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Role of digital technologies in agriculture sector and the constraints being confronted by the farmers in Punjab, Pakistan

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Abstract
Precision agriculture, incorporating elements such as real-time data collection, Internet of Things (IoT), sensors, predictive modelling, and digital farm data, has been viewed as a positive step towards improving farm process efficiency. But this idea is limited to farming, but the current paradigm has to cover the entirety of the food chain. A new paradigm in the entire food systems cycle is expected to be established in India by digital agriculture, also known as Agriculture 4.0. Digital agriculture is an evolution of precision agriculture. It makes use of robotics, satellites, artificial intelligence (AI), big data, sensors, and the Internet of Things. The industries that make up the majority of the country's GDP, industry and services, have made great strides in utilising digital technologies, whereas agriculture has not kept up. Better crop varieties, sound agronomic methods, effective livestock management, agricultural finance and marketing, processing, value chain management, and the creation of "Block Chains" for traceability have all benefited from the advancement of digital technologies. Agriculture should take a cue from other industries and priorities "good data" above "big data." Among the many digital gadgets with a tendency towards extreme usage, smartphones and the internet were used to a great degree. In conjunction with sensors, solar pumps were highly utilized. Drones and energy-efficient tractors, however, were not as useful. The primary obstacles to using digital tools were their high cost, the fact that the costs of technology outweigh the advantages to the economy, a lack of ownership, a lack of knowledge, a lackluster education, a lack of credibility, etc.

Keywords: Digital technologies, agriculture, precision farming, high yield, rural development

1. Introductions

1.1. Digital technologies in agriculture

Agriculture is seeing fast and varied advancements in the digitalization of operations and operational infrastructure, much like many other industries. As a result, farmers in western and mid-European regions have greater access to digital applications and precision agriculture (PA) technologies. In order to help practitioners make better decisions and to enable site-specific and more effective operations in crop and livestock farming, a wide range of technologies are available (Paustian and Theuvsen, 2017) [56].

There are two categories for ICTs: traditional and modern technology. According to Ejembi *et al.* (2006) [21], some examples of conventional technologies are radio, audio/video cassettes, television, fixed line phones, fax machines, and CDs. As stated by Butt *et al.* (2017), modern ICTs, on the other hand, comprise wireless technologies, cellular phones, computers, the internet, Geographic Information Systems (GIS), Global Positioning System (GPS), and other technologies related to data processing. Communication patterns have fundamentally changed as a result of contemporary ICT approaches.

According to Oyeyinka and Bello (2013) [55], ICT's accelerate economic growth, lessen poverty, support sustainable micro-development, and enhance the standard of living in rural areas, especially in emerging nations. They came to the conclusion that 63.30% of respondents used ICTs to obtain price-related information and 81.30% of respondents used them to obtain sales. Ganeshagouda *et al.* (2013) [25] stated that small farmers with modest land holdings are highly interested in current knowledge, production growth, and maximizing their earnings in order to improve living circumstances in their communities. Furthermore, they discovered that a substantial portion of respondents (96.36%) expressed

satisfaction with modern agricultural communication methods.

According to Danso-Abbeam *et al*. (2018) [16], a new era of agricultural extension services has been brought about by the widespread use of digital technology including cellphones, the internet, data analytics, and sensor-based devices. Real-time communication, data-driven decision-making, and access to a wealth of agricultural information have all been made possible by these technologies. With so many tools and apps at their disposal, farmers, extension agents, and policymakers may now make well-informed decisions that will boost agricultural productivity and sustainability. Furthermore, prompt employment and the supply of sufficient logistics need to enhance the provision of agricultural extension services.

Bolfe *et al*. (2020) [9] concluded that major technological breakthroughs in the field include precision agriculture, automation and robotics, livestock technology, current greenhouse practices, indoor vertical farming, artificial intelligence, and blockchain. According to them, almost 64.7% of farmers responded that their production increased by the involvement of digital technologies in agriculture, 62.7% responded that it made marketing and better planning of the daily activities of the property easier than before.

Pivoto *et al*. (2019) [57] concluded that the use of digital technologies in production leads to positive dynamics for labor productivity (average growth of 45-55%), a 10-40% decrease in maintenance costs and a 30-50% decrease in equipment downtime for production equipment, a 10-20% increase in quality indicators, and a 20-50% decrease in warehousing costs. It has been demonstrated that ideas commercialize between 20 and 50 percent faster, and sales predictions are more accurate than 85 percent of the time. They discovered that the primary driver of adoption, cited by almost 69% of the respondents, was enhanced productivity. Bolfe *et al.* (2020) [9], also concluded that vertical farming inside offers the ability to reduce supply chain lengths, alleviate land constraints, and boost agricultural yields. Up to 70% less water is used by vertical farms than by standard ones.

The digital technologies have the potential to transform a variety of smallholder farming tasks, including marketing food and managing postharvest activities, procuring inputs, managing crops, harvesting, and managing land. In terms of smallholder farming, digitalization services might encompass anything from basic cell phone consultations between farmers and specialists to advanced farm management employing drones and satellites. The use of smart technologies in smallholder farmers' farming operations can enhance operations by giving them access to crucial information, increasing productivity, and streamlining processes (Mukhamedova *et al*., 2022) [47].

According to projections from Brazil's Ministry of Agriculture, Livestock, and Supply, grain production could increase by 26.9%, or 2.4% annually, from the current 250.9 million tonnes in 2019/2020 (65.6 million hectares) to 318.3 million tonnes in the 2029/2030 harvest (76.4 million hectares). According to predictions, the output of meat (beef, pork, and poultry) should increase by 23.8% during the next ten years, from 28.2 million tonnes to 34.9 million tonnes. Brazil can meet or surpass these targets through precision agriculture and the digital revolution that has taken place in rural areas, solidifying the nation's standing as one of the global leaders in food production and export, founded on higher productivity and the sustainable use of natural resources (Cambra Baseca *et al*., 2019) [12].

Approximately 33% of the world's food supply - worth $940 billion USD annually - is wasted or lost. Digitalization can lower these losses by 25-30%, boost agricultural businesses' profitability and investment appeal, and take control of two thirds of the key variables influencing production. With an integrated strategy, the implementation of digital economy technologies will have economic consequences and save expenses by at least 23%, according to the Russian Ministry of Agriculture's Analytical Centre (Presentation of the Ministry of Agriculture of Russia, 2018) [58].

Molony (2008) [44] makes the case, drawing on instances from Tanzania, that producers' capacity to use price information may be constrained by their ties to specific middlemen and their reliance on them for loans. Knowing the market price does not benefit them because they are unable to trade with someone else if they are unhappy with the price they are offered. These findings imply that the advantages of knowledge for farmers differ based on the options at their disposal. It is becoming simpler to furnish farmers with precise, (close) continuous cost data to help them in pursuing the best showcasing choices, because of the quick expansion in cell phone proprietorship and inclusion in emerging countries. Nonetheless, to make such imaginative projects, it is essential to painstakingly think about the different promoting establishments, the idea of interconnected exchanges among purchasers and dealers, and the wide assortment of harvests.

2. Adoption of digital technologies

Germany, France, the Netherlands, and the United Kingdom currently have the greatest rates of digital agricultural technology use in Europe (Maloku, 2020) [37]. Kernecker *et al*. (2020) [30] showed that crop farming in the US, Australia, and South America uses digital technologies at a considerably higher rate than in Europe based on a twenty-year examination of adoption studies. Over the past 20 years, adoption rate percentages in Europe have usually been in the single or low double digits, depending on the technology. Adoption rates for GNSS-guided light bar systems, for instance, have been reported to reach 20% in the UK, yield mapping, in Germany and variable-rate fertilizer treatments, in Germany, to reach 12%.

Sala, (2020) [64] concluded that top among the digital technologies transforming agriculture are mobile phones. Of all the technologies created in the past century, their adoption rates are the highest. Approximately 5.2 billion individuals, or two thirds of the global population, were active mobile phone users as of 2019. With 49% of people worldwide having used a mobile device to access the internet, mobile internet usage is also increasing. Just 9% of the worldwide people lives past the inclusion region of a portable organization. Cell phones have modified the existences of numerous provincial individuals, especially limited scope farmers. Indeed, even without admittance to versatile web, farmers can in any case get arrangements, for example, warning administrations that give ideas to expanding yields, keeping up with the soundness of domesticated animals, and current climate data. Through cell phone applications that can distinguish crop issues and recommend medicines for various bugs, diseases, and healthful shortages, farmers could in fact approach a more prominent scope of cutting edge choices. Gabriel and

Gandorfer, (2022) [23] found that forecast models and apps and online communication and trading platforms had highest adoption rate of 23 and 38%, respectively.

Connecting farmers to markets and vital points in the value chain has been made possible by digital technologies. According to a recent survey of farmers in Bangladesh, China, India, and Vietnam, 80% of them had a cell phone and utilized it to communicate with brokers and dealers to gauge the size of the market and the price at which they should sell their produce (Reardon *et al.* 2012) [60]. For sales, over half of these farmers would use the phone to organize deals.

A 2017 survey of 127 wine technicians (i.e., consultants) in France revealed wildly disparate levels of technology use: over 100% of laptop computers, 80% of smartphones, around 75-80% of field- or soil-based sensors, nearly 60% of GPS units, and roughly 40% of portable or on-board measurement equipment were used. While soil and yield mapping are widespread practices in Australian viticulture, there has been very little adoption of digital tools among Australian vegetable growers (Suarez, 2018) [69].

According to Michels *et al*. (2019) [41], there is a growing number of smartphone applications available to help farmers make better decisions. Among farmers, 95% already use a smartphone, and 71% of them have specific applications that help with pest and disease detection and prediction as well as information about a particular culture.

According to Bolfe *et al*. (2020) [9], 84.1% of farmers employed one of the technologies, while 15.9% of farmers said they still do not use any of these. Global positioning systems (20.4%) and mobile applications, digital platforms, and software for obtaining general information are among the technologies used, which include internet access and connectivity (70.4%).

3. Debates on effectiveness of various digital tools

3.1. ICT's: Digital technologies for information creation, acquisition, processing, storing, sharing, and using are known as ICTs (Tiamiyu, 2002) [71]. Zappacosta (2001) [73] defined ICTs as electronic and digital means of gathering, distributing, analysing, retrieving, and storing data for use in broadcasting through a variety of media, including radio, television, fax machines, email, and web-based networks and connections. ICTs offer useful methods for distributing agricultural knowledge to rural periphery. To increase agricultural output, the farmers in these peripheries require precise, genuine, comprehensive, succinct, and dynamic agricultural information (Nkwocha *et al*., 2009) [53]. Small-scale farmers encounter a huge information gap that makes it difficult for them to implement effective agricultural techniques (Syngenta Foundation, 2011) [70]. The most practical way to slake farmers' desire for current information and close the knowledge gap among them is to employ modern, updated information and communication technologies.

Miller *et al*. (2013) [42] found that increasing agricultural production, food security, profitability, and employment possibilities has been achieved by connecting farmers with knowledge banks, institutions, and networks via modern information communication technology. Furthermore, in order to create a "community of practice," the contemporary system can connect development professionals with international organisations and give essential agricultural information to interested parties.

For example, a number of organisations have created applications to help farmers raise agricultural yields, offer financial services, and share information about market prices. Moreover, it was believed that the primary forces behind the expansion of the Dutch agro industry would be agro-knowledge, ICT, and data accessibility (Anil, 2008) [6].

According to Aina (2004), farmers' needs for agricultural information differ according to their unique circumstances. A rise in agricultural output and revenue is unattainable without suitable instruments that align with farmers' requirements.

Information must be readily available in a timely manner in order to conduct managerial tasks including organising, leading, regulating, and planning effectively (Rodriguez, 2008). ICTs typically help farmers increase productivity and reach greater levels of sustainability, income, and output. Without the use of suitable instruments that are in line with farmers' demands and efficient agricultural extension services, it is not feasible (Anil, 2008) [6]. Common instances of extension tactics implemented over time are numerous (Akubuilo, 2009) [5]. The extension sector works hard to make sure that farmers receive agricultural information in an efficient manner, which is important for increasing agricultural output. ICT offered a number of possible uses in agricultural extension for this reason, enabling the introduction of new services.

According to Bolarinwa and Oyeyinka (2011) [8], integrating ICT tools into extension work will facilitate the rapid sharing of a variety of information. ICTs give users easy-to-understand ways to access information. According to Isiaka *et al*. (2009) [27], extension workers were taking advantage of ICTs' potential to support the delivery of extension services, and about 88.5% of them were aware of these technologies' potential (Adebayo and Adesope, 2007) [1].

According to Salau and Saingbe (2008), 56.22% of the extension agents used ICTs, such as TV, mobile phones, radios, the internet, etc. Along with using traditional sources, extension agents in the Caribbean enhanced their professional output by utilising ICTs for personal gain. However, Lasley *et al*. (2010) [34] explained that ICTs might take the place of conventional information exchange systems and could be useful in changing the function of extension agents in the agricultural system.

According to Jensen (2007) [28], the use of mobile phones by farmers to obtain information seems to help in lowering price dispersion and maintaining a fixed price. It also shown the usefulness of mobile phones in post-harvest management. Extension agents encouraged farmers to use ICTs, and they distributed up-to-date market-related information on subscribers' phones (Aker, 2008) [4].

According to Mtega and Msungu (2013) [45], infrastructure improvements and cell phone services also enabled extension agents to inexpensively share educational opportunities with farmers.

Finally, the informational responsibilities of ICTs and the majority of digital technologies have the power to change agriculture and offer advantages. The potential of e-commerce platforms to assist in connecting farmers with markets, meteorological data, insurance companies, and input suppliers is typified in this argument (Deichmann *et al*., 2016) [18].

For many years, the Internet has been viewed as a growth engine for the economy. Internet technology has a beneficial or negative impact on economic growth, according to earlier

research. One of the more important results of information and communication technology (ICT) is the creation of the Internet (Maurseth, 2018) [38]. In terms of user numbers, infrastructure, and security, the nations with the most Internet access, according to World Bank (2022), are also the most developed. One of the primary tools for improving and sustaining agricultural productivity may be the Internet. Additionally, we discovered that there are a number of Internet-based applications in the field of agriculture, including productivity-boosting Internet of Things (IoT) apps. Agricultural food products can be traced using empirical applications. Additionally, an Internet-based decision support system enhances the agriculture industry (Rehman *et al*., 2022) [61].

3.2. Drones

Drones may be capable of autonomous operation with specialist software. Flight planning, GPS system deployment, and the input of various parameters - such as altitude, speed, ROI (Region of Interest), geofence, and fail-safe modes - are all made possible by this software. There are several reasons why drones are preferred over full-sized aircraft, such as their simple triggering mechanism, inexpensive operation, superior spatial resolution, and fast response times. In precision agriculture, large regions need to be watched and analysis needs to be finished as quickly as possible. In agriculture, drones are used to assess and monitor plant stresses such as pests, diseases, drought, weeds, and nutritional deficiencies (Dash *et al*., 2018) [17].

Drones will assist farmers with acquiring information about their homesteads. Farmers will subsequently be helped with creating more food with less synthetics. Essentially all farmers who have utilized drones have encountered an increase of some kind or another. By observing flames before they spread, improving water system for plants under heat pressure, altering soil quality to advance improvement in tricky locales, and disposing of vermin before they obliterate whole yields, they might have the option to capably deal with their property more. Drones could therefore play a significant role in agriculture in the future by assisting farmers in more sustainable and effective management of their farms and resources (Dutta and Goswami, 2020) [20].

Promising novel methods with benefits for resilience and sustainability have been identified by an expanding body of literature on precision pest management in speciality crops. Among the most modern digital instruments used by farmers in integrated pest management are reflectance-based crop monitoring systems that use remote sensing and precision pest control systems (such as natural enemy dispersion and chemical spray rigs). Drones can be used to deploy both systems, which might help reduce the need for pesticides by preventing insect outbreaks (Khujamatov *et al*., 2021) [32].

Drone assisted spraying works well for treating troublesome foci in the fields or small areas. A preliminary flight using a drone equipped with a camera is utilized to locate issue regions. It is useful to utilize drones in tandem with many units at the same time for continuous processing of big fields. One device can process up to 80 hectares of land each day with high productivity. Up to the bush, the drone can observe weeds in the field and can even identify different kinds of them. After that, information about their overall number is added to the database, which is then fed into the drone's "brain." Chemicals are introduced pointwise via the sprayer. Fertilizer and costly medication use are both decreased by 25-35% (Ghazali *et al*., 2022) [26].

Due of its greater application rates, drone fertilization is less common than the processing of pesticides. Applying micro fertilizers using drones is a successful method. In order to create maps of differentiated applicability, it is also required to perform an initial examination of the field on huge territories. Given that using drones on a constant basis is not advised. One drone may apply fertilizer to up to 50 hectares of land each day (Zhichkina *et al*., 2020) [75]. When used in conjunction with the same machinery (tractors, seeders, and combines), an unmanned complex can result in yield increases of up to 20% and cost reductions of up to 15%. The precise processing and lack of overlap during the preparation of plant protection chemicals result in an improvement in production. Furthermore, 3-6% of the field's total seeded area perishes beneath the wheels of wheeled vehicles, according scientific research (Zhichkin *et al*., 2023) [74].

3.3. Energy efficient tractors

The primary power plants in agricultural vehicles are tractors. The traction resistance varies often, the operational modes must be switched frequently, and the working conditions are complicated. Consequently, when the conventional tractor power system is in operation, the engine load rate is low and the engine power cannot be fully utilized. By including a motor, the hybrid system can increase the engine's operating area and boost the effectiveness of energy use. Thus, researching the use of hybrid technology in tractors to create a hybrid tractor power system is crucial for enhancing tractor fuel efficiency and lowering exhaust emissions, as well as for protecting the environment and energy conservation (Zhu *et al*., 2022) [76].

The electrification of road vehicles demonstrates that hybrid systems, which can significantly lower fuel consumption and enhance vehicle performance, also require the utilization of battery energy to help the engine operate at high loads and reserve engine power to charge the battery at low loads. This is also true for tractors. In majority of the examined characteristics, the tractor with Full Powershift (FPS) gearbox was more energy-efficient; it required 16.31% less fuel per hour and produced 16.29% more traction bar yield (Neto *et al*., 2022) [51].

3.4. Solar powered pumps

Many rural farming communities now want to use solar energy as their primary source of electricity. Farmers can increase their long-term profitability by using solar panels to lower their operating expenses related to power. By purchasing a solar energy system up front, farms that raise livestock or produce crops for medium- to large-scale commercial distribution can reduce labour and administrative costs over time. The use of solar irrigation as a tool for adaptation to climatic uncertainties, as well as for potential mitigation, has made it a component of the climate change agenda. Given the connection of the energy-groundwater nexus and unreasonable motivating forces connected with petroleum derivative endowments, the change of a sizable number of diesel and electric siphons into sun oriented fueled frameworks in South Asia proclaims a twofold success in diminishing fossil fuel

byproducts and the monetary weight (Caretta *et al*., 2022) [13].

With extremely little maintenance required, the solar tube well will continue to produce for the next ten years. The solar tube well also emits no harmful gases and produces no noise pollution, making it environmentally benign. This explains why solar tube wells are becoming a more desirable and cost-effective piece of equipment for irrigation systems and agriculture. It is considerably more beneficial to the environment and appropriate for farmers to employ in the future to maintain the agricultural environment and global sustainability (Bukhari *et al*., 2023) [10].

Users' lower watering expenses are the initial adaptive co-benefit of SIPs. Purchasing water from SIPs is 20%-30% less expensive than purchasing it from diesel pumps. Labour cost and time savings make up the second co-benefit. The expense of utilising a diesel pump to irrigate plots in Bangladesh is significant since it needs to be purchased, the pump needs to be transported and installed, irrigation delivery needs to be monitored, and the pump needs to be turned off when enough water is provided. Expenses like the opportunity cost of missed earnings or the salary paid to hired labour may arise from this. The fee-for-service concept, on the other hand, entails paying a pump operator to run the pump and guarantee a sufficient supply of water (Mitra *et al*., 2024) [43].

3.5. Leverage sensors

A sensor is an apparatus or tool intended to measure and identify physical characteristics, environmental factors, or alterations in its environment; it then transforms this information into signals or data that may be deciphered, shown, or used in a variety of ways. Sensors are a fundamental component of many technological systems and are used in a wide range of applications across various industries. They play a crucial role in gathering data for monitoring, control, automation, and analysis in fields such as electronics, robotics, automotive, healthcare, environmental monitoring, agriculture, and more. They empower the improvement of a biological system for information assortment and handling about a specific climate, working with simpler and more powerful checking, the executives, and control (Lin *et al*., 2020) [35]. IoT sensors are used in different settings, including houses, fields, vehicles, airplane, and processing plants. As the eyes and ears of a processing framework that deciphers and answers the information accumulated from the sensors, sensors fill the hole between the physical and legitimate universes (Ayaz *et al*., 2019) [7].

Sensors collect data on various environmental factors such as soil moisture, temperature, humidity, and light levels. This data allows farmers and horticulturists to make informed decisions about when and how to plant, irrigate, fertilize, and harvest crop. Soil moisture sensors, combined with weather data, help farmers optimize irrigation schedules. This prevents overwatering or under watering, which can lead to water wastage and crop stress. Sensors can monitor soil nutrient levels, allowing for precise application of fertilizers. This reduces the risk of nutrient runoff into water bodies. By using sensors to monitor environmental conditions, farmers and horticulturists can optimize the use of resources like water, energy, and pesticides. This not only saves money but also reduces the environmental footprint of agriculture (Nayagam *et al*., 2023) [49].

4. Challenges in adoption of digital technologies

Nyaga *et al*. (2021) [54] concluded that, despite the revolutionary promise of smart technology, access to and use of these tools have been inconsistent and delayed for the majority of farmers, especially smallholders in developing nations like sub-Saharan Africa. Numerous factors have contributed to this, including a lack of funding, insufficient government support, inadequate training and education programs, subpar facilities for research and development, collateral challenges, and cultural and social norms that are resistant to or reluctant to adapt to change.

4.1. Lack of digital infrastructure and connectivity

The agriculture industry's digital transformation faces considerable challenges due to inadequate infrastructure in a number of ways, each of which can be important on its own. To begin, farmers might find it hard to secure and utilize advanced innovations, like portable applications and accuracy horticulture gadgets, because of the absence of essential foundation in numerous rustic regions, like power and Web network. On the off chance that clients do not have solid admittance to power and the Web, it is conceivable that advanced innovations will not work to their full limit (Fox and Signé, 2022) [22].

This will result in decreased efficacy and efficiency levels for the technologies. The subsequent concern is the spiraling cost of everything. To exploit advanced innovations, farmers might have to put resources into expensive power generators and satellite web, which might be excessively exorbitant for some limited scale farms. The inability of farmers to save data and retrieve it when needed is the other issue. An insufficient infrastructure for data storage and retrieval may make it difficult for farmers to gather and use data to guide their farming practices, which lowers the effectiveness of digital technologies (Katsikouli *et al*., 2021) [29].

One of the main challenges in fostering success in media-tech scenarios, according to Madichie *et al*. (2021) [36], was the absence of technological infrastructure, which could be connected to low internet penetration rates. In a similar vein, it was discovered that the agri-tech industry encountered issues with infrastructure. Therefore, resolving the infrastructure-related challenges on the continent is crucial to the agricultural industry's effective digital transformation.

4.2. Limited access to technology and digital skills

It's possible that farmers lack the expertise needed to properly use the digital tools at their disposal. Inadequate digital skills and restricted technology availability might pose multiple challenges to the agriculture sector's digital transformation initiatives. Farmers are less likely to embrace and use digital products and services if they lack the requisite skills or have insufficient access to technology (Mhlanga and Mhlanga, 2022) [39].

The spread of digital transformation is likely to slow down where this occurs, lessening its overall impact. The majority of farmers are found in rural locations, and they lack the knowledge and resources to use these technology. The gap between access and adoption is further exacerbated by the possibility that farmers may be unable to successfully use

and benefit from digital technology in the absence of adequate digital expertise and training (Ndhlovu, 2022) [50].
The inability of many African farmers to access technology and possess the requisite digital skills makes it more difficult for them to collect and share data, which impedes the agricultural sector's capacity to progress digital transformation and make data-driven decisions. This is yet another concerning matter. Some farmer groups may benefit more from digital transformation than others due to the uneven distribution of technology and digital skills among farmers, which could maintain current socioeconomic disparities (Steensland and Zeigler, 2021) [68].
However, Kudama *et al*. (2021) [33] discovered that a large percentage of the population lacks digital literacy, that many farmers do not use adaptable tools, that digitalization in agriculture is expensive in the region, and that older and female farmers have lower participation rates due to their lower educational and income levels. Thus, by lowering the overall cost of digital agricultural instruments and offering farmers digital training, Kudama *et al*. (2021) [33] argued that sub-Saharan African nations must invest in technologies that can adapt to the population of interest.

4.3. Limited access to funding for digital initiatives in agriculture

Smallholder farmers may find it difficult to secure funding for investments in digital technology, which makes it challenging for them to enhance their business practices and maintain their competitiveness. Poor monetary access for computerized and innovation combination in agriculture can likewise be a boundary to computerized change in more ways than one, much as restricted admittance to innovations can give various impediments to computerized change. In the event that adequate supporting is not provided, plausible firms and associations in the agribusiness area would not have the option to execute and increase computerized innovation and arrangements. This might thwart the progression of computerized change endeavors (Chandra and Collis, 2021) [14].
It can be challenging for smaller businesses and farmers with limited resources to secure the significant upfront investment required for the adoption of digital technologies and solutions in agriculture. Insufficient finance for digital initiatives may impede the capacity of agriculture sector organisations to engage in research and development activities that promote digital transformation (Saiz-Rubio and Rovira-Más, 2020) [63].
Additionally, this can promote an unhealthy reliance on outside money. Reliance on external funding sources by organisations and firms working in the agriculture sector can also lead to instability and a lack of long-term commitment to digital transformation, as finance objectives and sources may change over time. As a result, limited financial sources may hinder the development, use, and spread of digital technologies and solutions within the industry, delaying the process of digital transformation (Mudzengi *et al*., 2021) [46].

4.4. Data privacy and security concerns

In a largely unregulated digital environment, concerns exist about the degree of security and privacy provided to confidential data. Concerns about security and privacy of data can impede digital transformation in agriculture in a few distinct ways. One of them is the construction of barriers to trust. Concerns regarding the security and privacy of their data may make farmers and organizations in the agriculture sector reluctant to use digital technologies and solutions, which would impede the adoption of digital transformation and lessen its overall impact (Nissenbaum, 2020) [52].
One such issue is that legal and regulatory barriers can exist in some of the countries in Southeast Africa. These are circumstances when organizations operating in the agriculture sector find it challenging to comply with the appropriate legal requirements due to complex and constantly evolving data privacy and security legislation. This, in turn, hinders the speed of digital transformation. Once more, having access to Specialised technological knowledge and resources is essential to safeguarding the safety and privacy of sensitive data in an increasingly digitalized and interconnected society (Agbehadji *et al*., 2021) [2].
For organisations in the agriculture sector, however, that are already working with limited resources, this can be difficult. Finally, companies in the agriculture sector may decide against pursuing digital transformation initiatives due to the significant financial and reputational consequences that data breaches and other security incidents might have. The process of digitally transforming the agricultural industry may be slowed down as a result of these challenges, which may cause people in the sector to have less faith in digital technology and solutions. Organisations in the agriculture industry must prioritise protecting sensitive data as part of their digital transformation efforts in order to address these issues. To guarantee that sensitive data is protected, these organisations must also endeavor to create strong technical and legal frameworks (Mhlanga and Ndhlovu, 2023) [40].

4.5. High cost

Coble *et al*. (2018) [15] report that a significant portion of respondents (66%), identified purchase costs as a hurdle, with connection problems accounting for 69% of the responses. The high percentage indicates challenges with credit acquisition, service value, and availability, which can be mostly attributed to the current situation where the majority of available technologies are imported. It was found that the two most common hurdles and obstacles were 68.5% indicating the value of purchasing machines, equipment, or apps, and 45.3% indicating the value of engaging specialised service providers. Therefore, across all farm sizes, acquisition expenses are regarded as a significant issue or task.

4.6. Education

Nadeem *et al*. (2024) [48] revealed a major importance for education in the adoption of technology, supporting the findings of Strong *et al*. (2014) and Doss and Morris (2014). The adoption of new technologies will increase with education level. Lederer *et al*. (2012) brought attention to the issue of how Ethiopia's use of ICTs is impacted by illiteracy. They believed that a language barrier, or non-native English speakers, was impeding consumers' ability to use ICTs. A person's attitude towards using ICTs changes significantly depending on their educational level.
Khan *et al*. (2012) [31] likewise upheld a solid and ideal connection between's farmers' instructive fulfillment and ICT devices, explicitly television. Sekabira (2012) [67] stressed the worth of training, calling attention to that

through better understanding appreciation, an expansion in instructive fulfillment improved the probability of utilizing ICT by 0.0005 times.

Gagoitsiwe and Keba (2019) [24] cite earlier research showing that individuals with higher levels of education have a tendency to accept new technologies more quickly than those with lower levels of education. This suggests that employees with higher levels of education have longer employment histories utilising computers than do those with lower levels of education, and that education influences the adoption of improved technology and increases the likelihood of employing computers in farms.

4.7. Farmer's profile

These reception factors line up with the difficulties illustrated by Schroeder *et al.* (2021) [66], which focus on factors connected with the farmer's profile (age, instruction, orientation, risk-taking capacity), property qualities (size, type, obligation, level of gift, asset enrichment), social relations (neighborhood societies, social climate, perspectives), support organizations, and the legitimate climate (regulations and guidelines); monetary variables (cost of venture, profit from speculation, and productivity); aspects connected with mechanical framework (convenience, saw handiness, accessibility of specialized help, intricacy of the framework, similarity with different innovations), data on mechanical accessibility (presentations, fairs, courses, and shows), and dec thus, these parts are essential for executing advanced agriculture (Nadeem *et al*., 2024) [48].

5. Conclusion

By boosting production, sustainability, and efficiency, digital technologies in agriculture have the potential to completely change the industry. Precision farming, drones, sensors, and smartphone apps are examples of digital tools that farmers may employ to make data-driven decisions, cut expenses, and increase yields. Nevertheless, a number of obstacles prevent digital technologies from being widely used in agriculture. These include expensive pricing, impediments to education, restricted funding, lack of digital skills, restricted access to digital infrastructure and connectivity, and privacy and security concerns. Similar issues, such as expensive costs, low digital skills, and restricted access to digital infrastructure, affect Punjab, Pakistan's agriculture sector. Digital technology usage in agriculture can assist in addressing these issues and enhancing the sustainability and productivity of the industry.

6. Recommendations

- Making investments in connection and digital infrastructure to guarantee that farmers have access to dependable and reasonably priced internet services.
- Offering programs for capacity-building and training to improve farmers' digital literacy and abilities.
- Providing monetary rewards and financial assistance to entice farmers to implement digital technologies.
- Creating strong legal and regulatory structures to ensure data security and privacy.
- Encouraging the use of digital technologies that are accessible, affordable, and suited to smallholder farmers' requirements.
- Fostering cooperation and information exchange between farmers, scientists, and decision-makers in order to advance the uptake of digital technology.

By implementing these recommendations, Punjab, Pakistan can unlock the potential of digital technologies to transform its agricultural sector and improve the livelihoods of farmers.

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