

The Role of Virtual Reality and Augmented Reality in Agricultural Training

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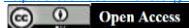
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ABSTRACT

Virtual Reality (VR) and Augmented Reality (AR) are increasingly powerful tools in global agricultural training, offering immersive, interactive, and learner-focused experiences that address persistent gaps in traditional education. VR provides fully simulated environments for practicing farm operations, operating machinery, and implementing climate-smart techniques, while AR enhances real-world learning by overlaying digital data such as crop health indicators, soil analysis, and repair instructions onto physical settings. This paper reviews the core concepts, practical applications, benefits, obstacles, and future directions of VR and AR in this field. Key advantages include improved knowledge retention, greater safety, expanded accessibility, and reduced costs, particularly in developing regions where physical equipment is scarce. Data show a clear upward trend: in 2018, global VR training adoption stood at 6%, compared to a 3% increase for AR; by 2025, these figures had risen sharply to 60% and 58%, respectively, reflecting a consistent annual growth trajectory. The study concludes that VR and AR are driving a fundamental transformation in agricultural education and will continue to define the competencies needed for tomorrow's farming workforce.

1. Introduction

Agriculture continues to serve as a cornerstone of economic progress in numerous developing countries, playing a vital role in securing food supplies, creating employment opportunities, and reducing poverty. As reported by the World Bank (2022), over 60% of the workforce in many sub-Saharan African nations is engaged in agricultural activities, with the sector contributing substantially to national gross domestic product. Beyond its economic weight, agriculture underpins the stability of domestic food systems, shapes rural social structures, and influences global trade dynamics (FAO, 2021). In recent decades, the sector has experienced significant shifts driven by technological advances, climate variability, demographic pressures, and growing calls for sustainable production methods. These evolving dynamics have introduced new prospects and complexities for farmers, educational institutions, and policy frameworks, highlighting the urgent need to modernize the methods through which agricultural expertise is imparted to current and future practitioners.

Modern farming has grown increasingly intricate, demanding proficiency in precision agriculture, intelligent water management, biotechnological innovations, climate-resilient strategies, and sophisticated equipment. Precision agriculture, for example, leverages data-centric tools such as satellite imaging, networked sensors, and geographic information systems to maximize input efficiency and boost crop output (Gebbers & Adamchuk, 2010). In parallel, smart irrigation systems harness real-time data and automated controls to optimize water usage, while mechanization reduces dependence on physical labor and enhances operational productivity. Biotechnological developments including genetically engineered crops and plant tissue culture provide effective responses to pest outbreaks, disease pressures, and climate-related stresses. While these technological breakthroughs hold

considerable promise for improving both productivity and environmental sustainability, they simultaneously necessitate a skilled workforce capable of translating theoretical knowledge into effective field application.

Despite the promise of modern agricultural innovations, conventional training approaches often prove inadequate for developing practical competence among learners. Traditional agricultural education tends to depend heavily on lecture-based instruction, textbook materials, and occasional farm visits. Although such methods convey essential theoretical foundations, they are inherently limited by seasonal cycles, restricted access to land and machinery, and safety concerns. For instance, trainees frequently have few opportunities to operate advanced equipment or apply contemporary farming techniques in authentic field conditions. Moreover, agricultural training institutions in developing nations often lack the necessary resources to deliver hands-on experiences that reflect current industry practices (Ozor & AI4AFS, 2025). This disconnect between theoretical instruction and applied skills can diminish the overall impact of agricultural education programs and impede the cultivation of a competent and innovative agricultural workforce.

Emerging digital technologies, particularly Virtual Reality (VR) and Augmented Reality (AR), hold significant promise for revolutionizing agricultural training. VR generates computer-based simulations that place learners within fully interactive environments, enabling them to perform tasks in a risk-free and controlled setting. Within the agricultural domain, VR can replicate a wide range of operations including planting, irrigation, harvesting, machinery operation, and pest control allowing users to practice repeatedly, receive instant feedback, and navigate challenging scenarios such as severe weather events or disease epidemics without endangering actual crops, equipment, or personal well-being (Hurst, 2021). This immersive pedagogical approach fosters experiential learning, strengthens long-term knowledge retention, and cultivates procedural skills that remain difficult to attain through traditional instructional methods alone.

AR, in contrast, superimposes digital information onto physical objects and environments, delivering context-rich learning experiences within actual farm settings. For example, AR applications can assist learners in conducting soil analyses, identifying crop diseases, or designing irrigation plans by projecting instructional visuals, performance metrics, or interactive guides directly onto the subjects under study. This fusion of digital content with the physical world enables trainees to bridge theoretical principles with hands-on application, thereby deepening comprehension and strengthening decision-making abilities (Ario et al., 2025). Unlike VR, AR permits simultaneous engagement with both virtual elements and real-world surroundings, effectively connecting classroom instruction with fieldwork.

The integration of VR and AR into agricultural training directly addresses numerous shortcomings inherent in traditional methodologies. Firstly, these technologies provide safe spaces for trial-and-error learning, significantly reducing the financial and operational consequences of mistakes. Secondly, they lessen dependence on scarce or costly physical inputs such as land, machinery, and laboratory supplies thereby broadening access to quality practical education. Thirdly, immersive and augmented experiences boost learner engagement and motivation, fostering active participation and the development of analytical thinking. Finally, VR and AR offer flexible and scalable solutions adaptable to a wide range of educational settings, from university curricula and vocational programs to extension services and farmer field schools.

Beyond individual skill enhancement, VR and AR carry broader implications for agricultural advancement. By cultivating a workforce proficient in contemporary techniques, these tools contribute to higher productivity, more sustainable land stewardship, and greater resilience to climatic shifts. They also facilitate continuous professional development, enabling farmers and extension officers to stay current with emerging technologies and practices. Evidence suggests that embedding immersive

technologies within agricultural education yields measurable gains in learning outcomes, operational efficiency, and problem-solving capacity (Liang et al., 2020; Smith & Tan, 2022).

1.1 Statement of the Problem

Notwithstanding the escalating complexity of modern agriculture and the rising demand for skilled practitioners, training systems across many developing countries remain insufficient and misaligned with prevailing farming realities. Conventional pedagogical approaches frequently fail to deliver adequate practical exposure due to restricted access to modern equipment, safety risks, high instructional costs, and seasonal limitations. Consequently, numerous learners and farmers lack direct experience in operating agricultural machinery, managing animal health, responding to climate-induced threats, or applying advanced production techniques. This competency gap stifles productivity, curbs innovation, and undermines the effectiveness of agricultural extension services. Although VR and AR have demonstrated considerable potential for enhancing experiential learning and practical skill acquisition, their uptake in agricultural training remains limited. Elevated equipment expenses, insufficient digital infrastructure, scarce technical expertise, and weak institutional backing continue to impede widespread deployment, particularly in resource-constrained regions. Hence, a critical examination of the role of VR and AR in agricultural training is necessary to elucidate their potential contributions, pinpoint adoption barriers, and propose strategies for effective integration into agricultural education systems.

1.2 Objectives of the Study

The specific objectives of this review are to:

- i. Examine the concept and applications of Virtual Reality and Augmented Reality in agricultural training.
- ii. Assess the benefits of Virtual Reality and Augmented Reality for skill development and knowledge retention in agriculture.
- iii. Identify challenges limiting the adoption of Virtual Reality and Augmented Reality in agricultural education.

2.0 Conceptual Clarifications

2.1 Virtual Reality (VR)

Virtual Reality (VR) is an advanced digital technology that generates wholly immersive, computer-generated environments, enabling users to experience and interact with virtual worlds as though they were physically present (Kanivets, 2025; Jerald, 2016). Within agriculture, VR can simulate farm landscapes, cropping systems, livestock facilities, irrigation networks, and intricate machinery operations, allowing learners to practice and experiment free from real-world risks, costs, or environmental constraints (Hurst, 2021). In contrast to traditional instructional methods often confined to classrooms, texts, or sporadic site visits VR creates interactive, experiential learning spaces where trainees can engage in practical tasks within controlled, repeatable settings.

VR systems typically employ head-mounted displays (HMDs), motion controllers, haptic feedback gloves, and positional sensors that track user movements and replicate tactile, motion, and spatial cues. These devices enable navigation through virtual farms, operation of equipment, manipulation of objects, and receipt of real-time performance feedback (Zhou et al., 2022). For instance, a student can practice tractor operation, fertilizer application, or pruning in a virtual setting, building confidence and procedural proficiency prior to handling actual machinery or plants. This immersive approach not only sharpens technical skills but also reinforces cognitive understanding by linking actions to outcomes in a safe, monitored environment.

A principal advantage of VR in agricultural training is its capacity to overcome geographic and seasonal barriers. Conventional education is often constrained by land availability, climatic conditions, and growing cycles, which restrict the timing and scope of practical instruction (Ozor & AI4AFS, 2025).

VR removes these limitations by offering year-round access to simulated farming scenarios. Learners in urban centers, remote localities, or regions with extreme climates can experience diverse agricultural contexts from paddy rice cultivation to greenhouse management without leaving their training facilities.

VR further enables scenario-based learning, permitting students to simulate rare, hazardous, or costly situations that would be impractical or unsafe to replicate physically. For example, trainees can practice pest and disease intervention strategies, respond to extreme weather events, or troubleshoot mechanical failures within virtual environments, thereby developing adaptive problem-solving skills (Liang et al., 2020). Such exercises not only enhance technical proficiency but also cultivate decision-making capacity and situational awareness essential for modern, technology-driven farming.

Beyond individual instruction, VR facilitates collaborative learning, allowing multiple users to inhabit the same virtual space simultaneously, thereby promoting teamwork, communication, and coordinated execution of farm tasks (Smith & Tan, 2022). A group of students might jointly plan and implement a planting schedule or conduct a virtual livestock health evaluation, mirroring real-world farm team dynamics. This collaborative dimension proves especially valuable in vocational programs, university courses, and extension initiatives where group-based farm management is paramount.

Recent research underscores VR's effectiveness in agricultural education. Hurst (2021) found that learners utilizing VR-based tools exhibited superior retention of procedural knowledge and faster skill acquisition relative to conventional methods. Similarly, Kanivets (2025) emphasized that VR enhances engagement and motivation, rendering agricultural education more attractive to digitally literate younger generations. VR has been successfully deployed across numerous domains including crop management, soil analysis, irrigation design, greenhouse operations, and animal husbandry attesting to its versatility and scalability.

2.2 Augmented Reality (AR)

Augmented Reality (AR) is a state-of-the-art technology that enriches real-world environments by superimposing digital content such as graphics, animations, text, or real-time data onto physical surroundings (Namkoong & Lee, 2023; Billinghurst & Duenser, 2012). Unlike VR, which submerges users in a wholly simulated realm, AR enables simultaneous interaction with both tangible objects and digital information. This integration yields a seamless blend of virtual and physical experiences, rendering AR especially suitable for agricultural training, where precision, real-time feedback, and contextual learning are critical.

AR can be accessed via smartphones, tablets, AR-enabled smart glasses, or head-mounted displays. These devices capture the physical environment through cameras or sensors, process the input in real time, and overlay digital enhancements that inform, guide, or instruct the user (Azuma, 1997; Dünser et al., 2012). For instance, an AR crop-monitoring application might display soil moisture levels, nutrient status, or pest infestation data directly onto a farmer's view of the field, enabling immediate interpretation and intervention. Similarly, AR-guided equipment repair can highlight specific components requiring attention, provide step-by-step instructions, and flag potential hazards, thereby improving accuracy and reducing errors.

In agricultural education, AR proves especially effective for tasks demanding high precision and contextual awareness. Soil testing, for example, can be augmented with applications that overlay nutrient concentrations, pH readings, or fertilizer recommendations onto real-time images of soil samples (Liarokapis et al., 2017). Pest and disease identification similarly benefits from AR, as learners can view virtual markers indicating affected areas alongside integrated pest management suggestions. In greenhouse or controlled-environment farming, AR can guide adjustments to temperature, humidity, or irrigation by displaying digital metrics and recommendations overlaid on the actual setting.

AR also fosters interactive, experiential learning through immediate feedback and contextual direction. This real-time support reduces the trial-and-error approach that often leads to errors in practical tasks (Martínez et al., 2021). For example, during pruning or grafting exercises, an AR application can indicate optimal cutting angles, distances, or pressure, enabling learners to refine their technique without jeopardizing plant health. By linking theory directly to observable practice, AR enhances knowledge retention, builds confidence, and accelerates skill acquisition.

Another significant advantage of AR is its potential to facilitate collaborative and remote learning. Multiple users can share the same augmented view of a farm or laboratory, allowing instructors to provide distance guidance or enabling teams to collectively perform tasks such as crop assessment, irrigation scheduling, or livestock health monitoring (Sotiriou et al., 2020). This collaborative feature makes AR highly suitable for extension services, vocational programs, and university-level courses, bridging gaps between urban educational centers and rural farming communities.

Research demonstrates that AR improves learner engagement and task performance across various agricultural domains. Namkoong and Lee (2023) reported that AR-based training increased accuracy in soil analysis and equipment handling by over 30% relative to conventional methods. Similarly, Dünser et al. (2012) emphasized that AR applications promote active learning, problem-solving, and critical thinking by creating interactive, context-rich environments. AR also offers scalability; once developed, applications can be widely distributed across educational institutions, extension programs, and farming cooperatives, delivering consistent, high-quality training without requiring costly infrastructure or repeated in-person instruction.

2.3 Agricultural Training

Agricultural training encompasses structured programs aimed at developing the knowledge, skills, and competencies necessary for efficient and sustainable farming practices. Such initiatives prepare learners to manage diverse activities, including crop production, livestock management, mechanization, irrigation systems, agribusiness, and climate-smart agriculture (FAO, 2021; Ozor & AI4AFS, 2025). Training is delivered through various channels, including universities, vocational centers, research institutes, extension agencies, and private organizations.

Traditionally, agricultural training has relied on classroom lectures, demonstration plots, seasonal farm visits, and apprenticeship models. While these approaches impart foundational knowledge, they often suffer from limitations related to accessibility, seasonal dependency, risk exposure, and the availability of modern equipment (World Bank, 2022). Moreover, as agriculture becomes increasingly technology-driven incorporating precision tools, smart machinery, and data analytics there is a growing need for programs that integrate practical experience with digital tools to enhance skill acquisition and decision-making (Hurst, 2021).

Modern agricultural training emphasizes not only technical proficiency but also problem-solving, critical thinking, and adaptive capacity to address challenges such as climate variability, pest outbreaks, and resource constraints. Incorporating digital technologies like VR and AR into training programs overcomes many traditional limitations, offering immersive, interactive, and context-specific learning opportunities.

2.3.1 Applications of VR in Agricultural Training

Virtual Reality provides immersive, simulated environments where learners can practice agricultural operations safely and repeatedly. VR applications have been widely adopted in universities, vocational schools, and research institutions due to their ability to bridge theoretical knowledge and practical competence (Kanivets, 2025). Key applications include:

2.3.1.1 Farm Machinery Operation

VR simulators can replicate tractors, harvesters, sprayers, seeders, and other equipment, enabling trainees to master controls, practice field operations, and improve efficiency without accident or crop damage risks (Liang et al., 2020). VR-based machinery training also reduces fuel consumption, maintenance costs, and wear associated with live operations. Trainees can repeatedly practice complex maneuvers, emergency procedures, and coordinated team activities in a controlled, risk-free environment. Such simulators are increasingly employed in agricultural colleges worldwide to enhance hands-on competency in mechanized farming (Smith & Tan, 2022).

2.3.1.2 Livestock Management

VR applications enable students to simulate animal housing, feeding, breeding, and veterinary procedures, allowing practice of proper welfare techniques, disease diagnosis, safe handling, and reproductive management without subjecting live animals to stress or injury (Hurst, 2021). For example, VR can simulate a dairy farm environment where students practice milking routines, vaccination schedules, and disease containment protocols, developing practical skills prior to interacting with real livestock.

2.3.1.3 Crop Production Training

VR can create interactive farm landscapes to simulate planting schedules, irrigation management, fertilization, pest identification, and harvesting techniques. By replicating complete crop cycles virtually, learners gain exposure to seasonal farming activities year-round, independent of weather or crop availability (Ozor & AI4AFS, 2025). Such simulations also allow experimentation with various crop management strategies and adaptive responses to biotic or abiotic stresses, enhancing decision-making capabilities.

2.3.1.4 Safety, Hazard Awareness, and Climate-Smart Simulations

VR environments can replicate hazardous scenarios such as machinery accidents, chemical exposure, or extreme weather events allowing learners to practice risk management and emergency response safely (Zhou et al., 2022). Additionally, VR can simulate climate-smart agriculture techniques by demonstrating the impacts of soil erosion, drought, or flooding on crops, enabling trainees to develop adaptive management strategies. This experiential learning improves preparedness, resilience, and situational awareness in agricultural operations.

2.4 Applications of AR in Agricultural Training

Augmented Reality overlays digital information onto real-world environments, enhancing learning through contextual guidance and interactive feedback. AR applications prove particularly useful in field-based learning, diagnostics, precision agriculture, and classroom visualization (Namkoong & Lee, 2023). Key applications include:

2.4.1 Field Demonstrations

AR enriches field-based learning by projecting digital information directly onto crops or soil surfaces. Trainees can visualize growth stages, nutrient levels, irrigation requirements, and pest infestations within the actual field environment, enabling precise interventions and deepening their understanding of crop physiology (Martínez et al., 2021). AR-enabled smartphones or tablets guide learners through sequential field activities, effectively bridging theoretical knowledge with practical application.

2.4.2 Crop and Livestock Diagnostics

AR-based diagnostic tools empower learners to identify plant diseases, detect nutrient deficiencies, monitor livestock health, and recognize invasive weed species in real time. Visual overlays deliver stepwise instructions, recommended treatments, or preventive measures, thereby reducing diagnostic errors and enhancing learning outcomes (Sotiriou et al., 2020). This real-time, context-specific guidance fosters accurate decision-making and robust skill development in agricultural management.

2.4.3 Operation Manuals, Maintenance, and Precision Agriculture

AR can display animated, interactive guides for machinery operation, maintenance, and repair. When integrated with Internet of Things (IoT) devices, GPS, and drone data, AR provides real-time insights on yield monitoring, soil moisture levels, fertilizer application, and weather conditions, thereby supporting precision agriculture practices (Namkoong & Lee, 2023). This synthesis of digital overlays and real-world observation enhances accuracy, efficiency, and informed decision-making in farm operations.

2.4.4 Interactive Classroom Models

AR transforms traditional two-dimensional educational content into interactive three-dimensional models of plant anatomy, soil profiles, animal physiology, and machinery components. Learners can rotate, zoom, and manipulate virtual objects, thereby improving spatial understanding and retention of complex concepts (Billinghurst & Duenser, 2012). Such models render classroom learning more engaging and complement field-based or virtual simulations to create a holistic agricultural training experience.

3.0 Benefits, Challenges, and Future Prospects

Benefits: VR and AR improve experiential learning, cost-efficiency, knowledge retention, and safety, while providing access to rare scenarios such as droughts or pest outbreaks (Chatterjee, 2024; Sharma & Patel, 2020).

Challenges: High device costs, technological limitations, limited locally relevant content, user health concerns, and resistance to adoption remain significant barriers (Hurst, 2021; Namkoong & Lee, 2023).

Future Prospects: Artificial intelligence integration, IoT synergy, local content development, and virtual agricultural universities promise personalized, globally accessible training (Iacopo & Bernetti, 2024; Ario et al., 2025).

4.0 Materials and Methods

4.1 The Study Area

The study was conducted at Adamawa State College of Education Hong, specifically within the Information Communication Technology (ICT) School of Undergraduate Studies. Hong Local Government Area is situated between Latitudes 10°23' and 10°28'N and Longitudes 12°48' and 13°00'E (Latur, 2002). Hong lies at an elevation of 304–400 meters above sea level (Adebayo & Tukur, 1999).

4.2 Research Design

The data obtained were analyzed using descriptive statistics, including frequency counts, means, and percentages. This method was selected because it enables systematic and accurate derivation of the desired results.

4.3 Instruments Used

A total of sixteen (16) academic sources comprising peer-reviewed journal articles, institutional reports, conference proceedings, and postgraduate research works were reviewed. Additionally, one hundred (100) questionnaires were administered. These materials were sourced primarily from Google Scholar and reputable academic databases including Springer Link, Science Direct, IEEE Xplore, MDPI, FAO, and the World Bank repositories.

4.4 Method of Data Collection

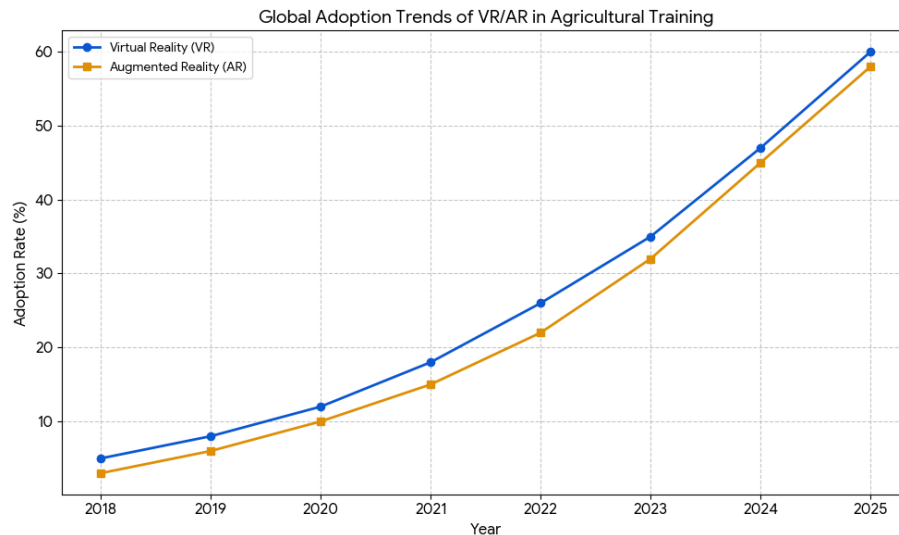
Multi-stage and simple random sampling techniques were employed in the study. From each of the five reputable databases Springer Link, Science Direct, IEEE Xplore, MDPI, FAO, and the World Bank repositories relevant materials were extracted. Each questionnaire contained 20 questions. The sample size was 80, determined using Krejcie and Morgan's (1970) formula (see Appendix 1).

4.5 Data Analysis

The data obtained were collected, coded, and analyzed using the Statistical Package for Social Sciences (SPSS) version 20.0. To test the hypothesis, a t-test was employed, as it is considered the appropriate method for comparing means of two different groups subjected to the same conditions.

5.0 Results and Discussion

Figure 1



Source: Field survey, 2025

Global adoption trends for Virtual Reality (VR) and Augmented Reality (AR) in agricultural training from 2018 to 2025 are as follows: In 2018, adoption rates stood at 6% for VR and 3% for AR. By 2019, these figures rose to 8% and 6%, respectively. In 2020, adoption increased to 12% (VR) and 8% (AR). The upward trajectory continued in 2021 with rates of 18% and 14%, respectively, followed by 2022 at 26% and 22%, and 2023 at 34% and 32%. In 2024, global adoption reached 48% for VR and 46% for AR, culminating in 2025 with rates of 60% and 58%, respectively.

Figure 2



The impact of Virtual Reality and Augmented Reality on agricultural training, as depicted in Figure II, reveals the following improvement scores: training safety recorded 86%, operational efficiency achieved 84%, while knowledge retention registered 83%. Accessibility of VR and AR recorded an impact improvement score of 67%.

6.0 Summary, Conclusions, and Recommendations

6.1 Summary

This study examined the role of Virtual Reality (VR) and Augmented Reality (AR) in agricultural training, focusing on their concepts, applications, benefits, challenges, and future prospects. The review established that modern agriculture increasingly demands advanced technical knowledge and practical competencies that conventional training methods alone are often unable to provide. Virtual Reality offers immersive and risk-free simulation environments for farm machinery operation, livestock management, crop production, and climate-smart agricultural practices, thereby strengthening experiential learning and improving skill retention. Augmented Reality complements this approach by integrating digital information with real-world farm environments, enhancing precision, contextual understanding, and real-time decision-making. The study further revealed that VR and AR technologies improve accessibility to agricultural training, enhance learner engagement, promote safety, and reduce training costs, particularly in regions where access to modern agricultural equipment and facilities is limited. These technologies also support continuous learning and adaptation by enabling learners and farmers to update their skills in response to emerging agricultural challenges and innovations. Despite these benefits, the adoption of VR and AR in agricultural training remains constrained by high initial investment costs, inadequate digital infrastructure, limited technical capacity, and low awareness, especially in developing countries. Overall, the study concludes that VR and AR possess strong potential to transform agricultural training systems and contribute meaningfully to sustainable agricultural development when effectively integrated into education and extension frameworks.

6.2 Conclusion

VR and AR technologies represent a modern, practical, and technology-driven approach to agricultural training. They enhance visualization, decision-making, safety, and learner engagement while reducing dependency on physical resources. Despite persistent challenges, continued technological advancement and increasing affordability will render VR and AR integral to mainstream agricultural education.

6.3 Recommendations

Based on the findings of this study, the following recommendations are made:

1. Governments should invest in improving rural digital infrastructure, including reliable internet connectivity and stable power supply, to facilitate the effective deployment of VR and AR technologies in agricultural training and extension services.
2. Agricultural training institutions, universities, and vocational centers should integrate VR and AR tools into their curricula to complement traditional teaching methods and strengthen practical skill acquisition.
3. Public and private sector partnerships should be promoted to develop affordable, locally relevant VR and AR training content tailored to specific agricultural systems, crops, livestock enterprises, and agro-ecological zones.
4. Capacity-building programs should be implemented to train educators, extension agents, and farmers on the effective use and maintenance of VR and AR technologies.
5. Research institutions should conduct empirical studies to evaluate the cost-effectiveness, scalability, and long-term impacts of VR and AR adoption in agricultural training.

Policymakers and development partners should support pilot projects and demonstration programs that showcase the practical benefits of immersive technologies, thereby increasing awareness, acceptance, and adoption among agricultural stakeholders.

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