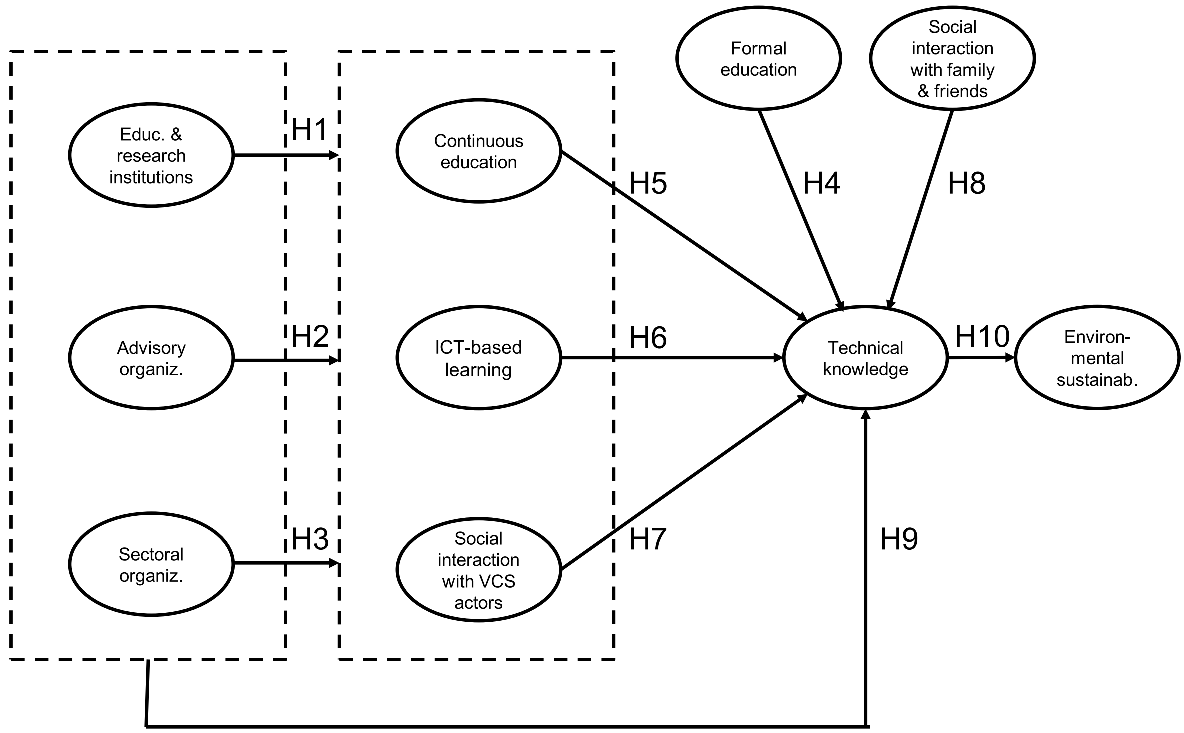

Fig. 1. Research model.
Note: VCS = value creation system.

In light of these considerations, we propose the following hypothesis:

H2. The greater the extent to which farmers rely on advisory organizations, the stronger (a) the participation in continuous education programs, (b) the utilization of ICT-based mechanisms, and (c) social interaction with key actors in the agricultural value creation system, including customers and/or consumers, suppliers, and other producers.

Farmers' or sectoral organizations (i.e., non-profit organizations created by farmers themselves, sometimes in collaboration with other actors, to defend their interests and/or promote the agricultural model they believe in) can also play a relevant role in facilitating organic farmers' learning processes. For example, research has demonstrated that farmers' organizations facilitated the acquisition of rice farming techniques in West Africa (Zossou et al., 2020). Additionally, belonging to a farmers' organization can significantly influence the type of knowledge management practices employed. A study conducted in Brazil (Da Silva et al., 2021) revealed noteworthy differences in knowledge management practices between farms affiliated with agricultural cooperatives and those that were not affiliated.

Sectoral organizations often provide their members with training materials and a wide range of ICT-based knowledge resources accessible through their websites, social media channels, blogs, journals, and newsletters. However, their primary role in knowledge provision extends to supporting farmers in the development of their social capital. They facilitate networking and promote knowledge sharing among farmers and other stakeholders within the agricultural value creation system. As emphasized by Girard (2015), in the context of organic agriculture, knowledge originating from practitioners themselves, often referred to as a 'bottom-up' approach, holds particular importance. This is because knowledge derived from local conditions and field practices is critical in this domain, making knowledge sharing among farmers a substantial and essential endeavor. Farmers' organizations actively encourage socialization processes among producers, thereby fostering tacit knowledge exchange (Nonaka and Takeuchi, 1995) through various means, including the organization of diverse events that provide opportunities for farmers to connect and build networks.

Based on the insights provided, we propose the following hypothesis:

H3. The greater the extent to which farmers rely on sectoral organizations, the stronger (a) the participation in continuous education programs, (b) the utilization of ICT-based mechanisms, and (c) social interaction with key actors in the agricultural value creation system, including customers and/or consumers, suppliers, and other producers.

2.3. Learning pathways and technical knowledge acquisition in organic farming

Education, encompassing both formal and continuous learning, serves as a fundamental pathway for acquiring knowledge regarding the principles and techniques underlying organic agriculture (Soulignac et al., 2012). Several studies have demonstrated the beneficial impact of training on farmers' acquisition of technical knowledge. For example, the educational programs initiated by the Chinese government focusing on farmers' knowledge of fertilizer management in rice production have proven highly significant. This knowledge is particularly crucial for mitigating environmental damage and adverse outcomes resulting from excessive nitrogen utilization (Ying et al., 2017; Pang and Zhang, 2018).

Educational programs are mostly related to the transmission of codified knowledge regarding the scientific principles and theories underlying organic farming (i.e., "know-why" knowledge; Lundvall and Johnson, 1994; Lundvall and Nielsen, 2007); the history, facts, and figures related to this kind of agriculture (i.e., "know-what" knowledge; Lundvall and Johnson, 1994; Lundvall and Nielsen, 2007), as well as the techniques to be applied and the steps and guidelines to be followed to perform different types of agricultural activities (i.e., "know-how" knowledge; Lundvall and Johnson, 1994; Lundvall and Nielsen, 2007). While educational programs primarily focus on codified knowledge, they may also incorporate hands-on activities and projects, particularly in the context of continuous education. This approach can provide participants with opportunities to develop and exchange tacit knowledge, albeit to a lesser extent. Consequently, educational programs are primarily aligned with the STI mode of learning and, to a lesser extent, with the DUI mode (Jensen et al., 2016).

Irrespective of the learning mode, the following hypotheses can be formulated:

H4. Formal education is positively related to the acquisition of technical knowledge.

H5. Continuous education is positively related to the acquisition of technical knowledge.

According to Doloreux et al. (2023), agriculture employs both STI and DUI learning modes, effectively integrating systems for the exchange of codified and tacit knowledge. However, as previously mentioned, in the context of organic agriculture, a 'bottom-up' approach to learning, primarily grounded in the exchange of field practices (i.e., tacit knowledge), gains particular prominence (Morgan and Murdoch, 2000; Girard, 2015). In the words of Morgan and Murdoch (2000:171), "the organic model provides greater opportunities for the utilization of tacit knowledge in combination with benign standardized forms. This combination seeks to revalue local knowledge, local ecosystems, and local identities so that farmers can once again become 'knowing agents' … knowledge is linked to both local production practices and a keen awareness of ecosystems and natural processes."

To facilitate the exchange of tacit knowledge, the concept of 'ba', as proposed by Nonaka and Konno (1998), proves to be highly valuable. "Ba" can be conceptualized as a shared space where relationships develop and knowledge is nurtured. This space can take various forms, including physical realms such as offices or dispersed business spaces, virtual spaces like email or teleconferences, and even mental spaces where shared experiences, ideas, and ideals converge (Nonaka and Konno, 1998).

To establish a virtual 'ba', the role of information and communication technologies (ICTs) is paramount. In this context, certain ICT-based tools, such as social media, prove highly effective (Nain et al., 2019; Prost et al., 2022). For instance, Slimi et al. (2023) illustrates the case of a farmers' community using WhatsApp for peer-to-peer interaction, allowing them to share agricultural practices, including both established and innovative or even transgressive practices that break away from conventional methods. Likewise, the use of a WhatsApp group for farmers allows a producer facing issues with a crop to capture images of the plants and share them through WhatsApp. This facilitates seeking assistance from other producers for diagnosing the problem and receiving advice on how to address it. Another noteworthy example is the utilization of YouTube videos created by farmers for fellow farmers and the use of social media among rice producers in West Africa. These platforms serve as means for sharing knowledge and also contribute to reducing gender bias (Zossou et al., 2020).

Indeed, ICT-based mechanisms are versatile tools that can also facilitate access to and sharing of codified knowledge in various ways. These mechanisms include platforms like email and the Internet (Ahuja, 2011; Soulignac et al., 2012) as well as expert systems that provide information on pests and diseases (Ahuja, 2011). Additionally, agricultural portals and specialized websites serve as valuable resources for accessing different types of publications related to recent developments in agroecological techniques, machinery, and ICT-based solutions for farm management. They offer organic farmers insights into best practices and practical advice for their work. Furthermore, these platforms can facilitate the identification of key experts and organizations that can be contacted to address specific issues, thus embodying 'know-who' knowledge (Lundvall and Johnson, 1994; Lundvall and Nielsen, 2007). As Ahuja (2011:4) suggests, "ICT also plays an important role in documenting both traditional and organic cultivation practices, thus acting as a bridge between traditional and modern knowledge systems."

In light of the multifaceted role of ICT-based mechanisms in facilitating the acquisition of technical knowledge by farmers, encompassing both STI and DUI learning modes, we can formulate the following hypothesis:

H6. ICT-based mechanisms are positively related to the acquisition of technical knowledge.

The heightened reliance of organic agriculture on natural processes implies a greater dependence on local conditions, including climate, soil, water, and fauna, in comparison to conventional agriculture. Within this context, knowledge derived from personal observation and practical experience becomes essential for organic farmers to operate effectively within their specific local environments. This type of knowledge entails a deep understanding of how local natural resources function, enabling farmers to interpret ongoing processes and propose optimal solutions (Šūmane et al., 2018). Consequently, this form of knowledge is challenging to articulate and document, making it best acquired through hands-on experience, utilization, and interaction with more experienced farmers (Jensen et al., 2016), whether they are relatives or friends (Pratiwi and Suzuki, 2017; Da Silva et al., 2021), as well as through peer discussions (Cuéllar-Padilla and Calle-Collado, 2011; Coquil et al., 2018; Soto et al., 2021).

Furthermore, interacting with other key actors within the agricultural value creation system (Dung et al., 2021), such as suppliers of machinery and ICT-based solutions for farm management, may help organic farmers gain valuable knowledge regarding how this equipment and software can be adapted to their specific circumstances, which may not be as easily achieved by simply reading technical documents. Additionally, engaging with customers and consumers can provide farmers with insights into how the techniques they employ affect product characteristics and their alignment with customer preferences and needs.

Beyond the role of knowledge-sharing promoters emphasized in hypotheses H1, H2, and H3, social interaction with researchers (Šūmane et al., 2018) and advisers (Pratiwi and Suzuki, 2017; Da Silva et al., 2021) themselves can significantly contribute to the acquisition of technical knowledge. In essence, given the intricate and location-specific nature of technical knowledge in organic agriculture, the creation of a physical "ba," where diverse actors can convene, interact, and share practice-based knowledge, particularly tacit knowledge, assumes heightened importance.

Building on the insights outlined above, the following hypotheses are proposed:

H7. Social interaction with key actors in the agricultural value creation system, including customers, consumers, furnishers, and other producers, is positively related to the acquisition of technical knowledge.

H8. Social interaction with family and friends is positively related to the acquisition of technical knowledge.

H9. Social interaction with technical staff from (a) education and research institutions, (b) advisory organizations, and (c) sectoral organizations can also facilitate the acquisition of technical knowledge.

2.4. *Technical knowledge and environmental sustainability*

Organic farming is often promoted as an eco-friendly and sustainable type of agriculture (Reganold and Wachter, 2016; Singh, 2021). Therefore, the acquisition of technical knowledge regarding the means and methods underpinning the practice of organic farming should play a vital role in achieving environmental goals. For instance, knowledge on natural methods for pest management and natural fertilizers should contribute to reducing pollution of both ground and surface waters; understanding composting techniques and utilizing animal waste as fertilizer should reduce organic waste going to landfills, thus contributing to waste reduction and minimizing environmental pollution; knowledge on crop rotation techniques, intercropping, cover crops, and micronutrient management should translate into improved soil health and biodiversity; knowledge on irrigation techniques and water conservation practices should help optimize water use, reducing the environmental impact of excessive water consumption; and technical knowledge on how to optimize farming operations should lead to lower energy consumption.

Moreover, knowledge on existing ICT-based solutions for farm management could incentivize their use and help extract the highest benefits from their functionalities to make decisions that help preserve the farm's environment. Likewise, being knowledgeable about agricultural machinery may facilitate choosing the most energy-efficient equipment for farmers' needs, as well as carrying out proper maintenance and thus reducing the likelihood of oil and/or fuel leaks that could contaminate the soil or the water.

Based on the above, it is reasonable to propose that:

H10. Technical knowledge is positively related to environmental sustainability.

In addition to their role in facilitating the acquisition of technical knowledge, the various learning pathways mentioned above can contribute to raising awareness about existing knowledge and techniques and the benefits they entail. Indeed, the dissemination work carried out by the different actors studied is important for publicizing various techniques that can improve the environmental sustainability of farms. This awareness-raising function is crucial for motivating individuals to apply the knowledge they have acquired and promote environmental sustainability in organic farming. Consequently, we also need to investigate the direct relationship between different learning pathways, such as formal education, continuous education programs, ICT-based mechanisms, and social interaction with diverse actors, and their impact on enhancing environmental sustainability. Regardless of their primary function as learning facilitators, these knowledge sources have the potential to influence individuals' awareness and commitment to sustainable farming practices. Therefore, understanding how these learning pathways contribute to environmental sustainability beyond knowledge acquisition is a valuable area of exploration.

3. Research methods

We tested research hypotheses using survey research data from a set of family-owned organic farms in Spain. Spain is the second European country with the largest area dedicated to organic agriculture behind France (2.8 million hectares vs. 2.6 million, respectively) (Willer et al., 2023).

3.1. Measures

As far as measures are concerned, knowledge acquisition facilitating actors (i.e., independent variables) encompass 3 indicators per group showing the extent to which different types of external actors within each category constitute a relevant source of knowledge for organic farmers: educational and research institutions (EDRES) include vocational education centers, universities, and agricultural research and development centers; advisory organizations (ADVORG) encompass agricultural advisory and consulting firms, business chambers, and rural development agencies; and sectoral organizations (SECTORG) include unions, sectoral associations, and agricultural social movements. While advisory organizations are public, private, or third sector entities specifically created by actors other than producers to provide advice, sectoral organizations are non-profit entities established by producers themselves (sometimes in collaboration with other actors) to defend their interests and/or promote the agricultural model they believe in.

Moving now to learning alternatives or pathways (i.e., first-level mediating variables), formal education (FORMED) encompasses 2 indicators measuring whether the farmer holds a vocational degree or a university degree in agriculture; continuous education (CONTED) includes another 2 indicators measuring whether the farmer has participated in specific courses in agroecology or in other agricultural matters; ICT-based knowledge acquisition (ICT) encompasses 4 indicators measuring the extent to which farmers' WhatsApp groups, other social networks, portals on agricultural issues, and other webpages enable the acquisition of valuable knowledge; social interaction with key actors in the agricultural value creation system (SIVALC) includes 4 indicators measuring the extent to which relationships with customers, consumers, furnishers, and other producers provide farmers with relevant knowledge; and social interaction with family and friends (SIFAM) encompasses 2 indicators measuring the extent to which interactions with both groups enables useful knowledge to be gained.

Regarding technical knowledge (TECKNOW) (i.e., second-level mediating variable), this includes 3 indicators measuring farmers' knowledge on agroecological production techniques, agricultural machinery, and ICT-based solutions for farm management. Finally, environmental sustainability (ENVSUST) (i.e., the final dependent variable) encompasses 8 indicators that correspond to the 3 dimensions considered within the context of the natural-resource-based view (Hart, 1995; Hart and Dowell, 2011): (a) pollution prevention (i.e., reducing waste and residues to a minimum: 2 indicators); (b) product stewardship (i.e., lower product life cycle cost by minimizing natural resource consumption: 2 indicators); and (c) sustainable development (i.e., producing in a way that can be maintained indefinitely into the future by protecting natural resources: 4 indicators).

Table 2 provides detailed information about the variables included in the research, such as their codes, nature, and item wording, along with descriptive analyses and measurement model evaluation parameters (see sections below). All the variables in the research are qualitative, describing different characteristics or qualities that cannot be measured numerically in a natural way. Most of these qualitative variables were measured using 0 to 10 Likert scales, making them ordinal. The only exceptions are formal and continuous education, which involved identifying whether the individuals responsible for the agricultural production unit possessed different types of education. Thus, these variables are purely nominal.

3.2. Data collection

The target population of the research was identified by means of the REGOE (*Registro General de Operadores Ecológicos de España*), which is the Spanish General Register of Organic Operators. In all, 28,283 vegetable producers were identified whose farms were family-owned. From this population, a sample of 406 producers was obtained that respected regional and gender proportions. The choice was then made to focus on those producers whose main production was crop-based (358 producers).

A questionnaire was designed to gather information about the variables included in the research and was administered by phone by a specialized company from February 2021 to April 2021. Total anonymity was guaranteed, and personalized reports of results were offered to encourage participation. All questionnaires were answered by people who actively participated in the management of the farm. Of these, 284 people (79.33%) were owners of the farm, and the remaining 74 (20.67%) while not being owners, were actively involved in decision making, planning, and organization of day-to-day activities. Table 1 offers a detailed description of the sample profile including regional distribution, respondents' profile (i.e., sex, age, role, and educational background), and farms' characteristics (i.e., size, % of hectares under organic agriculture, age of the farm, age of organic practices, ownership type, employment, external earning sources, main crop, diversification degree, environmentally friendly practices beyond those required by organic certification, and cooperative membership or equivalent).

Given that data for all variables were collected through the same self-reported survey, we considered the possibility of common method bias, as suggested by Podsakoff et al. (2003). To assess the extent of method-related variance in the dataset, we employed a full collinearity test specifically designed for partial least squares–structural equation modeling (PLS-SEM), as proposed by Kock (2015). A model is

Table 1
Sample profile.

Profile category	Characteristics	% in the population	% in the sample	Mean	STDEV
Geographical profile					
	Regional distribution				
	Southern Region (Andalusia, Ceuta, and Canary Islands)	38.93%	35.8%		
	Central-Southern Region (Castile La Mancha and Madrid)	20.78%	21.2%		
	Mediterranean Region (Catalonia, Valencia, Murcia, and Balearic Islands)	23.08%	26.0%		
	Western Region (Castile-Leon and Extremadura)	9.60%	8.1%		
	Northern Region (Galicia, Asturias, Cantabria, Basque Country, Navarre, La Rioja, and Aragon)	7.61%	8.9%		
Respondents' profile					
	Sex				
	Male		78.8%		
	Female		21.2%		
	Age			54.16	11.92
	Role				
	Owners		79.3%		
	Non-owners		20.7%		
	*Educational background**				
	Vocational education in agriculture		8.1%		
	University education in agriculture		7.0%		
	Specific courses in agroecology		48.6%		
	Specific courses in other agricultural matters		39.1%		
	Other vocational education		9.0%		
	Other university education		14.7%		
Organic farms' profile					
	Size (i.e., No. of hectares under crops and pastures)			44.31	232.23
	Farms with less than 4 ha		25.7%		
	Farms with 4 ha or more and less than 12		23.5%		
	Farms with 12 ha or more and less than 32		25.1%		
	Farms with 32 ha or more		25.7%		
	% of hectares under organic agriculture			87.85%	25.01
	Farm age				
	First generation		29.6%		
	Second generation		30.2%		
	Third generation		18.7%		
	Fourth generation or more		21.5%		
	Age of organic practices				
	First year of organic practices			2009	11.34
	Ownership type				
	Individual male ownership	64.4%	64.0%		
	Individual female ownership	31.1%	31.8%		
	Several owners (2 or more)	4.5%	4.2%		
	Employment				
	Permanent employees			1.58	1.44
	Female permanent employees			0.23	0.50
	External earning sources				
	% of farm owners combining agricultural activity with other earning sources		60.6%		
	Main crop				
	Olive trees		27.4%		
	Vineyards		12.0%		
	Nuts		11.5%		
	Citrus		8.4%		
	Other fruits		19.8%		
	Vegetables		11.2%		
	Cereals and grain legumes		9.7%		
	Diversification degree				
	No. of different crop types (according to the above categories)			1.86	0.999
	Environmentally friendly practices				
	Recovery and conservation of local seeds		12.0%		
	Production of organic fertilizers		27.9%		
	Renewable energy production for self-consumption		7.3%		
	Recycling and/or treatment of waste and residues		28.8%		
	Membership in a cooperative or equivalent		66.5%		

(*) More than one option per respondent was possible. STDEV = Standard deviation.

considered free from common method bias when all variance inflation factors (VIFs) are 3.3 or lower (Kock 2015). In our analyses, the highest VIF value observed was just 3.3. Consequently, we can confidently conclude that common method bias did not significantly influence our results.

3.3. Statistical analysis

Research hypotheses were analyzed using Structural Equation Modelling based on Partial Least Squares (SmartPLS 3.3.5 software) (Ringle et al., 2015). This choice was mainly determined by the nature of the measurement model implied in the research (Henseler, 2017; Hair Jr. et al., 2022). Indicators in our model build up (or define) the conceptual variables they represent. In other words, each research variable is conceived as a combination of different elements that make it up and that may not necessarily correlate. When this is the case, a composite measurement model applies (Henseler, 2017).

In composite measurement, latent variable scores are linear combinations (i.e., weighted composites) of the indicators making up the variables without error term. Two possibilities exist to estimate

Table 2
Measurement model evaluation.

Constructs and measures	Item wording	Mean (or %)	STDEV	VIF	Weight	p-val.
Educational and research institutions (EDRES) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all; 10 = Very much) the extent to which the relation dynamics with the following groups and actors favors the acquisition and generation of useful knowledge for the agricultural production unit:					
EDRES1 (Qual. Ord.)	Vocational training centers.	2.297	3.275	2.142	0.303	0.000
EDRES2 (Qual. Ord.)	Universities and other higher education institutions.	2.182	3.327	3.281	0.174	0.055
EDRES3 (Qual. Ord.)	Agricultural research and development centers or other technology centers.	2.538	3.464	3.196	0.613	0.000
Advisory organizations (ADVORG) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all; 10 = Very much) the extent to which the relation dynamics with the following groups and actors favors the acquisition and generation of useful knowledge for the agricultural production unit:					
ADVORG1 (Qual. Ord.)	Agricultural advisory and consulting firms.	2.922	3.604	1.626	0.302	0.000
ADVORG2 (Qual. Ord.)	Business chambers.	1.546	2.764	2.710	0.149	0.061
ADVORG3 (Qual. Ord.)	Rural development associations and associations of municipalities.	2.050	3.125	2.479	0.674	0.000
Sectoral organizations (SECTORG) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all; 10 = Very much) the extent to which the relation dynamics with the following groups and actors favors the acquisition and generation of useful knowledge for the agricultural production unit:					
SECTORG1 (Qual. Ord.)	Unions and other professional organizations of farmers and livestock breeders.	3.709	3.833	1.234	0.343	0.000
SECTORG2 (Qual. Ord.)	Sectoral associations.	3.443	3.700	1.718	0.278	0.000
SECTORG3 (Qual. Ord.)	Agrarian social movements in favor of food sovereignty, the defense of peasants' rights or others	2.364	3.345	1.724	0.599	0.000
Formal education (FORMED) Mode "B" composite	Please mark with an "X" what type of training the person(s) in charge of the agricultural production unit has/have (you can indicate more than one option):					
FORMED1 (Qual. Nom.)	Vocational education in agriculture	8.1%	0.273	1.002	0.606	0.002
FORMED2 (Qual. Nom.)	University education in agriculture	7.0%	0.255	1.002	0.821	0.000
Continuous education (CONTED) Mode "B" composite	Please mark with an "X" what type of training the person(s) in charge of the agricultural production unit has/have (you can indicate more than one option):					
CONTED1 (Qual. Nom.)	Specific courses in agroecology	48.6%	0.500	1.081	0.637	0.000
CONTED2 (Qual. Nom.)	Specific courses in other agricultural matters	39.1%	0.488	1.081	0.615	0.000
ICT-based knowledge acquisition (ICT) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all important; 10 = Very important) the degree of relevance of the following means in obtaining relevant information for the management of the agricultural production unit:					
ICT1 (Qual. Ord.)	Farmers' WhatsApp groups	4.075	3.926	1.612	0.349	0.000
ICT2 (Qual. Ord.)	Other social networks (Facebook, Twitter, etc.)	2.953	3.715	1.799	0.171	0.024
ICT3 (Qual. Ord.)	Agricultural portals	3.989	3.845	2.389	0.300	0.002
ICT4 (Qual. Ord.)	Other webpages	3.718	3.756	2.099	0.391	0.000
Social interaction with key actors in the agricultural value creation system (SIVALC) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all; 10 = Very much) the extent to which the relation dynamics with the following groups and actors favors the acquisition and generation of useful knowledge for the agricultural production unit:					
SIVALC1 (Qual. Ord.)	Customers	3.560	3.763	1.178	0.201	0.001
SIVALC2 (Qual. Ord.)	Consumers' groups and organizations	2.417	3.389	1.846	0.599	0.000
SIVALC3 (Qual. Ord.)	Furnishers	3.392	3.570	1.741	0.255	0.000
SIVALC4 (Qual. Ord.)	Other producers	5.947	3.468	1.822	0.188	0.000
Social interaction with family and friends (SIFAMF) Mode "B" composite	Please rate from 0 to 10 (0 = Not at all; 10 = Very much) the extent to which the relation dynamics with the following groups and actors favors the acquisition and generation of useful knowledge for the agricultural production unit:					
SIFAMF1 (Qual. Ord.)	Family	6.402	3.683	1.137	0.668	0.000
SIFAMF2 (Qual. Ord.)	Friends	5.413	3.516	1.137	0.548	0.000
Technical knowledge (TECKNOW) Mode "B" composite	Please rate from 0 to 10 (0 = None; 10 = Excellent) the degree of knowledge of the person(s) running the agricultural production unit about the following aspects:					
TECKNOW1 (Qual. Ord.)	Agroecological production techniques	6.886	2.843	1.890	0.529	0.000
TECKNOW2 (Qual. Ord.)	Agricultural machinery	6.712	2.838	1.644	0.121	0.112
TECKNOW3 (Qual. Ord.)	Information applications and technologies for farm management	4.570	3.363	1.452	0.522	0.000
Environmental sustainability (ENVSUST) Mode "A" composite	Please rate from 0 to 10 (0 = Strongly disagree; 10 = Strongly agree) your degree of agreement or disagreement with the following statements regarding your agricultural production unit:					
ENVSUST1 (Qual. Ord.)	Our energy consumption has reached an optimum level: there is no other technique or action that will allow us to reduce it further.	6.227	3.211	1.407	0.189	0.001
ENVSUST2 (Qual. Ord.)	Our water consumption has reached an optimal level: there is no other technique on the market or type of action that will allow us to reduce it further.	7.042	3.281	1.459	0.160	0.005
ENVSUST3 (Qual. Ord.)	Our fertilizer supply to the soil is always in line with the requirements of good environmental care.	9.286	1.540	1.578	0.196	0.000
ENVSUST4 (Qual. Ord.)	We have a good soil quality: all parameters are at adequate levels.	8.025	2.392	1.595	0.193	0.000
ENVSUST5 (Qual. Ord.)	Pests and/or diseases are adequately controlled.	7.403	2.522	1.442	0.178	0.000
ENVSUST6 (Qual. Ord.)	The biodiversity of our agricultural production unit is very high.	7.798	2.693	1.325	0.324	0.000
ENVSUST7 (Qual. Ord.)	The volume of waste and residues generated is minimal.	8.529	1.913	1.646	0.143	0.002
ENVSUST8 (Qual. Ord.)	The degree of reuse of the waste and residues we generate is 100%.	8.162	2.850	1.468	0.195	0.000
Control variables						
Financial resources (FINRES) Mode "B" composite	Please rate from 0 to 10 (0 = Strongly Disagree; 10 = Strongly Agree) your degree of agreement or disagreement with the following statements regarding your agricultural production unit:					

(*continued on next page*)

Table 2 (*continued*)

Constructs and measures	Item wording	Mean (or %)	STDEV	VIF	Weight	p-val.
FINRES1 (Qual. Ord.)	We have sufficient financing to undertake the necessary investments (in facilities, machinery, technology, etc.) to carry out the improvements required by the agricultural production unit.	3.858	4.046	2.200	0.067	0.447
FINRES2 (Qual. Ord.)	We have sufficient financing to carry out our daily activities (planting, cultivation, harvesting, livestock feeding, etc.).	4.782	3.670	2.200	0.949	0.009

Notes:
STDEV: Standard deviation.
VIF: Variance inflation factors.
P-val.: P-values.
Qual. Ord.: Qualitative ordinal.
Qual. Nom.: Qualitative nominal.

indicators' weights: mode "A" (i.e., correlation-based) and mode "B" (i.e., ordinary least squares regression-based) (Rigdon, 2016). This choice will depend on the degree of collinearity of the indicators within a particular construct. If collinearity is high, this could cause problems in the estimation of indicators' weights in mode "B" composites. Under these circumstances, researchers should consider using mode "A" (Henseler, 2017; Rigdon, 2016). As in our case some collinearity issues were identified in the dependent variable (i.e., environmental sustainability), mode "A" was chosen for this variable, while mode "B" was kept for the remaining variables, as this allows to assess the relative relevance of each indicator when it comes to maximizing the amount of variance explained of the mediating and dependent variables.

4. Research findings

4.1. Descriptive analysis

Prior to evaluating the measurement and the structural model, a descriptive analysis was carried out to portray the extent to which Spanish organic farmers rely on different types of actors and mechanisms for acquiring knowledge, as well as to assess the degree of development of technical knowledge and environmental sustainability in organic farms. As can be observed in Table 2, the degree of reliance of organic farmers on educational and research institutions and advisory organizations for acquiring relevant knowledge is quite low, as all the indicators within both categories are well below 3 on a 0 to 10 scale. The situation is a little bit better in the case of sectoral organizations, where 2 out of the 3 items included are clearly above 3 but still below 5.

As far as knowledge acquisition pathways are concerned, social interaction with family and friends shows the highest scores (with both indicators clearly above 5), followed by social interaction with key actors in the agricultural value creation system (where relationships with other producers constitute the most used knowledge source and indicators' scores range from 2.417 to 5.947) and by ICT-based mechanisms (where indicators' scores range from 2.953 to 4.075). Regarding education, continuous education is much more common than formal education: while 48.1% and 39.1% of the respondents report that people in charge of the farm have participated in specific courses in agroecology or in other agricultural matters, only 8.1% of the farms participating in the study have personnel with a vocational training degree in agriculture and only 7% with a university degree in the field.

In terms of technical knowledge, knowledge on agroecological production techniques and on agricultural machinery constitute the most salient aspects, although with room for improvement (scores in this case are 6.855 and 6.712 out of 10, respectively), while knowledge on ICT-based applications for farm management is quite behind, its score being 4.570. Finally, environmental sustainability items are clearly above 5 in all cases.

4.2. Measurement model evaluation

In composite measurement, concepts emerge as the combination of the different elements included in the definition and thus measurement model assessment should guarantee that the indicators capture the essence of the conceptual variables (i.e., 'conceptual fidelity'; Rigdon, 2012). As can be observed in Table 2, in the case of knowledge acquisition facilitating actors, conceptual fidelity is quite straightforward. Vocational education centers and universities are both educational institutions that also perform research activities, while agricultural research and development centers are purely research organizations. Thus, all of them are educational and/or research institutions. Regarding advisory organizations, the three of them included in this research clearly have and advisory orientation or include advisory services among their functions without being promoted by producers themselves. This is the case of agricultural advisory and consulting firms, but also of business chambers, and of rural development associations and associations of municipalities. As far as sectoral organizations are concerned, agricultural unions, sectoral associations, and agrarian social movements constitute three types of collective organization that imply the direct participation of producers in their funding and management (despite external professionals could also be hired).

Moving now to different learning pathways, both vocational education and higher education lead to the award of an official degree accredited by the Ministry of Education and thus are part of the formal education system. Conversely, specialized courses outside officially recognized vocational or university degrees (such as specialized courses on agroecology and on other agricultural matters) fall within the label of 'continuous education' (i.e., education provided for adults after they have left the formal education system). Social networks (e.g., WhatsApp, Twitter, or Facebook), internet portals, and webpages, unequivocally constitute ICT-based knowledge acquisition mechanisms, as they are grounded on such technologies. Producers, customers, end-consumers, and furnishers are part of the agricultural value creation system, while family and friends constitute informal sources of knowledge. Regarding technical knowledge (i.e., knowledge about the means and methods underpinning the practice of organic agriculture), agroecological production techniques constitute the methods, while agricultural machinery and ICT-based solutions for farm management represent the means.

Finally, as far as environmental sustainability is concerned, as already explained, indicators included correspond to the three dimensions suggested by the natural-resource-based view: (a) pollution prevention (i.e., reducing waste and residues to a minimum: ENVSUST7; and reusing waste and residues: ENVSUST8); (b) product stewardship (i.e., lower product life cycle cost by minimizing natural resource consumption: ENVSUST1 and ENVSUST2); and (c) sustainable development (i.e., producing in a way that can be maintained indefinitely into the future by protecting natural resources: ENVSUST3, ENVSUST4, ENVSUST5, and ENVSUST6).

Collinearity between indicators (measured in terms of VIF values) is another aspect to be analyzed, as this could cause problems in the estimation of indicators' weights (Rigdon, 2016). Ideally, VIF values should be close to 3 and lower (Hair et al., 2022). As can be observed in Table 2, all indicators' VIFs meet the above condition, with only two indicators whose VIF is slightly over 3 (EDRES2 and EDRES3). However, in the case of environmental sustainability, the large number of indicators (8) makes that some reversed signs appear when using mode "B" estimation for indicators' weights (even though VIF values are well below 3 and even below 2). For this reason, mode "B" estimation has been replaced by mode "A". In the rest of the cases, however, mode "B" has been kept, as no reversed signs have been obtained.

Finally, in mode "B" composites, the significance and relevance of indicators should be assessed (Hair et al., 2022). Significance levels were tested by means of a one-tailed 5,000 subsample bias-corrected and accelerated (BCA) bootstrap (Hair et al., 2022). As Table 2 shows, all indicators' weights are statistically significant but three (EDRES2, ADVORG2, and TECHKNOW2) whose p-values are indeed very close to the 0.05 threshold (0.055, 0.061, and 0.112, respectively). Thus, no changes have been included in the research model. Detailed comments regarding indicators' weights will be provided in the next section once the overall role of each independent and mediating variable is clarified.

4.3. Structural model evaluation

Once the quality of the measurement model was guaranteed, a collinearity test of the inner model was carried out to rule out any potential bias in path coefficients due to critical levels of collinearity among the predictor constructs (Hair et al., 2022). As in the assessment of composite measurement models, VIF values should be close to 3 and lower. Of the 24 VIF values implied, only 2 of them were slightly above 3, the highest one being 3.215. Therefore, it can be concluded that collinearity in the structural model is not a problem in this research. To test the significance and strength of the research hypotheses, we used a one-tailed 5,000 subsample BCA bootstrap (Hair et al., 2022). Table 3 shows the results obtained.

Regarding the role of knowledge acquisition facilitating actors, sectoral organizations are positively and significantly related to continuous education (β = 0.176), while educational and research institutions, and advisory organizations are not. Hence, hypothesis H3a is supported, while hypotheses H1a and H2a are not supported.

Moreover, educational and research institutions (β = 0.309), and sectoral organizations (β = 0.268) are positively and strongly related to ICT-based knowledge acquisition, while advisory organizations are not. Therefore, hypotheses H1b and H3b are supported, while hypothesis H2b is not supported. Finally, the three types of knowledge acquisition facilitating actors (i.e., educational and research institutions, advisory organizations, and sectoral organizations) are positively and strongly associated to social interaction with key actors in the agricultural value creation system, their path coefficients being 0.346, 0.332, and 0.217, respectively. Thus, hypotheses H1c, H2c, and H3c are supported.

Moving now to the role of different learning alternatives in the acquisition of technical knowledge, all possibilities included in the research (i.e., formal education—β = 0.173—, continuous education—β = 0.150—, ICT-based knowledge acquisition—β = 0.213—, social interaction with key actors in the agricultural value creation system—β = 0.161—, and social interaction with family and friends—β = 0.188) are positively and significantly related to technical knowledge. Therefore, hypotheses H4, H5, H6, H7, and H8 are supported, and both STI and DUI learning modes (as well as mixed options) are relevant. Moreover, social interaction with technical staff from sectoral organizations appears to be a relevant technical knowledge acquisition mechanism in itself (β = 0.174) besides the role that such organizations play in the promotion of other types of knowledge acquisition by farmers (hence, hypothesis H9c is supported). However, in the case of educational and research institutions and advisory organizations, no direct role has been identified. Thus, hypotheses H9a and H9b are not supported.

Based on the above results, and looking at the degree of significance

Table 3
Structural model evaluation.

	Effects	STDEV	t statistics	p-values
Dependent variable: Continuous education				
$R^2 = 5.6\%$				
Direct relationships				
Educational and research institutions	0.056	0.097	0.577	0.282
Advisory organizations	0.025	0.099	0.257	0.399
Sectoral organizations	**0.176**	**0.076**	**2.319**	**0.010**
Dependent variable: ICT-based knowledge acquisition				
$R^2 = 36.2\%$				
Direct relationships				
Educational and research institutions	**0.309**	**0.080**	**3.886**	**0.000**
Advisory organizations	0.095	0.076	1.257	0.104
Sectoral organizations	**0.268**	**0.066**	**4.060**	**0.000**
Dependent variable: Social interaction with key actors in the agricultural value creation system				
$R^2 = 64.3\%$				
Direct relationships				
Educational and research institutions	**0.346**	**0.065**	**5.317**	**0.000**
Advisory organizations	**0.332**	**0.065**	**5.069**	**0.000**
Sectoral organizations	**0.217**	**0.048**	**4.538**	**0.000**
Dependent variable: Technical knowledge				
$R^2 = 33.6\%$				
Direct relationships				
Educational and research institutions	−0.102	0.071	1.439	0.075
Advisory organizations	−0.005	0.068	0.079	0.468
Sectoral organizations	**0.174**	**0.054**	**3.223**	**0.001**
Formal education	**0.173**	**0.043**	**3.992**	**0.000**
Continuous education	**0.150**	**0.047**	**3.208**	**0.001**
ICT-based knowledge acquisition	**0.213**	**0.060**	**3.542**	**0.000**
Social interaction with key actors in the agricultural value creation system	**0.161**	**0.071**	**2.264**	**0.012**
Social interaction with family and friends	**0.188**	**0.054**	**3.456**	**0.000**
Indirect relationships via continuous education				
Educational and research institutions	0.008	0.015	0.549	0.291
Advisory organizations	0.004	0.016	0.245	0.403
Sectoral organizations	**0.026**	**0.015**	**1.813**	**0.035**
Indirect relationships via ICT-based knowledge acquisition				
Educational and research institutions	**0.066**	**0.026**	**2.510**	**0.006**
Advisory organizations	0.020	0.018	1.132	0.129
Sectoral organizations	**0.057**	**0.020**	**2.811**	**0.002**
Indirect relationships via social interaction with key actors in the agricultural value creation system				
Educational and research institutions	**0.056**	**0.028**	**2.009**	**0.022**
Advisory organizations	**0.053**	**0.027**	**2.014**	**0.022**
Sectoral organizations	**0.035**	**0.018**	**1.998**	**0.023**
Dependent variable: Environmental sustainability				
$R^2 = 13.1\%$				
Direct relationships				
Financial resources	**0.191**	**0.056**	**3.438**	**0.000**
Formal education	**−0.155**	**0.063**	**2.468**	**0.007**
Continuous education	0.005	0.057	0.087	0.466
ICT-based knowledge acquisition	0.006	0.084	0.071	0.472
Social interaction with key actors in the agricultural value creation system	−0.052	0.071	0.729	0.233
Social interaction with family and friends	−0.002	0.065	0.034	0.486
Technical knowledge	**0.292**	**0.066**	**4.398**	**0.000**
Indirect relationships via technical knowledge				
Formal education	**0.051**	**0.018**	**2.874**	**0.002**
Continuous education	**0.044**	**0.019**	**2.325**	**0.010**
ICT-based knowledge acquisition	**0.062**	**0.022**	**2.759**	**0.003**
Social interaction with key actors in the agricultural value creation system	**0.047**	**0.024**	**1.969**	**0.025**
Social interaction with family and friends	**0.055**	**0.021**	**2.564**	**0.005**

Notes:
STDEV: Standard deviation.
Figures in bold show significant relationships.

of indirect relationships, it can be concluded that ICT-based knowledge acquisition (i.e., mixed learning mode) and social interaction with key actors in the agricultural value creation system (i.e., DUI learning mode) fully mediate the relationship between educational and research institutions and technical knowledge; that social interaction with key actors in the agricultural value creation system (i.e., DUI learning mode) fully mediates the relationship between advisory organizations and technical knowledge; and that continuous education (i.e., predominantly STI learning mode), ICT-based knowledge acquisition (i.e., mixed learning mode), and social interaction with key actors in the agricultural value creation system (i.e., DUI learning mode) partially mediate the relationship between sectoral organizations and technical knowledge.

On the other hand, technical knowledge is strongly and significantly related to environmental sustainability ($\beta = 0.292$). Therefore, hypothesis H10 is supported. Finally, regarding the direct role of different learning pathways on environmental sustainability, this role in non-significant in the case of continuous education, ICT-based knowledge acquisition, social interaction with key actors in the agricultural value creation system, and social interaction with family and friends, while it is negative and significant in the case of formal education. As the indirect relationships between the above knowledge acquisition mechanisms and environmental sustainability via technical knowledge are positive and significant, partial mediation applies.

Regarding the most significant elements within each construct, in the case of educational and research institutions, agricultural R&D centers play the most significant role ($\gamma = 0.603$), followed by vocational training centers ($\gamma = 0.303$). Conversely, the role played by universities and other higher education institutions is non-significant ($\gamma = 0.174$). In the case of advisory organizations, rural development associations and associations of municipalities are the most important ($\gamma = 0.674$), followed by advisory and consultancy firms ($\gamma = 0.302$). On the contrary, the role played by business chambers is non-significant ($\gamma = 0.149$). Regarding sectoral organizations, all of them (i.e., unions, sectoral associations, and agrarian social movements) play a significant role, even though agrarian social movements stand clearly ahead ($\gamma = 0.599$ versus $\gamma = 0.343$ and $\gamma = 0.278$, respectively).

In the case of formal education, both types considered (vocational education and higher education) exert a significant role, with higher education slightly ahead of vocational education ($\gamma = 0.821$ versus $\gamma = 0.606$). As far as continuous education is concerned, both specialized courses on organic agriculture and on other agricultural matters play a very similar and significant role, their weights being $\gamma = 0.637$ and $\gamma = 0.615$, respectively. Regarding ICT-based knowledge acquisition mechanisms, all of them (i.e., farmers' WhatsApp groups, other social networks such as Facebook or Twitter, agricultural portals, and other webpages) prove to be statistically significant, with other social networks clearly behind ($\gamma = 0.171$ versus $\gamma = 0.391$ for other web pages, $\gamma = 0.349$ for farmers' WhatsApp groups, and $\gamma = 0.300$ for agricultural portals). In the case of social interaction with key actors within the agricultural value chain (i.e., customers, consumers, furnishers, and other producers), all of them show a significant relative contribution, with consumers and furnishers occupying the two first positions ($\gamma = 0.599$ and $\gamma = 0.255$, respectively, versus $\gamma = 0.201$ for customers, and $\gamma = 0.188$ for other producers). The same happens with social interaction with family and friends, where the interaction with both types of actors is statistically significant ($\gamma = 0.668$ and $\gamma = 0.548$, respectively). Finally, as far as technical knowledge is concerned, it is noteworthy to signal that knowledge on ICT applications for agricultural management shows almost the same importance as general knowledge on agroecological production techniques when it comes to enhancing environmental sustainability ($\gamma = 0.522$ and $\gamma = 0.529$, respectively), while knowledge on agricultural machinery is non-significant ($\gamma = 0.121$).

5. Discussion

5.1. Theoretical contributions

The research conducted aimed to examine how educational and research institutions, advisory organizations, and sectoral organizations contribute to boosting various learning pathways for organic farmers. It also assessed the effectiveness of each learning alternative in relation to the acquisition of technical knowledge and its impact on environmental sustainability. This study aligns with the epistemology of possession as defined by Cook and Brown (1999), viewing knowledge as a human possession rather than an inherent component of action (i.e., epistemology of practice). By treating knowledge as a resource, whether explicit or tacit, it also contributes to the advancement of the knowledge-based view of the firm, which sees knowledge as the main resource for creating long-term competitive advantages (Grant, 1996; Spender, 1996).

The findings indicate that sectoral organizations are the most important actors in promoting different learning pathways, as they exhibit strong and positive associations with all the learning alternatives considered in the study: those that mostly involve an STI learning mode—i.e., continuous education programs—those with a mixed orientation—i.e., ICT-based learning alternatives—and those implying a DUI learning mode—i.e., social interaction with different kinds of actors. Therefore, sectoral organizations contribute to promoting technical knowledge acquisition across various learning pathways, including traditional training programs, ICT-based knowledge resources, and the development of social capital. This is consistent with Girard (2015), who stressed the importance of knowledge that originates from practitioners themselves, often referred to as a 'bottom-up' approach, and it is also aligned with the high level of cooperative membership observed among organic farms in the sample.

On the other hand, agricultural advisory organizations primarily contribute to promoting social interaction with key actors in the value creation system, aligning with the DUI learning mode. This is consistent with previous research on the role of agricultural advisors in farmers' communities aimed at sharing experiences. Advisors can help farmers conceptualize and verbalize their experiences and question their understanding (Girard and Magda, 2020). However, organic farmers do not perceive advisory organizations as relevant providers of continuous education or ICT-based learning, which are more aligned with mixed or mostly STI learning modes.

As for educational and research institutions, they are positively and significantly related to farmers' learning through both ICT-based methods and social interaction. Surprisingly, they do not appear to be heavily involved in continuous education programs in organic farming, which are more commonly associated with sectoral organizations. This contrasts with other countries where the conventional research and education agenda is being questioned to address new challenges in agriculture, including the development of solutions consistent with ecological principles. In such contexts, courses on organic farming in universities and colleges are rapidly spreading (e.g., in the USA; Francis, 2009).

Findings also indicate that all learning alternatives play a relevant role when it comes to improving organic farmers' technical knowledge, thus confirming previous research that acknowledges the relevance of combining both STI and DUI learning modes in other industries (e.g., Lundvall and Nielsen, 2007; Jensen et al., 2016; Parrilli and Alcalde-Heras, 2016) or, in other words, codified and tacit knowledge-oriented knowledge acquisition methods. Despite the emphasis on local and contextual knowledge in organic farming, and the relevance of personal experience (Toffolini et al., 2019), learning modes that rely on the transmission of codified knowledge remain highly relevant. In line with Doloreux et al. (2023), it is important to note that the STI learning mode contributes to a more reflective, innovative, and long-term market strategy, which is crucial for the survival of organic farms, often characterized by small size and a disruptive approach to traditional farming models. Thus, as pointed out by Girard and Magda (2020), both scientific knowledge and knowledge linked to experiential singularity are relevant and compatible, not opposed.

Regarding technical knowledge components, the study underscores the importance of ICT applications for farm management in improving environmental sustainability. In addition to knowledge related to agroecological production techniques, understanding ICT applications and solutions that aid in decision-making regarding the environmental aspects of farming plays a substantial role when it comes to enhancing environmental sustainability. This is the case, for instance, with the usage of artificial intelligence in organic farming (Parrenin et al., 2023).

5.2. Practical implications

The results of this study offer valuable insights for policymakers, knowledge acquisition facilitating actors, and organic farmers themselves. From a policymaking perspective, and consistently with previous studies in the field (e.g., Ahuja 2011; Soulignac et al., 2012), these findings emphasize the relevance of promoting digitalization in rural areas through initiatives such as extending optical fiber networks, implementing awareness-raising programs, offering targeted training initiatives, and providing funding opportunities to facilitate the integration of ICTs for farm management. Policymakers should also consider supporting the creation of multimedia materials that can effectively transmit practical knowledge related to organic agriculture and provide access to expert knowledge. As demonstrated, ICT-based learning exhibits the strongest relationship with technical knowledge in organic agriculture, and knowledge on ICT applications for farming purposes (e.g., artificial intelligence) proves to be highly relevant to improve organic farms' environmental sustainability (Mokaya, 2019; Parrenin et al., 2023).

Considering the relatively low reliance of organic farmers on social interaction with key actors beyond family, friends, and other producers for knowledge acquisition, ICTs can serve as a valuable tool for overcoming barriers related to time and space. They can facilitate the acquisition of both codified and context-dependent tacit knowledge by creating a virtual 'ba' (Nonaka and Takeuchi, 1995), as described in the theoretical background. Specifically, the use of WhatsApp and other social media tools to facilitate farmers' peer-to-peer interaction and knowledge sharing can be especially useful (Nain et al., 2019; Prost et al., 2022; Slimi et al., 2023). This approach can help organic farmers access the right knowledge at the right time combining both STI and DUI learning modes and fostering innovation within the organic farming community.

Policymakers should also recognize the significance of the 'bottom-up' approach in knowledge creation within the context of organic farming, as highlighted by Girard (2015). This approach is evident in the prominent role played by sectoral organizations in facilitating various learning pathways, including continuous education, ICT-based learning, and social interaction with key actors in the value creation system. Policymaking efforts should align with this grassroots-driven knowledge dissemination and support the activities of sectoral organizations in promoting sustainable organic farming practices.

On the other hand, the negative relationship between formal education and environmental sustainability raises important questions about the role of universities and vocational institutions in promoting organic agriculture through their training programs. As the EU aims to increase the prevalence of organic farming by 2030, in line with the European Green Deal's Farm to Fork strategy (European Environmental Agency, 2023), achieving this goal not only requires economic incentives for those transitioning to organic practices but also ensuring that adequate training is available. As several authors point out (e.g., Morgan and Murdoch, 2000; Zundel and Kilcher, 2007; Jouzi et al., 2017), organic farming is especially demanding in terms of knowledge requirements, meaning that organic farmers need to possess a unique set of skills to meet these demands. Therefore, policymakers should guarantee that formal education programs, including those offered by universities and vocational institutions, incorporate the principles of organic and environmentally sustainable agriculture into their curricula. This would help bridge the gap between formal education and the goals of environmental sustainability in agriculture.

However, it is important to note that continuous education programs are the preferred training option among organic farmers. According to the results obtained, neither education and research institutions nor advisory organizations appear to play a significant role in this domain. Instead, sectoral organizations take on a more prominent role in providing continuous education opportunities for organic farmers. This aligns with the bottom-up approach emphasized in organic farming (Girard, 2015), where knowledge and experience sharing among practitioners plays a central role in learning and knowledge dissemination (Toffolini et al., 2019). Nevertheless, it is important to recognize that education and research institutions, as well as advisory organizations, possess valuable expert knowledge that could enhance the training offerings provided by sectoral organizations. Thus, collaborative efforts to create joint training programs could prove beneficial in promoting a well-rounded and effective learning environment for organic farmers.

Collaboration among various knowledge acquisition facilitating actors, particularly among education and research institutions and sectoral organizations, can be particularly advantageous in promoting ICT-based learning and developing the materials and infrastructure needed to support it. This includes creating and maintaining resources such as written documents, videos, online forums, tutorials, blogs, and more. Indeed, as previously discussed, ICT-based learning has demonstrated the strongest association with organic farmers' technical knowledge development. By working together, these actors can leverage their expertise and resources to enhance the accessibility and effectiveness of ICT-based learning for the organic farming community.

Furthermore, consistent with the DUI learning mode (Parrilli and Alcalde-Heras, 2016; Santos et al., 2022), it is crucial that knowledge acquisition facilitators continue to promote social interaction among organic farmers and key actors in the value creation system. These interactions have proven to be highly beneficial in improving farmers' technical knowledge base. In the agricultural domain, interactions between producers, consumers, farmers, and other actors have been highly effective for problem-solving and knowledge acquisition (Cuéllar-Padilla and Calle-Collado, 2011; Soto et al., 2021). Collaborative efforts to facilitate social interaction and knowledge sharing can further strengthen the learning pathways available to organic farmers, ultimately contributing to their success and the overall sustainability of organic agriculture.

Finally, concerning organic farmers themselves, the study underscores the importance of combining different learning modes, including both STI and DUI, to enhance technical knowledge and, subsequently, environmental sustainability. Particularly, ICT-based learning, which can facilitate the acquisition of both codified and context-dependent tacit knowledge, proves to be highly effective. This suggests that organic farmers should emphasize becoming aware of and regular users of such technologies. What is more, the study emphasizes that ICT applications and solutions for farm management play a significant role in improving environmental sustainability. Yet, research findings also reveal that it is crucial for organic farmers to expand their social capital and engage with actors beyond other producers. This includes interacting with customers and/or consumers as well as suppliers and other relevant stakeholders. Such interactions can further contribute to knowledge acquisition and the promotion of environmental sustainability in organic agriculture.

5.3. Limitations

This study has some limitations that warrant future research. For example, while our research method (i.e., survey) allowed us to analyze the relative relevance of different actors and learning alternatives in acquiring technical knowledge by organic farmers and promoting environmental sustainability, qualitative methods such as case studies could provide deeper insights into these findings.

As pointed out above, in this study we primarily followed the knowledge-based view (Grant, 1996; Spender, 1996), which considers knowledge a critical resource for improving competitive advantage. Therefore, we focused on the acquisition of knowledge (particularly technical knowledge) and the means through which it was acquired by farmers (i.e., modes of learning and learning pathways). From the perspective of the epistemology of possession (Cook and Brown, 1999), our interest lay in the technical knowledge possessed by organic farmers and the ways in which this knowledge was acquired.

Given this approach, a survey-based study allowed us to obtain an overall picture of different technical knowledge acquisition methods (i.e., learning modes) and their effectiveness. It was not our purpose to answer the question of how the knowledge acquisition processes (i.e., learning processes) occurred, which would require a qualitative methodological approach (e.g., case studies). Future research might address this question by focusing on the knowing processes and adopting another epistemological approach (i.e., epistemology of practice, Cook and Brown, 1999). Qualitative case studies would enable us to understand in depth the underlying learning processes and explore how different learning modes were used and combined by organic farmers.

Second, environmental sustainability was measured using perceptual indicators. Such perceptions could be geographically sensitive, as specific climate conditions operating in each region may affect the perception of sustainability. Future research could address this limitation by incorporating objective measures of environmental sustainability, such as soil health, biodiversity indices, or carbon footprint analysis. Additionally, comparing perceptual data with these objective measures across different regions could provide a more comprehensive understanding of the factors influencing sustainability perceptions and their alignment with actual environmental conditions.

Third, this study primarily examined technical knowledge acquisition modes in organic farming. It would be interesting to conduct a comparative analysis to assess the role played by knowledge acquisition facilitators in the context of conventional agriculture and determine whether the relevance of various learning pathways differs significantly between organic farming and conventional agriculture. Such a comparison could provide valuable insights into how these facilitators should adapt their roles to better align with the specific needs of organic farming compared to conventional agriculture.

Moreover, it would be relevant to investigate whether the effectiveness of various learning pathways and their associated learning modes varies significantly between developed and emerging countries, as well as among different profiles of producers. Such research could help tailor educational and support programs to specific contexts and the needs of diverse agricultural communities, contributing to more effective knowledge dissemination and sustainable agricultural practices.

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Declarations of interest

We have nothing to declare.

CRediT authorship contribution statement

Josune Sáenz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nekane Aramburu:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Henar Alcalde-Heras:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Marta Buenechea-Elberdin:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization.

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During the preparation of this work the author(s) used ChatGpt in order to improve readability and language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Data availability

The data that has been used is confidential.

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