Digital Technologies and Education, strategies to Strengthen Food Security in Smallholder Farming Communities

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Tecnologías digitales y educación, estrategias para fortalecer la seguridad alimentaria en comunidades campesinas

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ABSTRACT

The objective of this review article was to analyze how digital content has been used over the last five years to strengthen food security in rural communities. It was developed using a qualitative interpretive approach, with a phenomenological design and descriptive scope, based on a review of literature indexed in databases. The methodology consisted of identifying, systematizing, and categorizing studies published in Scopus, Elsevier, Google Scholar, and multilateral organizations, grouping the information into thematic areas related to digital skills, good agricultural practices, hygiene and handling, sustainable use of inputs, food preservation, food security education, and barriers to technology adoption. The results showed that digital tools, such as mobile applications, interactive platforms, local videos, and digitized participatory methodologies, promoted the acquisition of technical and cultural knowledge in rural communities. Likewise, limitations associated with infrastructure gaps, digital literacy, and unequal access to technological resources were identified. The main contribution of the study was to highlight the relevance of digital content as a means of promoting food security with a territorial approach. It was concluded that educational digitization is a viable strategy for capacity building in the agri-food sector.

Keywords: Food; Agriculture; Apps; Digital; Safe.

RESUMEN

El presente artículo de revisión tuvo como objetivo analizar cómo los contenidos digitales se han utilizado en los últimos cinco años para fortalecer la seguridad alimentaria en comunidades campesinas. Se desarrolló bajo un enfoque cualitativo interpretativo, con diseño fenomenológico y alcance descriptivo, a partir de la revisión de literatura indexada en bases de datos. La metodología consistió en la identificación, sistematización y categorización de estudios publicados en Scopus, Elsevier, Google Scholar y organismos multilaterales, agrupando la información en ejes temáticos relacionados con competencias digitales, buenas prácticas agrícolas, higiene y manipulación, uso sostenible de insumos, conservación de alimentos, educación en seguridad alimentaria y barreras de adopción tecnológica. Los resultados evidenciaron que las herramientas digitales, tales como aplicaciones móviles, plataformas interactivas, videos locales y metodologías participativas digitalizadas, favorecieron la apropiación de conocimientos técnicos y culturales en comunidades campesinas. Asimismo, se identificaron limitaciones asociadas a brechas de infraestructura, alfabetización digital y acceso desigual a recursos tecnológicos. La principal contribución del estudio radicó en visibilizar la pertinencia de los contenidos digitales como medio para promover seguridad alimentaria con enfoque territorial. Se concluyó que la digitalización educativa constituye una estrategia viable para el fortalecimiento de capacidades en el sector agroalimentario.

Palabras clave: Alimentos, Agricultura; Aplicaciones; Digital; Seguro.

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INTRODUCTION

In recent decades, access to safe food has been considered a central focus in agri-food systems, especially in rural communities facing socioeconomic vulnerability and limited technological resources.[1] According to DANE, in 2024, "46,1 % of rural households had an internet connection (fixed or mobile)".[2] In this context, education emerges as an essential tool for strengthening producers› capacities and ensuring agricultural practices that reduce contamination risks and improve food safety.[3]

With the advancement of digital technologies, new opportunities have emerged for designing and implementing flexible, participatory educational strategies tailored to rural realities.[4,5] However, questions remain about how to orient these digitization processes toward the specific needs of rural communities, preventing the technological divide from widening inequalities in access to knowledge.[6,7] This is where the research question arises: What digital topics allow for the transmission of educational content aimed at training in safe food production in rural contexts? Answering this question enables us not only to identify the primary areas of digital training in food safety but also to analyze the transformative potential of these tools in strengthening food sovereignty, equity in access to knowledge, and the intergenerational continuity of safe agricultural practices in Colombia and Latin America.[8,9]

METHOD

The study employed a qualitative, interpretive approach with a phenomenological design and descriptive scope. A qualitative, interpretive, descriptive document review method was adopted with a descriptive scope and phenomenological approach, aimed at understanding how digital content has been used in education to strengthen food security in rural communities and obtain safe food, integrating theoretical perspectives, empirical findings, and community experiences, offering a comprehensive and contextualized view of the phenomenon. In addition, the information was extracted using an analysis matrix where categories such as thematic axis, subtopics, authors, year, relevant findings, and type of resource were organized.

Priority was given to data related to digital education topics, technological applications, implementation barriers, and participatory methodologies. The databases consulted were selected from highly indexed academic databases, including Scopus, Elsevier (ScienceDirect), SpringerLink, and Google Scholar, as complementary sources for theses and gray literature, as well as FAO and Frontiers (reports and journals specializing in food security and digital agroecology). Secondary sources of information were identified at the first level in the selected databases, which were chosen for their thematic relevance. These sources were complemented by available open resources, as well as technical reports issued by international organizations such as FAO and IICA, which provided updated documents on digital education and food security in rural contexts.

The search covered the last five years, using Boolean operators and keywords such as "digital education," "food safety," "safe food production," "rural communities," and "digital agriculture," filters that allowed the results to be refined to academic publications from 2020 to 2025, in Spanish and English, with open access or DOI, reviews. The sample of documents identified consisted of approximately 103 documents published between 2020 and 2025, from which a sample of 26 papers that met the established inclusion criteria was selected. Documents that were duplicates in different repositories and that did not specifically address food security or digital training in rural contexts were excluded.

DEVELOPMENT

The relationship between agriculture, education, and digitization in rural contexts has become a focus of strategic analysis in Latin America. Colombia, in particular, faces a scenario in which technological transformation must go hand in hand with training processes.

Digital agriculture and rural education

Digital agriculture has emerged as a paradigm that integrates information and communication technologies (ICT), artificial intelligence (AI), remote sensors, big data, and the Internet of Things (IoT) into agricultural management.[10] This transformation, also known as Agriculture 4.0, aims to optimize production, minimize waste, and produce safe food through more precise resource management.

However, implementing these digital tools depends on the capacity of farmers and the education of rural workers, who play a central role, as technical language must be translated into simple practices that are understandable, useful, and culturally relevant to those who produce food.[11] In Colombia, agricultural digitization has been driven by the expansion of 5G connectivity and remote monitoring projects, although it remains concentrated in areas of higher agricultural profitability. This situation highlights that technologies alone are insufficient without an inclusive educational framework that can empower small producers to adapt to market changes and food safety regulations.

Food security and peasant sovereignty

Food security is defined as physical, social, and economic access to safe, nutritious, and culturally acceptable food.[9] For peasants, ensuring food safety involves not only producing food, but also processing, storing, and marketing it using practices that reduce the risk of biological, chemical, or physical contamination.

In Colombia, it is emphasized that food security and sovereignty are closely linked to the preservation of peasant knowledge and control over seeds, land, and water. However, market pressures and the expansion of agro-industrial models pose a threat to the productive autonomy of communities. This is where educational digitization can play a dual role: on the one hand, it offers access to technical information on safety standards, pest management, and post-harvest conservation; on the other hand, it opens up spaces for farmers to record and disseminate their traditional practices, thus reinforcing food sovereignty in the face of external dynamics. An example can be seen in Jamaica, where the ABIS system enabled the digitization of food traceability, while also training farmers in quality standards.[13] This case shows how a technological tool can become an educational one, as, beyond providing information, it promotes practical training in food safety procedures.

Precision agriculture and smallholder farming

Precision agriculture is based on the use of sensors, drones, satellites, and algorithms to optimize the use of inputs and improve productivity.[14] However, in Colombia, these systems

have had greater penetration in export crops such as flowers, sugarcane, and palm, leaving small-scale farmers behind. They also point out that, for peasant communities, barriers range from the high cost of equipment to low digital literacy, which limits their adoption.[15] Added to this are cultural factors: mistrust of external technologies and a preference for traditional methods that have proven effective historically.

From an educational perspective, the solution is not to impose digital tools, but to promote participatory training programs that highlight the importance of collaborative innovation design, where farmers jointly create digital applications that respond to their real needs.[16] Thus, education becomes the bridge between technological sophistication and rural reality. Digital extension programs using videos, for example, have proven effective in demonstrating agricultural practices in accessible language.[4,5]

Digital skills for safe food

Simply having access to a smartphone or an application does not ensure that a farmer can produce safe food. Specific digital skills are required to interpret information, record field data, apply hygiene protocols, and manage traceability systems.

It is worth noting that digital literacy among farmers is a crucial factor in the sustainability of food systems.[17] This skill even influences the willingness to adopt low-carbon technologies, linking digital education with environmental sustainability.[18]

In Colombia, various initiatives have sought to strengthen these skills through digital educational materials adapted to the rural context. The Food and Agriculture Organization of the United Nations (FAO) and the Inter-American Institute for Cooperation on Agriculture (IICA) have developed offline applications and audiovisual content that teach safe food handling practices, reduce contamination risks, and promote proper storage. This audiovisual approach is particularly crucial in areas with low literacy rates, where farmers primarily learn through observation and practice.

Digital divides in Latin America

Despite progress, agricultural digitization in Latin America reproduces structural inequalities, and digital agriculture processes can marginalize small farmers if they are not accompanied by inclusive policies.[6] Similarly, in the MENA region, digital platforms have concentrated benefits among large producers, a risk that can be extrapolated to Latin America.[19]

In Colombia, the report "Digital Agriculture: Implications for Small Farmers" reveals that the lack of technological infrastructure in rural areas, particularly in dispersed areas, restricts access to the internet and devices. At the same time, inadequate training in digital skills hinders farmers' ability to utilize the available tools.[20] Given this situation, the proposal is to build smart rural communities through collaborative projects that include infrastructure, training, and social organization. These experiences show that education should not be an isolated effort, but rather a comprehensive process that combines digital inclusion, community strengthening, and the building of autonomy.[7]

Relevance for Colombia and Latin America

Colombia is a representative case of the challenges and opportunities of educational digitization in agriculture. The coexistence of high-tech territories and disconnected rural areas reflects the tensions inherent in Latin America: urban-rural gaps, unequal access to resources, and the risk of technological exclusion.[6,11] A similar situation is unfolding in Mexico and Peru, which face similar challenges, including limited connectivity and low levels of digital training in rural communities. Brazil, on the other hand, has developed a more robust digital agriculture sector, but faces criticism because it focuses on large producers, which translates into structural inequalities.[15,21]

Educational strategies and practical experiences in rural training for food safety

Digital extension models and farmer training

Traditional agricultural extension, based on face-to-face visits and field training, has shown limitations in dispersed and low-resource rural contexts. In response, digital extension models have emerged as alternatives with greater coverage and lower costs.

Educational videos are an effective format for transmitting agricultural practices to small producers. In Ethiopia, this model improved the adoption of new techniques compared to traditional training.[4,5] In Colombia, where internet access is irregular, this approach could be replicated through the distribution of content on USB drives, community radio stations with audiovisual material, and offline platforms adapted to low-end phones.

The educational value of videos lies in their visual and practical nature. Farmers learn by observing how other farmers perform a task, reducing technical abstraction and increasing confidence in replicability. Additionally, the materials can include food safety recommendations, such as washing fruit, disinfecting utensils, and storing food in the refrigerator, facilitating knowledge transfer. However, this model faces challenges, as content production requires technical resources, and distribution must be accompanied by community dialogue spaces where farmers can validate and contextualize what they have learned. Thus, education cannot be limited to the passive consumption of information, but must foster participatory processes.

Living labs and learning communities

An innovative strategy in the field of education is the creation of agri-food living labs. In Colombia, these spaces enable farmers, researchers, and local actors to engage in participatory design, providing solutions to address food security. In a living lab, farmers are not passive recipients, but protagonists who contribute their knowledge and evaluate digital technologies in real-life scenarios. These spaces have proven crucial to participatory design and innovation in agri-food systems, as they facilitate the integration of local practices with technological tools.[16]

One example is a laboratory that focuses on managing plant pathogens in vegetables, combining farmers' empirical knowledge with monitoring systems using mobile applications, which facilitates the transition to safer production systems.[14] From an educational perspective, living laboratories promote dialogic and situated learning, as knowledge is constructed in practice and in interaction with specific problems related to safe food production, aligning with the approach proposed for sustainable agri-food systems in Colombia.[22]

This methodology contrasts with traditional classroom training, as it prioritizes collective action and adaptive innovation, aligning with the FAO's vision of the need for inclusive and collaborative training processes.[9] In addition, living labs have a

multiplier effect, as participating farmers become training agents within their communities, transmitting what they have learned in a contextualized manner and strengthening food sovereignty.[12]

Artificial intelligence and mobile applications in farmer education

The use of artificial intelligence (AI) and mobile applications to diagnose crop diseases, optimize irrigation, or classify products has advanced in Latin America.[14,23] When designed in a participatory manner, these tools can be integrated as educational resources for farmers.

For example, an application that detects symptoms of phytopathogens in mangoes through photographs not only fulfills a technical function, but also an educational one: farmers learn to visually recognize the signs of disease, acquire specialized vocabulary, and understand the logic of integrated control. However, this educational challenge lies in ensuring that the applications are intuitive, that they work in contexts of low connectivity, and that they are adapted to the digital literacy levels of users, highlighting the need to build inclusive digital ecosystems where learning does not depend on large urban infrastructures, but rather on scalable, community-based solutions.[7]

In Colombia, pilot projects have demonstrated the viability of digital early warning systems for pests and contaminants, linked to training programs in rural schools.[9,10,11] These experiences integrate rural children and youth into educational processes that strengthen the generational continuity of safe agriculture, which is key to ensuring food sovereignty and resilience in rural communities.[1,16,22]

RESULTS AND DISCUSSION

The review identified experiences that demonstrate how digital technologies in agriculture, along with their connection to education, enhance food security in rural communities across various regions of Colombia, Latin America, and the world. The findings are organized into analytical categories that demonstrate how these tools can enhance the safety of food production. However, they also generate risks, tensions, and inequalities that require critical attention (see table 1).

Digital transformation and *agricultural* extension have traditionally been limited to face-to-face and one-way models. However, thanks to the incorporation of digital technologies, these approaches have undergone significant transformation, demonstrating that the use of videos in extension processes increases knowledge retention and promotes concrete changes in the agricultural practices of small producers in Ethiopia and Asia.[4,5] Similarly, in Uganda, it was highlighted that extension, when mediated by technology, strengthened food security by expanding access to timely information.[3]

In Latin American contexts, the report *Digital Agriculture's Implications for Small Farmers: Evidence from Colombia* confirms that digitization opens up new opportunities, but also runs the risk of concentrating on large producers. Thus, the results show that digital extension constitutes a mechanism for democratizing knowledge, provided that it is accompanied by inclusive access policies and training adapted to rural realities.[6,20]

On the other hand, precision agriculture and emerging technologies constitute another fundamental category (see Table 2), as they focus mainly on technological innovation. Evidence shows that the implementation of sensors connected to 5G networks in Colombia enables detailed monitoring of crop conditions, thereby improving the efficiency of water and fertilizer use.[11] Similarly, the usefulness of computer vision, artificial intelligence, and the Internet of Things (IoT) for automating seedling counts and managing crops intelligently was demonstrated.[10,23]

These technologies offer benefits such as the accuracy and speed with which information is generated, as well as their impact on the productivity and sustainability of agri-food systems. However, it is noted that integrating these disruptive technologies requires governance models to prevent the exclusion of small farmers, who may lack the financial resources or digital literacy necessary for their adoption.[24,25]

Precision agriculture, when combined with digital education initiatives and participatory programs, can become a strategic tool for ensuring sustainable and safe agricultural practices.

One of the most persistent findings in the literature is the existence of a digital divide that limits the incorporation of innovations. It was noted that, despite technological advances, rural and farming communities continue to face inequalities in access to the internet, infrastructure, and training.[7] Digital literacy was also identified as a determining factor for the sustainability of digital agriculture among small producers (see table 3).[15]

For farmers to adopt technologies, they will depend directly on their digital skills and the social capital available in their communities.[17,18] McCampbell's findings reinforce this, as in low- and middle-income countries, the digitization of agriculture is not advancing uniformly, resulting in "hyperconnected" territories coexisting with areas of technological exclusion.[21]

In Colombia, these gaps are intertwined with socioeconomic and geographic factors, suggesting that rural and urban inequalities are reflected in the distribution of digital access.[8,12] Thus, the results demonstrate that technological literacy is a crucial prerequisite for rural communities to capitalize on the opportunities presented by digitization effectively.

Table 1. Digital transformation in agricultural extension

Author(s)/Year	Context	Main contributions	Risks/Limitations
Abate et al. (2023)	Ethiopia	Extension videos increase retention and changes in practices	Unequal access to devices
Baul et al. (2024)	Asia	Use of digital resources improves knowledge transfer	Limited rural infrastructure
Brenya & Zhu (2023)	Uganda	Digital extension strengthened food security	Risk of exclusion for communities without connectivity
Bahn et al. (2021)	Global	Warns of reproduction of inequalities in digitization	Concentration of benefits among producers with greater resources
Carballo et al. (2022)	Latin America	Digitization opens up opportunities, but is concentrated among large producers	Little visibility for small farmers

Table 2. Precision agriculture and emerging technologies

Author(s) / Year	Applied technology	Observed benefits	Risks/Stresses
Arrubla-Hoyos et al. (2022)	Sensors and 5G	Better distribution of water and fertilizers in Colombia	High cost and low accessibility
Fuentes-Peñailillo et al. (2023, 2024)	Computer vision, AI, IoT	Automated seedling counting, smart crop management	Requires specialized digital literacy
Klerkx & Rose (2020)	Global	Disruptive potential for sustainability	Inadequate governance may exclude small producers
Lajoie-O'Malley et al. (2020)	International	Identifies global policy challenges	Models prioritize corporate interests over local interests

Table 3. Digital divide and technological literacy

Author(s) / Year	Main findings	Implications
Gómez-Carmona et al. (2023)	Persistence of digital inequality in rural areas	Need for investment in rural connectivity
Gumbi et al. (2023)	Digital literacy as key to sustainable agriculture	Digital education for farmers is a priority
Wan Mokhtar et al. (2022)	Adoption depends on digital skills and social capital	Training processes must be community-based
Yuan et al. (2025)	Digital literacy determines the use of technologies	Risk of exclusion if capacities are not strengthened
McCampbell (2022)	Differences in low- and middle-income countries	Global gap reproduces internal inequalities
Osorio Arias et al. (2024)	Rural and urban inequality in digital access in Colombia	Farmers vulnerable to digitalization
Dueñas-Ocampo et al. (2025)	Hybrid narratives needed to integrate knowledge	Connection between local culture and technology

Participatory innovation and *living* labs (table 4) are another key category within participatory approaches. They highlight that designing digital innovations together with rural communities generates more robust and sustainable appropriation processes.[16,22] Living labs enable the integration of farmers' empirical knowledge with the potential of digital technologies, thereby building solutions tailored to local contexts.

The results show that these spaces not only promote technical innovation but also collective learning processes and community strengthening. It is said that laboratories in Colombia are not limited to validating technologies, but also function as venues for dialogue and knowledge sharing that strengthen the resilience of agri-food systems.[22] This vision contrasts with vertical models of technology transfer, in which producers were recipients of information. It is also suggested that participatory innovation be used to ensure that digitization is not an imposed process, but rather one that is developed in collaboration with rural communities.

Food security and sovereignty in the digital era are not only linked to productive efficiency, but are also directly linked to food security. In Jamaica, it was documented how the implementation of digital systems contributed to improving traceability and strengthening the agricultural value chain, reducing the risks of food insecurity.[13] Similarly, they pointed out that digital extension allowed Uganda to improve food availability in contexts of vulnerability (table 5).[3]

In the Colombian case, it is emphasized that the food sovereignty of peasant families depends on both access to technologies and the capacity of communities to maintain their traditional practices in balance with digital innovation.[8] This aligns with those who argue that food systems require hybrid narratives that recognize cultural diversity and the need for innovation.[8,12]

Table 4. Participatory innovation and living labs.

Author(s) / Year	Key findings	Impact on communities
Steinke et al. (2022)	Living labs enable joint innovation	Strengthens ownership and sustainability
Montenegro et al. (2024)	Digital innovation in Colombia linked to rural knowledge	Generates resilience and collective learning
Abate et al. (2023)	Horizontal interaction promotes the adoption of good practices	More participatory and effective education
Baul et al. (2024)	Digital resources strengthen community innovation	Democratizes access to knowledge

Table 5. Food security and sovereignty

Author(s)/Year	Contributions	Risks/Tensions
Johnson (2024)	In Jamaica, digital systems strengthen traceability and reduce food insecurity	Requires public policies to consolidate
Brenya & Zhu (2023)	Digital extension in Uganda improved food availability	Access gaps limit scalability
Osorio Arias et al. (2024)	Peasant sovereignty depends on integrating tradition and digital innovation	Risk of cultural displacement
Dueñas-Ocampo et al. (2025)	Need for hybrid narratives in food systems	Innovation can disrupt local practices
Carballo et al. (2022)	Digitization may displace small farmers	Invisibility of the peasantry

Everything depends on how technologies are implemented, as they can either strengthen or weaken food security. If the efficiency of large producers is prioritized, small farmers risk being displaced. On the other hand, if inclusive digital education and community participation are strengthened, technologies can become a means of ensuring safe and equitable food.[6]

Consequently, agricultural digitization is promising but presents risks that cannot be ignored. Table 6 shows that digital systems can concentrate power in large corporations and create technological dependence among small producers.[19] However, international policies tend to prioritize global visions of digitization, leaving local realities in the background. This impact is not neutral but will depend on political, economic, and, above all, educational decisions to accompany this implementation.[25]

In contrast, documents such as FAO Digital for Impact (2022) and What's Cooking highlight the opportunity to use digital transformation to democratize agri-food systems.[25]

Table 6. Risks of digitization in the agricultural sector

Author(s) / Year	Risk identified	Implication
Bahn et al. (2021)	Technological dependence and centralization in corporations	Vulnerability of small producers
Lajoie-O'Malley et al. (2020)	International policies that are insensitive to local realities	Exclusion of rural communities
Carballo et al. (2022)	"Invisible farmers" in global digitization processes	Threat to peasant sustainability
FAO (2022)	Digitalization can democratize agri-food systems	Requires inclusive strategies
Schroeder et al. (n.d.)	Digital transformation as a global opportunity	Need for support in rural education

CONCLUSIONS

The analysis shows that digital content applied to training in safe food production in rural communities has contributed to the improvement of agricultural practices, food hygiene, and sustainability, accompanied by low-cost solutions and highly sophisticated systems, which have a direct effect on farmers as they access knowledge and apply innovations such as videos and digital platforms.

On the other hand, significant limitations were identified, including the digital divide characterized by disparities in connectivity, technological literacy, and access costs. These weaknesses undermine the empirical logic of the programs and compromise the coherence of the strategies employed. In agricultural technologies such as robots and automation, although they promise efficiency, they can lead to exclusion if inclusive educational strategies are not designed.

Strengthening rural education, with a focus on obtaining safe food and mediated by digital technologies, needs to go beyond reductionist perspectives. We must seek strategies to achieve sustainability and equity in digital agriculture, which extend beyond the transmission of knowledge through education. Consequently, we must also articulate pedagogical processes, languages, communities, and technologies that transform digitization into an instrument of emancipation, not a tool that generates dependency.

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None.

CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTION

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