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REVIEW ARTICLE

Impact of open and distance learning on agricultural education: A systematic review and bibliometric analysis

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Abstract

Open and distance learning (ODL) plays a crucial role in agricultural education due to its potential to transform knowledge dissemination. It enhances agricultural productivity and addresses educational accessibility challenges. This study employs systematic literature review and bibliometric analysis to examine the evolution and impact of ODL in agricultural education. A total of 759 relevant studies were identified from the Web of Science database and analysed using VOS viewer and R Studio to map research trends and thematic clusters. The selection process was systematically documented following the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The analysis highlights the growing scholarly interest in this field, with significant research output emerging between 2020 and 2024 and peaking at 90 articles in 2022. The bibliometric analysis reveals diverse authorship with 3789 contributors and a strong collaborative focus, as evidenced by a 36.76 % international co authorship rate. The thematic analysis underscores four major clusters focusing on the impact of COVID-19, training and technology integration, educational frameworks and curriculum design. Geographical contexts indicate varied implementation across regions, with countries such as the USA, the UK, Germany and Italy emerging as central nodes in research networks. Future research should explore low-tech solutions, assess long-term impacts, integrate emerging technologies and establish robust evaluation frameworks. The findings highlight ODL's vital role in creating an inclusive, knowledge driven agricultural sector aligning with global development goals.

Keywords

bibliometric analysis; distance learning; educational impact; research trends; technology integration

Introduction

Agriculture is a cornerstone of global food security, employing a significant portion of the population, particularly in rural areas (1). Despite its significance, the agricultural sector faces pressing challenges, Limited access to high quality education, poor dissemination of modern practices and increasing environmental stress, which hinder productivity and sustainability (2). For example, in sub-Saharan Africa, only about 5 % of farmers have access to formal agricultural training, limiting their ability to adopt modern techniques (3). Similarly, in South Asia, ineffective knowledge transfer has led to yield gaps of up to 40 % in staple

crops like rice and wheat (4). These issues threaten the livelihoods of millions of smallholder farmers and endanger food security efforts. As the demand for sustainable agricultural practices grows, there is an urgent need for innovative solutions to empower agricultural communities and bridge knowledge gaps (5). To bridge these gaps, many countries are increasingly adopting open and distance learning (ODL) to enhance accessibility and inclusivity in agricultural education (6).

ODL delivers education through flexible, learner-centered methods without requiring a physical classroom attendance (7). It harnesses the potential of information and communication technologies (ICTs) to bridge the gap between knowledge dissemination and practical application in agriculture. Through mobile phones, the internet and satellite communication, ODL extends education to even the most remote farming communities. This flexibility is particularly beneficial for adult learners who juggle agricultural responsibilities with limited time and resources for formal education (8). ODL offers farmers and agricultural stakeholders the opportunity to learn at their own pace and convenience, overcoming geographical and time constraints. This educational model has gained momentum globally, particularly in low- and middle-income countries where traditional educational infrastructures are often inadequate (9). Successful case studies highlight its impact, such as India's National Institute of Open Schooling (NIOS), which provides agricultural education through distance learning and the Food and Agriculture Organization (FAO)'s e-learning programs, which offer specialized training to farmers and extension workers worldwide.

The integration of ODL in agriculture has demonstrated significant potential for improving knowledge transfer, enhancing skills and promoting sustainable practices. For example, mobile learning platforms and e-learning courses have been instrumental in disseminating information on crop management, pest control and climate-resilient practices to farmers in rural areas (10). These platforms provide timely, actionable information while fostering continuous learning in farming communities. Similarly, virtual agricultural universities and massive open online courses (MOOCs) have empowered agricultural professionals to stay updated on emerging technologies and market trends (11). These platforms offer specialized courses enabling learners to customize their education to fit their needs and interests,

The impact of ODL in agriculture extends beyond individual learners, influencing the broader agricultural ecosystem. By equipping farmers with the knowledge and skills to adopt innovative practices, ODL contributes to increased agricultural productivity, improved livelihoods and sustainable rural development (12). This enhances farmers' capacity while strengthening community resilience against socioeconomic and environmental challenges. Furthermore, ODL initiatives prioritize inclusivity, targeting marginalized groups such as women and smallholder farmers, who are traditionally underserved by conventional education systems (13). Empowering these groups through education helps reduce inequalities and fosters equitable access to opportunities within the agricultural sector. These inclusive supports global initiatives like the United Nations Sustainable Development Goals (SDGs), particularly quality education (SDG 4) and sustainable agriculture (SDG 2)

ODL's impact on agriculture lies in its ability to enhance resilience and adaptability among learners. By promoting continuous learning, ODL enables agricultural stakeholders to respond effectively to evolving challenges, such as climate change, market fluctuations and technological advancements (14). Access to real-time information and training enables farmers to make data-driven decisions, boosting productivity and sustainability. ODL facilitates the spread of research and innovations, bridging the gap between academic knowledge and real-world agricultural practices. However, the successful implementation of ODL in agriculture is contingent upon several factors, including technological infrastructure, digital literacy and the availability of relevant and localized educational content (15).

While ODL holds great promise, it faces significant challenges that must be overcome to reach its full potential. One major obstacle is the digital divide, which refers to the disparity in access to ICTs between rural and urban populations. Bridging this divide requires targeted investments in infrastructure, such as expanding internet connectivity and providing affordable access to digital tools. Poor internet access, high technology costs and low digital literacy in rural areas hinder ODL adoption (16). Additionally, the development of context-specific and culturally relevant educational content remains a critical challenge, as agricultural practices and needs vary widely across regions. Collaboration between governments, educators and tech providers is key to overcoming these challenges and expanding ODL's reach (17, 18).

Materials and Methods

This review adopts an integrated methodological framework, combining a systematic literature review (SLR) with bibliometric analysis, to comprehensively explore the impact of open and distance learning (ODL) on agriculture. By integrating quantitative and qualitative techniques, this research offers a multidimensional perspective on the existing scholarly landscape. The SLR identifies and synthesizes relevant literature to answer the research question: What are the impacts of open and distance education on agriculture? This question follows the Population or Problem [P], Interest [I] and Context [CO] (PICo) framework (19). This question shaped the search strategy for a structured investigation. The data for this study were sourced from the Web of Science database, ensuring the inclusion of high-quality, peer-reviewed articles. The search strategy used Boolean operators and a broad set of keywords. These included 'Distance education, ' Open Education,' 'online education,' 'e-learning' and 'Blended learning,' paired with agricultural terms like 'Farming' and 'Cultivation,' as well as impact-related terms such as 'Outcome' and 'Effect. This approach ensured the inclusion of diverse relevant studies. A rigorous set of inclusion and exclusion criteria was applied to maintain analytical reliability (Table 1). The inclusion criteria covered open-access, English-language research articles published between 2000 and 2024 in their final form. Studies were selected if they were focused on

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Literature type	Research article	Review papers, conference paper, book chapters and series
Source type	Journal	Trade journal
Publication stage	Final	Press
Access type	Open source	Restricted access
Subject area	Agricultural and Biological Sciences, Social Sciences, Behavioral Science, Business, Management, psychology and social issues	
Language	English	Non - English
Timeline	2000-2024	<2000

subject areas such as agricultural and biological sciences, social sciences, behavioral sciences, business, management, psychology and social issues. Conversely, the exclusion criteria eliminated review papers, trade journals and restricted-access publications, ensuring that the dataset was composed of primary research articles relevant to the study's scope.

The study selection process was meticulously documented and visualized via the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart (Fig1). This flowchart details the process of identifying, screening and including studies, ensuring transparency and replicability. It clearly presents the number of records identified, screened and excluded at each stage, demonstrating the study's rigorous methodology. To complement the SLR, a bibliometric analysis was conducted, leveraging tools such as VOS viewer and R Studio. This enabled the quantitative examination of research trends, identification of influential authors and visualization of thematic clusters, thus mapping the intellectual structure and research trajectories in the field. VOS viewers mapped networks of co-

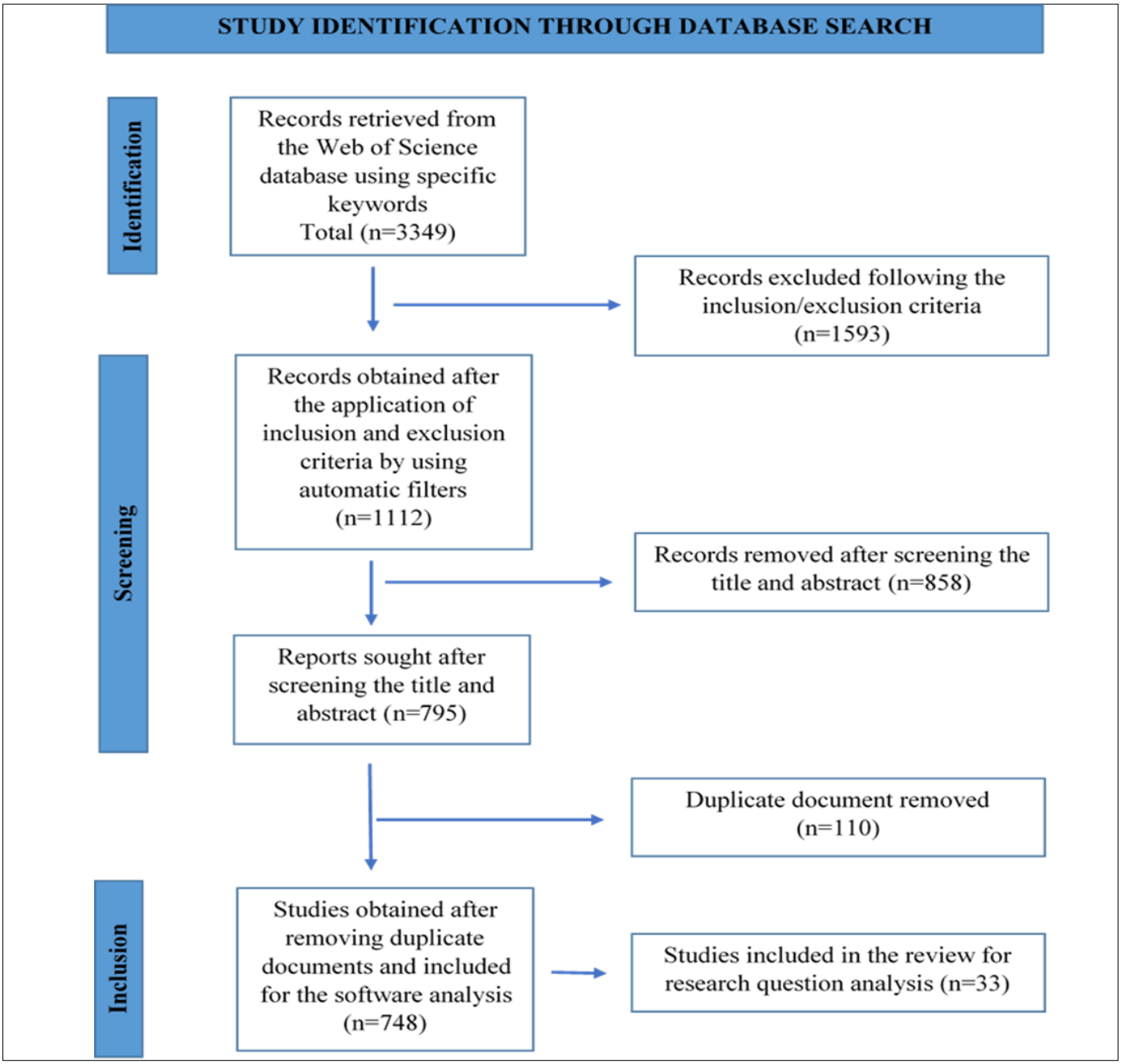

Fig. 1. The PRISMA flow chart employed in the study outlines the process used to select documents.

authorship, co-citation and keyword co-occurance, uncovering collaboration patterns and thematic clusters. Moreover, bibliometric packages in R Studio facilitated advanced analyses, such as citation trends and topic modelling, highlighting influential studies and emerging areas of research. By synthesizing findings from the SLR and bibliometric analysis, this study provides a holistic understanding of the evolution and intellectual structure of ODL research in agriculture. The integration of these methodologies reveals key contributions, gaps and thematic trends within literature. This approach maps the scholarly landscape and outlines future research directions, providing a structured and insightful analysis.

Results and Discussion

Global trends and collaboration in ODL Agricultural Research

The bibliometric analysis (2000-2025) highlights significant growth and global collaboration in research on the impact of open and distance learning in agricultural education. The 759 documents from 364 publications with an annual growth rate of 8.09 % indicate the growing significance of this field. The average document age of 3.79 years and 14.9 citations per document indicate a focus on contemporary and impactful research, supported by a substantial total of 40682 references. The diversity of research topics is evident from 2,066 keywords plus and 2961 author keywords. Key trends emerging from the research include technology adoption in ODL, e-learning platforms for farmers, MOOCs and mobile learning in agriculture and challenges and barriers in ODL adoption. Of the 3,789 authors, only 28 produced single-authored papers, underscoring the field's highly collaborative nature, with an average of 5.21 coauthors per document and a 36.76% international co-authorship rate. Majority of publications are articles [739], supplemented by data papers [7], early-access articles [3], proceedings papers [7] and retracted publications [3]. The low number of retractions suggests robust scientific rigor overall. These findings collectively demonstrate the dynamic, collaborative and globally relevant nature of research in this critical area.

Trends in ODL Research in Agriculture: 2000-2024

The annual scientific production of open and distance learning (ODL) in agriculture has exhibited a dynamic growth pattern over the years (Fig. 2.). This trend highlights the increasing academic interest and expanding research contributions in the field, reflecting its growing significance in addressing educational challenges and opportunities in the agricultural sector. From 2000-2009, the output was relatively sparse, with an average of fewer than three articles per year, indicating the nascent stage of research in this field. A gradual rise began in 2010, with a surge in 2014 [9 articles], reflecting increasing academic interest in ODL's role in agricultural education. The most significant growth occurred between 2020 and 2023, with a dramatic increase from 31 articles in 2020 to a peak of 90 articles in 2022, likely driven by the increasing integration of digital education technologies, accelerated by the global COVID-19 pandemic. Although there was a slight decline to 46 articles in 2024, this drop can be attributed to several factors. One possible explanation is the post-pandemic stabilization of digital education research, as the rapid expansion during the pandemic has given way to more mature and focused studies. Additionally, there may be a shift in funding priorities toward AI-driven education, which could divert resources from ODL-specific agricultural research. Overall, the trend suggests a sustained high level of research activity compared to earlier years. This trend highlights ODL's growing importance in agricultural education and its adaptability to global educational challenges.

Key authors and collaborative trends

The analysis of key contributors to ODL research in agriculture highlights both individual and collaborative efforts (Fig. 3.). Hodgkinson-Williams CA leads with 5 articles and a fractional contribution of 2.17, signifying substantial involvement in coauthored works. Reynnell's R, with 4 articles and a fractionalized contribution of 4.00, is notable for predominantly single-authored publications, emphasizing individual scholarship. Other authors, such as Wilson SB and Mayisela T, also contribute significantly, with fractionalized scores of 1.58 and 1.50, respectively, showing balanced participation in both solo and collaborative works. Moreover, Knysh I and Kulyk N, with 3 articles each but lower fractional

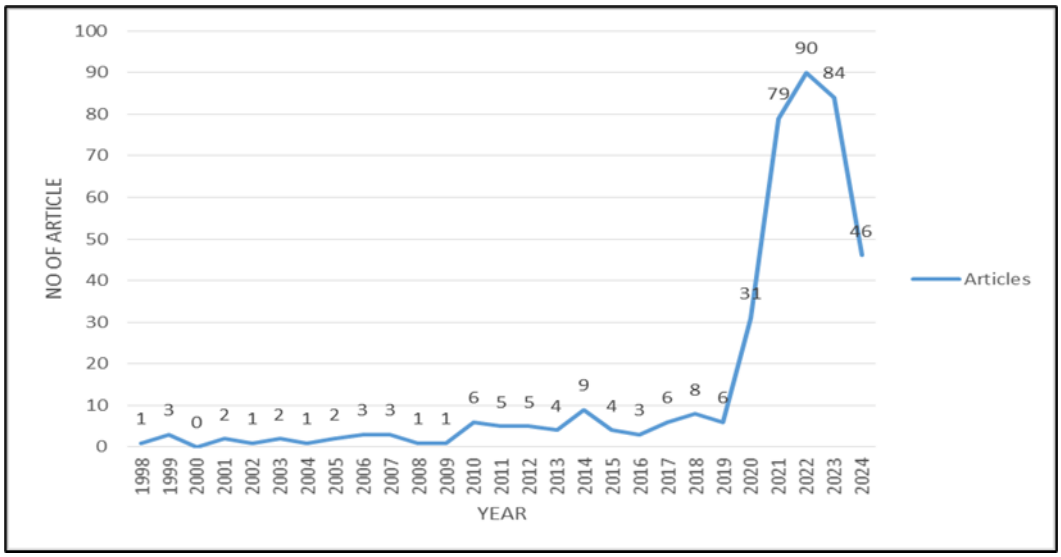

Fig. 2. Annual Scientific Production of articles.

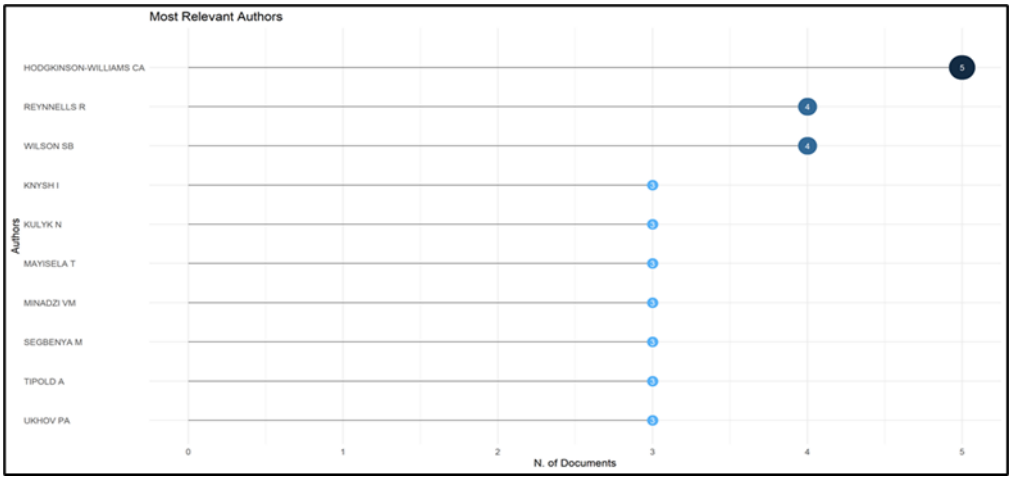

Fig. 3. Most relevant authors.

contributions (0.60), reflect their participation in larger collaborative teams. This trend indicates a blend of extensive individual contributions and collaborative research networks, underscoring the interdisciplinary and team-oriented nature of research in this field.

Authors' research impact and citation trends

The analysis of authors' production over time provides valuable insights into their research contributions and citation impact within the field of open and distance learning (ODL) in agriculture (Fig. 4.). One key observation is that factors such as publication venue, topic relevance and indexing delays may influence citation patterns. For instance, Hodgkinson-Williams CA published five articles in 2022 but received no citations (TC = 0), which could be due to a lack of visibility in high-impact journals, a highly specialized research focus, or a delayed indexing process in major citation databases. Similarly, Knysh I and Kulyk N both demonstrated active publishing in 2023 and 2024, with Knysh I am achieving a higher citation frequency (TC = 12 in 2023) and an average of four citations per year (TCpY), reflecting greater research impact during that period. This suggests that timely and widely relevant research topics may contribute to higher citation rates.

Minadzi VM and Mayisela T contributed in 2022 and 2023, with limited citations, which may indicate a niche focus area or the need for further dissemination efforts. Reynnell's R, despite having earlier publications in 2006 and 2007, shows a modest citation count (TC = 3) and low citations per year (TCpY = 0.15), indicating enduring but minimal impact over time. This aligns with broader trends in ODL research, where older studies may become less frequently cited unless they address persistent challenges or foundational theories. In terms of publishing strategies, authors with higher citation counts, such as Knysh I, may be leveraging high-impact journals, collaborative networks, or interdisciplinary approaches to enhance visibility, whereas others may be publishing in niche or regional journals with limited reach.

Despite these variations, a key gap in literature remains the long-term impact and sustained citation trajectory of ODL research in agriculture. Future research should explore how authors can optimize dissemination strategies, engage with global research networks and address emerging challenges in ODL for sustainable agricultural education. These patterns suggest that both emerging and established contributors actively shape the research landscape.

Most frequently used words

Fig. 5. illustrates key themes in ODL research in agriculture by analyzing the most frequently used words, highlighting core topics and research priorities. The dominance of terms such as "education" (34 occurrences) and "students" (27 occurrences) underscores the centrality of learning processes and learner engagement in this field. The frequent mention of "technology" (14 occurrences), "multimedia technologies" (9 occurrences) and "online" (12 occurrences) reflects the critical role of digital tools and platforms in enabling effective remote

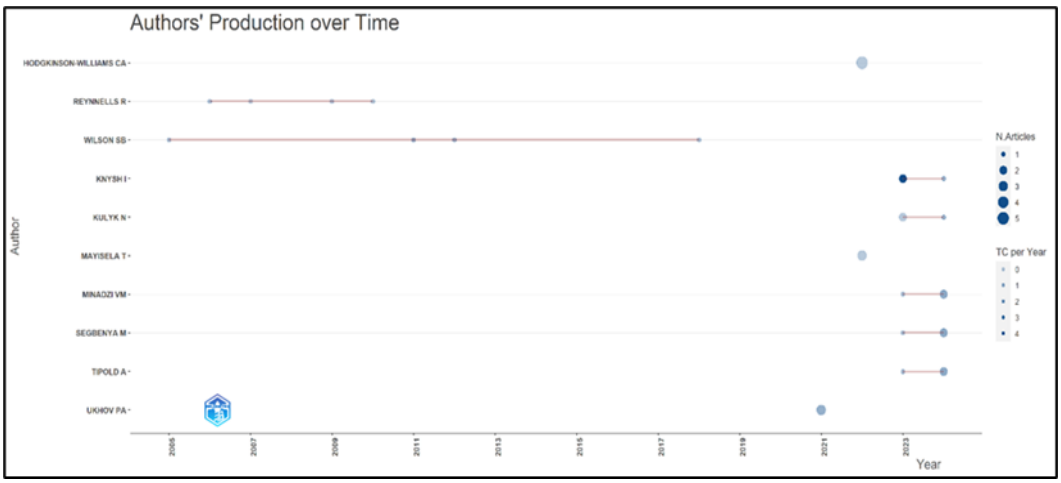

Fig. 4. Authors' production over time.

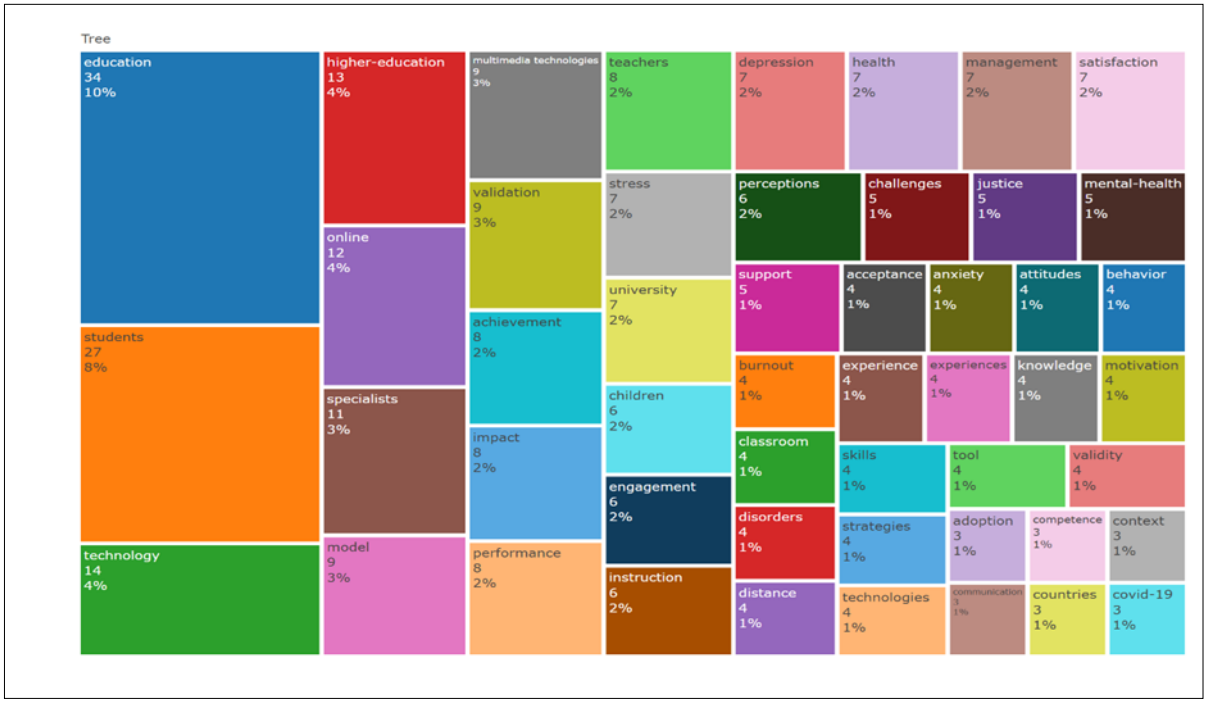

Fig. 5. Key thematic focuses in the literature.

learning. The emphasis on "higher- education" [13 occurrences] indicates a focus on postsecondary institutions' contributions to agricultural education, whereas terms such as "specialists" [11 occurrences] and "models" [9 occurrences] point to expert involvement and the development of theoretical frameworks for ODL. Additionally, the occurrence of "validation" [9] and "achievement" [8] highlights the importance of evaluating the effectiveness and outcomes of ODL programs. These evaluations are often conducted through student performance assessments, feedback surveys and comparative studies measuring knowledge retention before and after course completion. For instance, some agricultural ODL programs assess effectiveness by tracking student progress through pre- and post-course tests, while others use qualitative methods such as structured interviews and focus group discussions with learners and instructors to gauge engagement and satisfaction. Furthermore, digital learning analytics, including tracking completion rates and interaction levels on online platforms, provide insights into learner participation and overall program impact. Together, these terms depict a research landscape integrating technology, pedagogy and assessment to enhance the ODL's on agricultural education.

Co-occurrence network

The co-occurrence network visualized on Fig. 6. and generated via VOS viewer highlights the thematic landscape of research on open and distance learning (ODL) in agricultural education. The co-occurrence network reveals four major thematic clusters. The Green cluster focuses on the impact of COVID-19 on relationships, instructional methods and mental health in education. The Red cluster emphasizes training, resource development and the integration of technology to enhance societal and institutional outcomes. The Blue cluster is centered on frameworks, flexibility and region-specific studies, such as those in South Africa. The Yellow cluster explores curriculum design and the balance between traditional and blended learning approaches. Central keywords such as "COVID" and "Training" connect multiple clusters, reflecting

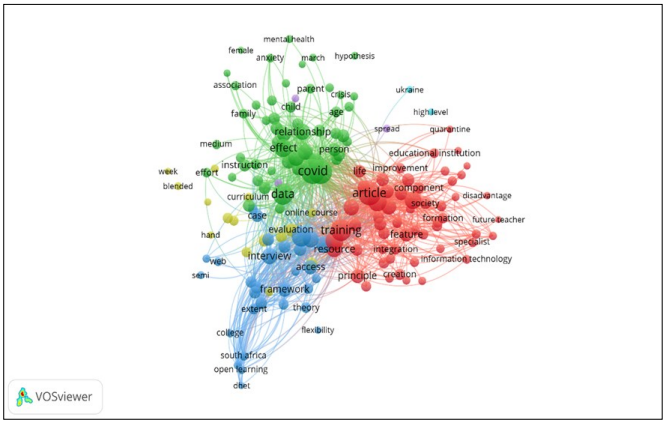

Fig. 6. Co-occurrence network visualization.

their pivotal role in shaping ODL practices during and beyond the pandemic. While "COVID" played a crucial role in accelerating the adoption of digital learning strategies, its long-term prominence may decline as institutions shift towards hybrid and blended learning models. Conversely, "Training" is expected to remain central, with increasing emphasis on capacity-building, skill development and lifelong learning in agriculture. Emerging themes such as "adaptive learning," "artificial intelligence," and "sustainability" may gain prominence as the field continues to evolve. Strong interconnections between these clusters signify the multidisciplinary nature of this research, highlighting the importance of collaboration across themes such as mental health, technology and curriculum design. This visualization underscores the transformative potential of ODL in agricultural education by providing flexible frameworks, accessible resources and effective training programs to address diverse learner needs, particularly in response to crises such as the pandemic.

Thematic map

The collaboration network (Fig. 7.) visualization highlights the interconnectedness and research collaborations among key authors in the field of open and distance learning (ODL) in

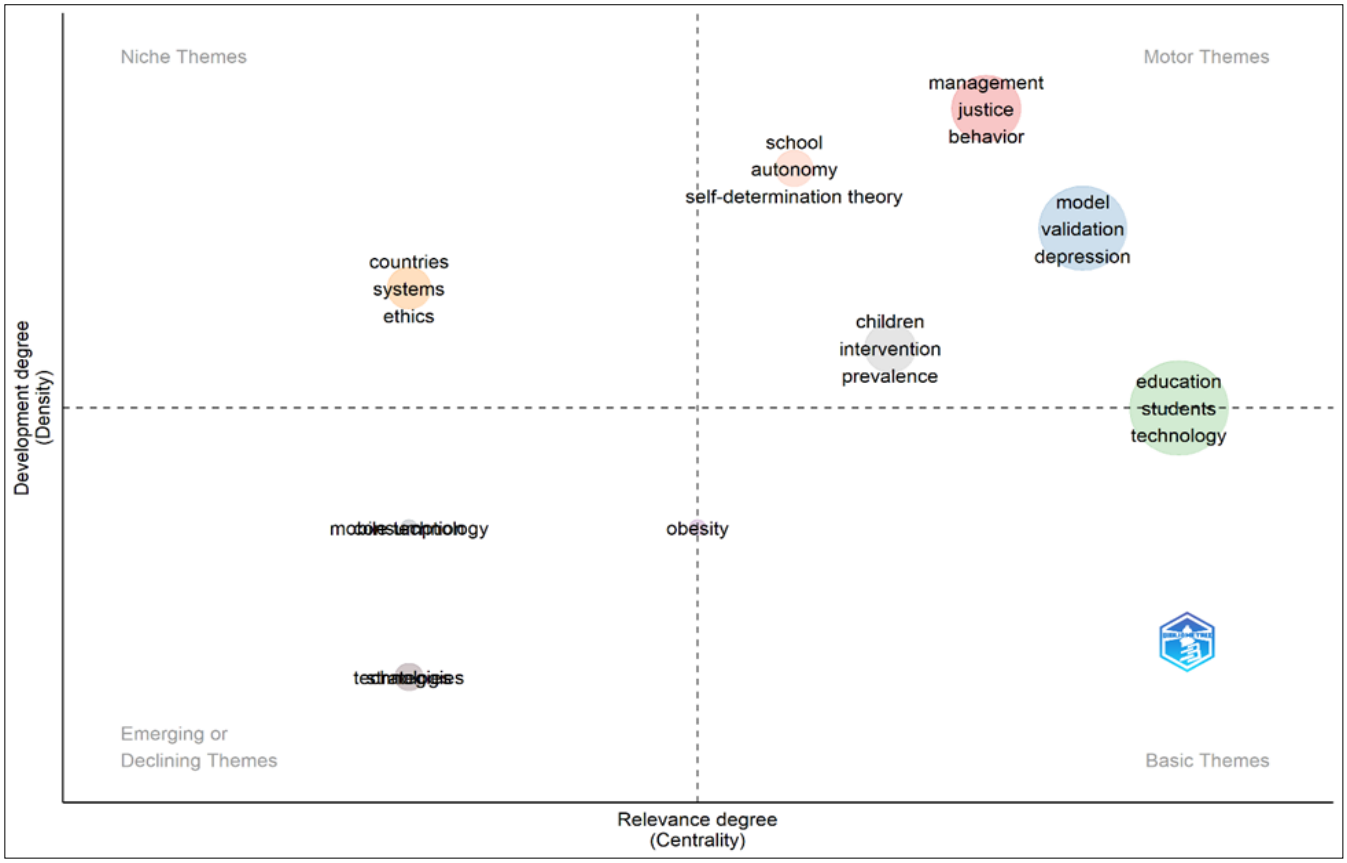

Fig. 7. Thematic map.

agricultural education. The size of the nodes corresponds to an author's impact or productivity, which is determined based on a combination of citation counts and publication volume. Larger nodes indicate either highly cited researchers or those with a significant number of publications, signifying their influence within the field. "Hodgkinson-Williams CA" emerges as a central figure, indicating a prominent and influential role in the research community through extensive collaboration or highly cited works. Clusters represent distinct collaborative groups, such as "Wilson SB," "Barakhsanov VP," and "Heise Satipold A," which likely focus on specific subfields or regional contexts. The presence of isolated clusters or dyads, such as "Didenko I" and "Davis T," suggests independent or niche contributions with limited cross-network integration. The dyads may represent either emerging research areas that are yet to establish broader collaborations or a lack of engagement with the wider ODL research community. Encouraging collaboration between these smaller networks and larger clusters could foster interdisciplinary insights and enhance the dissemination of niche research to a broader audience.

From a practical perspective, the structure of the collaboration network has significant implications for the development of ODL in agricultural education. Strongly connected clusters may drive dominant research themes and influence policy decisions, while fragmented or isolated groups could limit knowledge exchange and slow innovation. Strengthening inter-cluster collaboration through joint research initiatives, international partnerships and academic networking platforms could help bridge these gaps, ensuring a more integrated and dynamic advancement of ODL applications in agricultural education.

Collaboration network

Fig. 8. visualizes the collaboration network, illustrating the interconnectedness and research partnerships among key authors in ODL for agricultural education. The size of the nodes corresponds to an author's impact or productivity. "Hodgkinson-Williams CA" emerges as a central figure, indicating a prominent and influential role in the research community through extensive collaboration or highly cited works. Clusters represent distinct collaborative groups, such as "Wilson SB", "Barakhsanov VP" and "Heise Satipold A" which likely focus on specific subfields or regional contexts. The presence of isolated clusters or dyads, such as "Didenko I" and "Davis T" suggests independent or niche contributions with limited cross-network integration. This structure reflects a fragmented yet active scholarly landscape where dominant contributors drive research agendas whereas smaller groups pursue localized or specialized topics. This network underscores the need for enhanced collaboration across clusters to foster interdisciplinary innovation and broaden the scope of ODL applications in agricultural education.

Country collaboration network

The country collaboration network (Fig. 9.) illustrates the intricate global web of research partnerships, with major hubs such as the USA, the United Kingdom, Germany and Italy serving as central nodes driving extensive collaborations. The USA demonstrates widespread influence through connections with Argentina, India, South Africa and Turkey, while Germany strengthens European integration via links with Austria, Belgium and the Netherlands. Emerging players such as Malaysia, China and the UAE are increasingly integrated into global research, forming connections with key nations like Canada and Saudi Arabia. These international collaborations

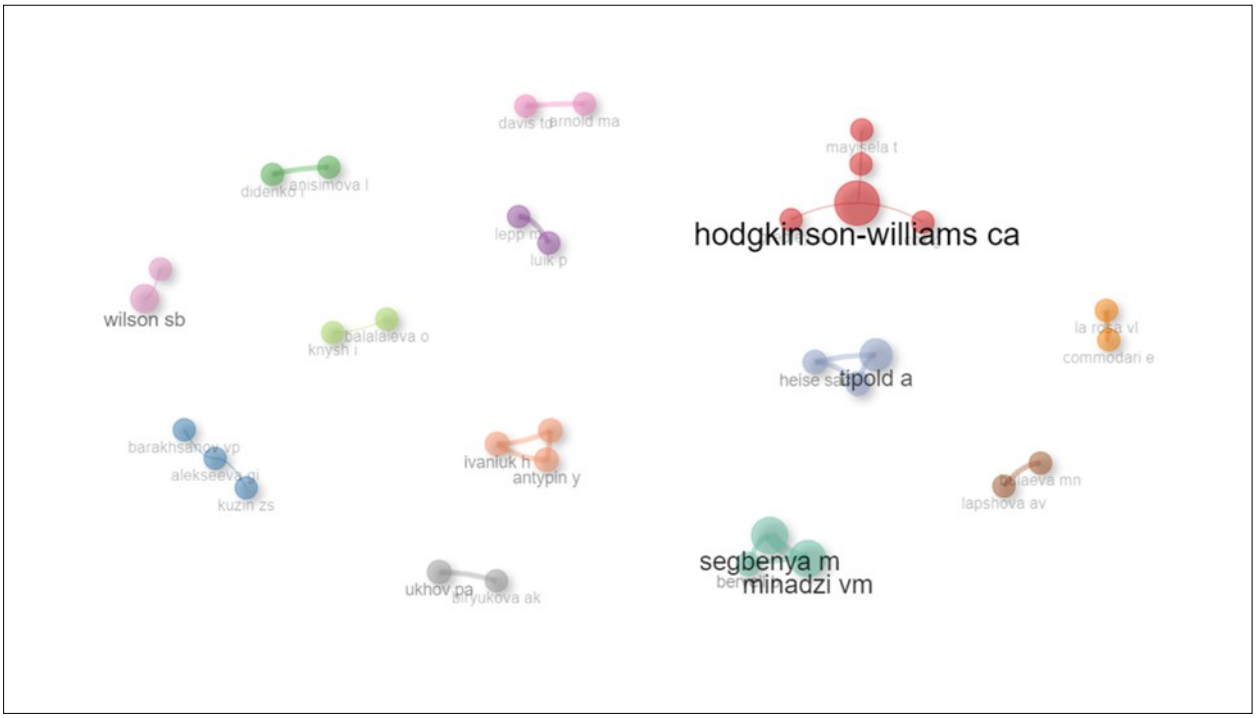

Fig. 8. Collaboration network visualization.

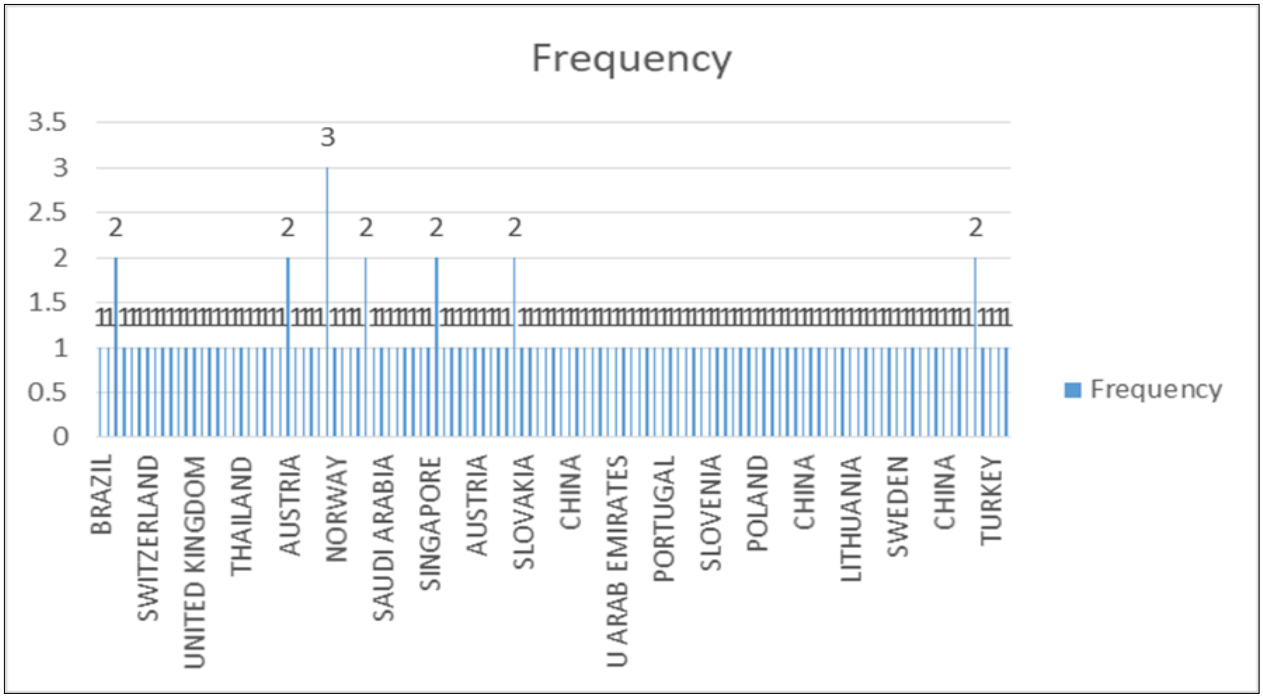

Fig. 9. Country collaboration network.

significantly advance ODL in agricultural education through joint publications, knowledge-sharing initiatives and cross-border educational programs. For instance, partnerships between European and African institutions have facilitated open-access agricultural training platforms, enabling broader knowledge dissemination. Despite strong regional and intercontinental linkages, the presence of less-connected nodes, such as Australia with Jordan or Sweden with Lithuania, presents opportunities to expand collaboration and enhance global knowledge exchange.

Emerging nations are making notable contributions to ODL in agricultural education by introducing innovative methodologies tailored to their unique contexts. Malaysia has led efforts in mobile-based learning solutions for smallholder farmers, while China has focused on AI-driven adaptive learning systems that personalize agricultural education. The UAE has pioneered block chain-based credential verification to enhance transparency in online agricultural training programs. These contributions highlight how newer players are not only participating in global research but also shaping the evolution of ODL practices. Strengthening underutilized connections and fostering interdisciplinary collaboration across regions could further accelerate innovation and impact in agricultural education worldwide.

Cocitation network

The Cocitation network (Fig. 10.) reveals a scholarly landscape dominated by key works such as "Fraser N 2005" which serves as a pivotal foundational reference due to its influential discourse on social justice in education, shaping debates on

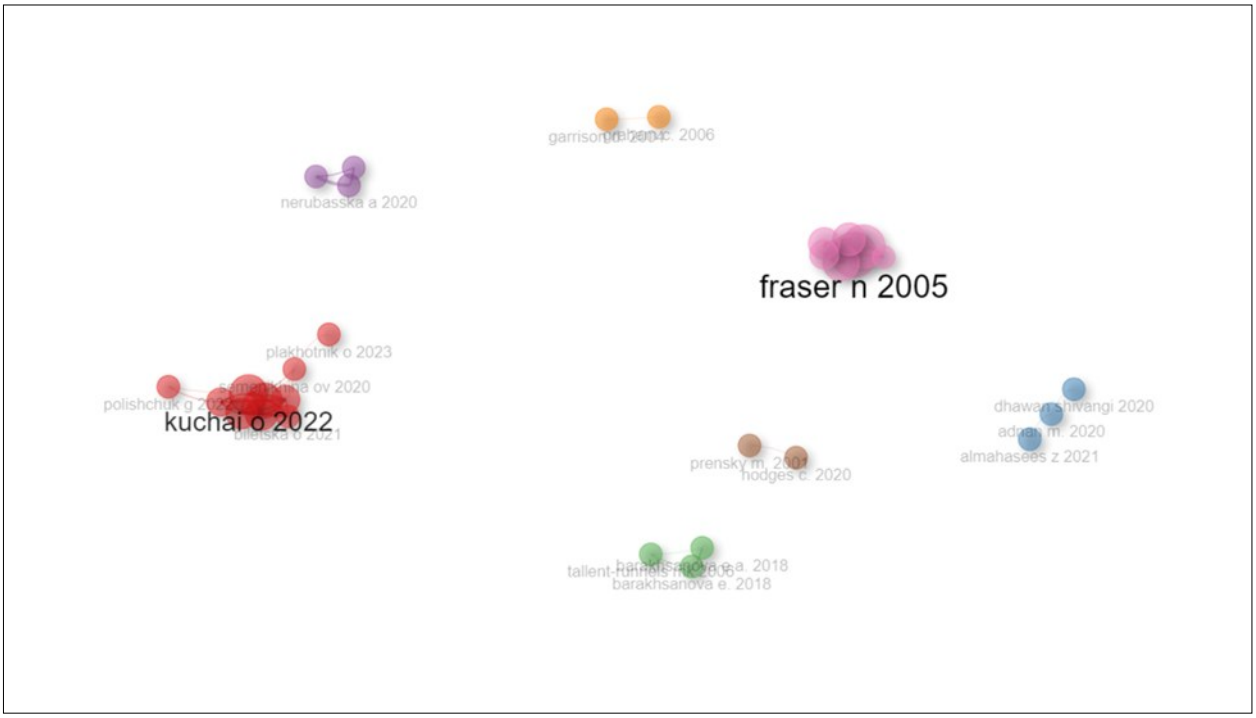

Fig. 10. Co-citation network.

equitable access and inclusivity in ODL. Its widespread citation suggests its enduring relevance in discussions on digital learning inequalities and policy frameworks. Another major node, "Kuchai O 2022" has rapidly gained prominence for its contributions to digital pedagogy and learner engagement, anchoring a cluster of contemporary studies such as "Plakhotnik O 2023" and "Polishchuk G 2023" which expand on its exploration of adaptive learning strategies and the effectiveness of emerging educational technologies.

Smaller clusters, such as those centered around "Garrison D R 2006" known for its work on the Community of Inquiry (CoI) framework and "Prensky M 2001" which introduced the concept of digital natives, represent specialized subfields with strong intracluster cohesion but limited intercluster connectivity, underscoring thematic independence. Emerging contributions, including "Dhawan Shivangi 2020" and "Almahassees Z 2021" reflect shifts in research priorities, particularly in the post-pandemic acceleration of online learning methodologies and the integration of AI-driven instructional models. These newer studies build upon earlier theories by emphasizing the role of digital transformation and learner adaptability, marking a shift from theoretical discourse to applied research in scalable ODL solutions. Overall, the network illustrates a dynamic scholarly ecosystem, anchored by influential works that bridge established theories with contemporary innovations, highlighting a gradual shift from foundational educational philosophies to more technology-driven and data-informed approaches.

Impact of open and distance learning (ODL) on agricultural productivity

Open and distance learning (ODL) has emerged as a transformative tool for delivering education in remote and rural areas, particularly for farmers and agricultural professionals (20). Studies reveal ODL's potential to enhance agricultural productivity, professional competence and knowledge dissemination, as summarized in (Table 2). The following discussion explores ODL transformative impact on agriculture, including increased productivity, sustainable practices, professional development, solutions for resource-constrained regions and bridging the digital divide.

Enhancing agricultural productivity through open and distance learning

Open and distance learning (ODL) has played a significant role in enhancing agricultural productivity by providing essential agricultural knowledge and practices to a wide range of audiences. The review highlights that ODL programs have led to measurable improvements in labour and land productivity, primarily by offering training in modern techniques, scientific methods and innovative tools. This access helps farmers optimize their agricultural outputs and foster sustainable growth (37). ODL programs often incorporate key topics such as sustainable farming practices, crop rotation and soil health management. These well-structured learning opportunities not only improve farm management but also enable rural populations to diversify their income sources. For instance, many ODL initiatives support off-farm employment, allowing individuals to explore alternative economic activities while sustaining agricultural productivity. This dual approach helps drive rural development and addresses issues like poverty and unemployment in agricultural communities. However, the impact on household income varies, influenced by factors such as the education level and asset ownership of participants. Higher education levels allow learners to better engage with complex agricultural content, while ownership of assets like land, technology and capital facilitates the practical application of new knowledge. Households with fewer resources may face challenges in applying learned techniques due to financial constraints or limited infrastructure (38). Targeted interventions, such as financial support, mentorship programs and mobile-based learning tools, can help bridge these gaps for resource-poor farmers.

Table 2. Key impact areas and findings of open and distance learning (ODL) and technology-enhanced education in agriculture

Impact area	Key findings	Study
Positive Impacts of Rural Distance Education Projects	RDEP improved agricultural productivity, labor and land productivity, increased off-farm employment time, but did not increase household income. More effective for households with junior high education and more assets.	(21)
Enhancing Social Competence of Extension Workers	ODL improved social competence among agricultural extension workers across four locations, highlighting the potential to enhance skills and capabilities necessary for effective agricultural advisory services.	(22)
Active Engagement through CSCL	CSCL in food science promoted active engagement, peer learning, skill development and knowledge construction, improving student writing outcomes, confidence, ability and understanding.	(23)
Dual-Enrollment Programs in Agriculture	Positive impact on student success, in-depth agriculture knowledge, college credit acquisition and appreciation of college course challenges. Influenced counselors and benefitted the overall school environment.	(24)
Enhancing HOTS through Online Learning	Inquiry-based online learning environments improved Higher Order Thinking Skills (HOTS) in mathematics, facilitating active self-regulated learning and cognitive development.	(25)
Role of Art Education in Comprehensive Development	Art education fosters creative abilities, human aesthetics and emotional regulation, with an interactive teaching mode necessary for diverse learners' needs in the contemporary Chinese education system.	26
Distance Learning in Crisis Contexts	Addressed re-skilling and up-skilling of the agricultural workforce in Syria through a pilot course on Soilless Cultivation Systems, highlighting the potential and challenges of distance learning in crisis contexts.	27
Simulation Games for Agricultural Education	Simulation games positively impacted subjective knowledge and internal efficacy but slightly lowered interest in agricultural politics. Perceived as interesting and informative by participants.	(28)
Changing Nature of Statistical Training	Discussed the impact of the SDGs Global Indicator Framework and COVID-19 on virtual training tools, emphasizing the need for new data-related skills and integrating various learning modalities.	(29)
Sustainable Consumption Behavior in Online Education	Introduced a model promoting sustainable consumption behavior in the online education industry, integrating consumer value theory, social exchange theory and planned behavior theory.	(30)
Impact of COVID-19 on Student Research Projects	Examined the impact of the pandemic on high school students' biology research projects, emphasizing the importance of continued academic engagement despite restrictions.	(31)
IoT Awareness and Training Programs	Highlighted the importance of IoT training programs in equipping students with skills for leveraging IoT technology in agriculture, e-learning, healthcare and engineering.	(32)
Evaluation of Online Learning During COVID-19	Evaluated online learning in Chinese universities during COVID-19 using AHP, finding that cultivating online learning abilities was more crucial than course resources and environments for promoting equity and development.	(33)
Virtual Field Trips in Agricultural Education	Found Virtual Field Trips (VFT) valuable with multimedia satisfaction but needing navigation improvements. VFTs are valuable but not a complete replacement for in-person field trips.	(34)
Open Distance Learning in Post-Conflict Nations	Compared outcomes of traditional face-to-face methods and ODL for teaching agricultural practices in Cambodia, finding no significant differences, suggesting ODL's effectiveness in regions with teacher shortages.	(35)
Environmental and Sustainability Education	Emphasized the value of Environmental and Sustainability Education (ESE) through extracurricular activities, integrating knowledge, enhancing motivation and achieving cognitive and affective learning objectives.	(36)

Scalability is another challenge for ODL programs. Expanding these programs to a larger audience often faces obstacles such as limited internet connectivity, language diversity and the need for localized content. To overcome these barriers, innovative strategies are necessary, such as low-bandwidth digital platforms, multilingual course materials and community-based learning hubs. Collaborative efforts between educational institutions, government bodies and agricultural cooperatives can also help improve outreach and ensure ODL remains an effective tool for sustainable agricultural development. By tackling these challenges and implementing inclusive strategies, ODL can enhance the accessibility and equity of agricultural education for diverse populations, thereby maximizing its positive impact (39).

Improving Social Competence and Professional Development

ODL plays a pivotal role in enhancing the social competence and professional development of agricultural professionals, particularly extension workers. These professionals act as intermediaries between researchers and farmers, disseminating innovations and addressing local agricultural challenges. The flexible learning opportunities provided by ODL allow extension workers to increase their skills and acquire new knowledge without disrupting their professional responsibilities (40). For example, in India, the National Institute of Agricultural Extension Management (MANAGE) offers an ODL-based diploma program that has significantly improved the communication and advisory skills of extension workers, enabling them to better engage with farmers and promote sustainable farming practices (41).

Continuous professional development through ODL enhances the ability of extension workers to communicate effectively with farmers, promotes the adoption of innovative practices and fosters collaboration among stakeholders. Improved social competence translates into better teamwork and problem-solving capabilities, which are critical for implementing community-based agricultural projects (42). A case in Kenya's Agricultural Information Resource Centre (AIRC) demonstrates how an ODL program helped extension workers refine their problem-solving strategies, resulting in increased

farmer participation in climate-resilient farming techniques (43). Additionally, ODL ensures that agricultural professionals in remote areas have access to high-quality educational content, bridging the gap between urban and rural education systems. For instance, in the Philippines, an ODL initiative by the Agricultural Training Institute (ATI) provided distance learning courses to farmers and extension workers, significantly reducing the rural-urban knowledge gap. This democratization of knowledge has strengthened the agricultural workforce and promoted equitable development across the sector, ensuring that even those in remote areas benefit from advancements in agricultural science and technology (44).

Addressing challenges in post conflict and resource-constrained regions

In regions recovering from conflict or experiencing severe resource limitations, Open and Distance Learning (ODL) serves as a critical lifeline for agricultural education and skill development. Traditional education systems in these areas often face logistical challenges, such as inadequate infrastructure, a shortage of trained teachers and limited financial resources. By leveraging technology, ODL overcomes these barriers, delivering educational content at scale and reaching learners who might otherwise be excluded (45). For example, in post-conflict areas like Sierra Leone, ODL programs have been pivotal in rebuilding agricultural knowledge by offering courses in sustainable farming practices, which directly supported the recovery of local agricultural productivity (46).

Programs implemented in post-conflict settings demonstrate the effectiveness of ODL in rebuilding education systems and empowering local communities. In regions such as Rwanda, ODL has been used to train farmers in crop management, pest control and irrigation techniques, which played a crucial role in restoring agricultural productivity after the 1994 genocide (47). The scalability of ODL ensures that entire community's benefit from educational interventions, enabling widespread knowledge dissemination. In addition, ODL programs that focus on locally relevant content have proven particularly successful. For instance, in Afghanistan, an ODL curriculum tailored to local farming conditions improved the productivity of small-scale farmers by integrating traditional practices with modern techniques. By addressing the unique challenges faced by resource-constrained regions and adapting curricula to local contexts, ODL programs have not only enhanced agricultural knowledge but also directly contributed to agricultural recovery in crisis-affected regions (48).

Bridging the digital divide in rural agriculture

A critical challenge for ODL in agriculture is its reliance on digital tools and platforms, which can be inaccessible for rural communities with limited technological infrastructure. Addressing this digital divide is crucial for ensuring inclusivity and effectiveness of ODL programs (49). Innovative initiatives that combine low-tech (e.g. SMS-based learning) and high-tech solutions (e.g. mobile learning applications) help bridge this gap. For example, distributing preloaded learning materials on mobile devices or USB drives enables learners in areas with poor internet connectivity to access educational content.

Community learning centers equipped with basic digital infrastructure can serve as hubs for ODL in rural areas. Governments and development organizations play a pivotal role in supporting the necessary infrastructure, including internet connectivity, affordable devices and digital literacy training. Collaborative efforts between the public and private sectors can foster environment conductive to the successful implementation of ODL in agriculture, ensuring that rural populations are not left behind in the digital era (50).

Promoting sustainable agricultural practices through ODL

Sustainability is a cornerstone of modern agricultural education and ODL is uniquely positioned to promote sustainable practices on a large scale. By offering targeted modules and courses, ODL programs educate farmers on environmentally friendly techniques such as organic farming, conservation agriculture and agroforestry. These practices not only increase productivity but also protect natural resources and mitigate the impacts of climate change. Successful collaborations between public and private sectors have further strengthened ODL's role in sustainability education. For instance, the partnership between the Food and Agriculture Organization (FAO) and digital learning platforms has enabled the development of ODL courses that train farmers in climate-smart agricultural techniques, improving their adaptive capacity in regions vulnerable to climate change (51).

The flexibility of ODL allows it to address the diverse needs of farmers, ranging from smallholders to large-scale producers. Courses can be customized to reflect local environmental conditions, crop types and cultural practices, ensuring relevance and practicality. To make educational content more engaging and accessible for rural learners with varying levels of digital literacy, ODL programs employ strategies such as interactive voice response (IVR) systems, mobile-based learning applications with audio-visual content and community radio broadcasts. For example, India's Digital Green initiative integrates video-based training with peer learning networks, allowing farmers to adopt sustainable practices through culturally relevant and easily understandable formats. Interactive tools, such as simulations and virtual field trips, further enhance the learning experience by helping farmers visualize the benefits of sustainable practices and apply them effectively in their fields. By fostering a culture of sustainability, ODL contributes to the long-term resilience of agricultural systems and ensures that productivity is maintained for future generations (52).

Scaling up ODL for agricultural transformation

Scaling up successful ODL programs is essential to fully realizing their potential in transforming agriculture. This requires coordinated efforts among governments, educational institutions and development agencies. Investments in technology infrastructure, curriculum development and capacity building are critical to expanding the reach and impact of ODL initiatives. In addition to improving technical knowledge, ODL has significant psychosocial impacts, particularly in enhancing farmers' motivation, problem-solving abilities and self-efficacy. Studies have shown that participation in structured ODL programs increases learners' confidence in adopting new agricultural techniques, fosters resilience in adapting to climate challenges and improves decision-making skills. These outcomes can be measured

through surveys assessing self-reported confidence levels, behavioral changes in farming practices and engagement in collaborative problem-solving activities (53).

Monitoring and evaluation play a crucial role in the scaling-up process. Regular assessments of program outcomes, learner satisfaction and community impact provide valuable insights for refining and improving ODL initiatives. Feedback from participants can inform you about the development of new courses and learning materials that address emerging challenges in agriculture. Gender inclusivity is also a key consideration in scaling ODL programs. Successful gender-focused strategies, such as the African Women in Agricultural Research and Development (AWARD) fellowship, demonstrate how targeted training and mentorship programs empower women in agriculture. ODL can integrate similar gender-responsive approaches by offering flexible learning schedules, incorporating women-centric agricultural content and providing digital literacy training tailored to female farmers. Such strategies help bridge the gender gap in agricultural education and ensure that women have equal access to knowledge and opportunities. Partnerships between educational institutions and industry stakeholders further enhance the relevance of ODL programs by aligning content with market needs and incorporating the latest advancements in agricultural research. These collaborations also create opportunities for experiential learning and practical training, bridging the gap between theory and practice (54).

Implications and directions for future research

The findings of this review highlight the transformative role of open and distance learning (ODL) in agricultural education, particularly in addressing challenges such as limited access to traditional educational systems and the digital divide. ODL empowers rural and marginalized farming communities by providing flexible, technology-driven educational opportunities that enhance knowledge transfer, promote sustainable practices and support livelihoods. It aligns with global development goals, such as the Sustainable Development Goals (SDGs), by reducing educational inequities and fostering resilience among farmers. Future research should focus on bridging the digital divide through low-tech and offline learning solutions (e.g., radio-based education and SMS learning). Additionally, it should explore public–private partnerships to enhance digital infrastructure. Tailoring the ODL content to address local agricultural needs and assessing its long-term impact on productivity and income levels in diverse socioeconomic contexts are critical areas for further investigation. Additionally, the integration of emerging technologies such as AI, IoT and VR into ODL platforms could revolutionize agricultural education. Researchers should also evaluate the psychosocial impacts of ODL, such as its influence on motivation and problem-solving skills (e.g., self-efficacy and decision-making confidence). Additionally, they should develop gender-inclusive strategies to ensure equitable access for women farmers. In crisis and post conflict settings, the adaptability of ODL to rebuild agricultural education systems merits deeper exploration. Finally, future studies should refine evaluation frameworks to measure ODL effectiveness via metrics such as knowledge retention, behavioral change and learner satisfaction. By addressing these research directions, ODL can further advance sustainable agricultural development and create a more inclusive, knowledge-driven farming ecosystem globally.

Conclusion

This study underscores the significant potential of open and distance learning (ODL) in transforming agricultural education by addressing accessibility and knowledge transfer challenges in rural and marginalized communities. Systematic methodologies highlight the role of ODL in promoting sustainable practices, enhancing productivity and supporting global development goals such as the SDGs. However, overcoming barriers such as the digital divide, content localization and equitable access remains critical for maximizing its impact. By addressing these challenges, the ODL can drive meaningful progress in agricultural education, fostering a more inclusive and resilient farming ecosystem worldwide.

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Authors' contributions

GS conceptualized and formulated the manuscript and analyzed the data. BSP guided by formulating the review concept and approved the final manuscript, and helped in procuring grants. SRN contributed by developing the ideas reviewed in the manuscript. SJ and LS helped summarize and revise the manuscript. GSR helped in summarizing and statistical analysis of data.

Compliance with ethical standards

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