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Technology as a tool for empowering women farmers in a climate-change scenario

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Abstract
The impact of climate change is reshaping agricultural practices worldwide, disproportionately affecting vulnerable communities, particularly women farmers in developing countries. Women, who constitute a substantial portion of the agricultural workforce, often face barriers such as limited access to resources, education, land ownership and decision-making power. However, technological innovations have the potential to empower women farmers, improving their resilience to climate change, enhancing productivity and promoting sustainability. This review paper explores the role of technology in addressing the unique challenges faced by women farmers in the context of climate change. It examines various technologies, such as mobile apps, remote sensing, precision agriculture and climate-smart practices and their potential to enhance women's access to knowledge, resources and markets. By highlighting case studies from around the world, this article underscores the importance of inclusive technological interventions and the need for gender-sensitive policies to ensure that women farmers benefit from these advancements. The research concludes that technology, when implemented thoughtfully and inclusively, can serve as a powerful tool for women's empowerment, fostering greater economic independence, improved food security and enhanced resilience to climate change.

Keywords: Technology, women farmers, climate change, empowerment, agricultural innovation, resilience, gender equality, sustainable agriculture, mobile apps, precision agriculture

1. Introduction
Climate change presents one of the most significant global challenges, with agricultural communities, especially those in developing countries, bearing the brunt of its impacts. In many of these countries, women constitute a large portion of the agricultural labour force, yet they face numerous obstacles that hinder their ability to adapt to changing environmental conditions [14]. Limited access to education, technology, resources and decision-making processes prevents women from fully benefiting from agricultural innovations that could bolster their productivity and resilience [104, 116]. In this context, technology can act as a powerful tool to empower women farmers, helping them overcome these barriers [32]. By improving access to knowledge, enhancing productivity and facilitating market connections, technology has the potential to transform agriculture, particularly in rural and marginalized communities [43]. This review paper examines the ways in which technology can be used as a tool to empower women farmers in the face of climate change, fostering resilience, improving agricultural practices and promoting gender equality [71].

1.1 The Gendered Impact of Climate Change on Agriculture
Climate change has profound effects on agriculture globally, impacting crop yields, water availability, soil quality and overall food production. While its effects are widespread, they are not felt equally across all sectors of society. Women, particularly in rural and developing areas, face gendered vulnerabilities that make them more susceptible to the adverse impacts of climate change [15]. In the context of agriculture, women are especially affected because of their roles as primary producers, caregivers and managers of household food security.
In this section, we explore the gendered impact of climate change on agriculture, focusing on the

challenges women face and how their experiences differ from those of men. Understanding these disparities is essential for developing targeted interventions that can reduce inequalities and build resilience in agricultural communities [1].

1.1.1 Women's Role in Agriculture

Women play a central role in agricultural production, especially in developing countries. The Food and Agriculture Organization (FAO) estimates that women make up nearly 43% of the agricultural labour force in low-income countries [44]. They are involved in a range of activities, including planting, weeding, harvesting, processing and selling crops. In many parts of the world, women also manage household food production, ensuring food security for their families [33]. Despite their critical role, women farmers often lack the same resources and opportunities as their male counterparts. This includes limited access to land, technology, credit, education and decision-making power. As a result, women are often less able to adopt modern agricultural practices that could help them cope with climate change, which exacerbates gender inequalities in agricultural productivity and resilience [57, 105].

1.2. Increased Vulnerabilities Due to Climate Change

Climate change affects agriculture in multiple ways, including erratic weather patterns, droughts, floods, shifts in planting seasons and the increased frequency of pests and diseases. These changes disproportionately impact women for several reasons:

1. **Unequal Access to Resources:** Women often have less access to land, irrigation systems and financial resources compared to men. In many regions, women do not own the land they farm, which limits their ability to make long-term investments in soil fertility, irrigation systems or climate-resilient crops. Without secure land tenure, women face challenges in implementing adaptive measures like adopting drought-resistant crops or improving soil quality [71].
2. **Time Constraints and Multiple Roles:** Women's roles extend beyond farming; they are also responsible for household chores, child-rearing and care giving for the elderly or ill. These multiple roles reduce the time and energy women can dedicate to agricultural activities, leaving them less able to adapt to changing climate conditions. For example, long hours spent fetching water in areas suffering from drought may take away time from other productive activities [83].
3. **Limited Access to Climate Information:** Access to weather forecasts, agricultural advice and other relevant climate information is crucial for making informed decisions about planting, harvesting and pest control. However, women often have limited access to this information due to social norms, lack of education or restricted access to technology. Without timely information, women are less able to respond to changing weather patterns, such as preparing for floods or droughts [13].
4. **Gendered Economic Barriers:** Climate change has the potential to affect the economic stability of agricultural households. Women, who are typically in charge of household food security, may find it harder to meet the nutritional needs of their families during crop failures or reduced yields. They may also have limited access to credit and markets, which makes it harder to recover from economic losses or invest in climate-resilient practices [84].
5. **Health Risks and Food Security:** Climate change exacerbates health risks in agricultural communities, particularly through the spread of diseases like malaria, cholera and dengue, which are associated with changing precipitation and temperature patterns. Women, who are often the primary caregivers, are on the front lines of responding to health crises. In addition, they are responsible for ensuring the nutritional needs of their families are met, making them more vulnerable to the impacts of reduced food availability [58, 115].
6. **Social and Cultural Barriers:** Social norms and gender roles often restrict women's participation in decision-making processes, both within the household and at the community level. These cultural barriers prevent women from accessing resources, such as land rights, credit or extension services, that would help them adapt to climate change. Women may also be excluded from formal or informal decision-making bodies that influence climate policy, reducing their influence on policies that directly affect them [16].

1.3. Impacts of Climate Change on Women's Livelihoods

Women's livelihoods in agriculture are particularly vulnerable to the impacts of climate change, as they often rely on subsistence farming or smallholder agriculture, which is more susceptible to climate variability. These impacts can manifest in several ways:

1. **Crop Failures and Income Losses:** Climate change is contributing to more frequent and intense droughts, floods and extreme weather events, all of which can result in crop failure and reduced agricultural productivity. For women farmers, these failures directly affect their incomes and food security, as they are often responsible for growing and preparing food for their families. With limited access to alternative income sources, women are more likely to suffer from food insecurity and economic instability [92].
2. **Increased Migration and Displacement:** In areas where agriculture is no longer viable due to changing climate conditions, women may be forced to migrate to urban areas or other regions in search of work. This migration can lead to social dislocation, loss of community support networks and further marginalization. Women who migrate for work often face exploitation and abuse, particularly in low-wage labour sectors [2].
3. **Increased Workload and Stress:** As climate change disrupts traditional agricultural patterns, women may find themselves working longer hours to secure food for their families. This increased workload can result in physical and mental stress, which is compounded by their other caregiving responsibilities. The cumulative stress of climate-related impacts on women's livelihoods can have detrimental effects on their well-being and productivity [59].
4. **Impact on Smallholder Agriculture:** Women smallholder farmers are particularly vulnerable to climate change due to their dependence on rain-fed agriculture. These farmers typically lack the financial resources, technology and support systems needed to adapt to climate variability. As rainfall patterns become more unpredictable, smallholder women farmers are increasingly at risk of crop failure, which undermines their livelihood and overall food security [12, 117].

1.4. Gender Inequality in Climate Adaptation and Mitigation

Climate adaptation and mitigation efforts often fail to address the gender-specific challenges faced by women in agriculture. Many climate policies and programs are designed without considering the differential impacts on men and women, leading to missed opportunities for empowering women and enhancing

their resilience.

1. **Exclusion from Decision-Making:** Women are often excluded from decision-making processes that shape climate adaptation and mitigation strategies. At the household, community and policy levels, men often hold the power to make decisions regarding land use, resource allocation and the adoption of climate-resilient technologies. This exclusion means that women may not benefit from policies and programs that could improve their adaptive capacity [31].
2. **Lack of Gender-Sensitive Climate Policies:** Many climate policies overlook the specific needs and vulnerabilities of women farmers. For example, agricultural extension services, which provide advice on climate-resilient farming practices, are often designed with male farmers in mind and do not account for the gendered division of labour in farming households. As a result, women may not have access to the training and resources they need to adapt to climate change effectively [45].
3. **Gender-Responsive Financing for Adaptation:** Access to finance is critical for adopting climate-smart agricultural practices, such as drought-resistant crops, water-saving technologies and sustainable farming techniques. However, women farmers often lack access to credit and financial services due to gendered barriers, including lack of collateral, legal constraints and discriminatory practices. Without financial resources, women struggle to invest in technologies or practices that could enhance their resilience to climate change [34, 106].

2. Technology as a Catalyst for Change

In the face of climate change, technology has emerged as a crucial tool for addressing the challenges posed to agriculture, particularly for marginalized communities such as women farmers in rural areas [30]. These women, despite their pivotal role in food production, often face barriers such as limited access to resources, education, land ownership and decision-making power [3]. Technology, however, holds the promise of overcoming many of these barriers and empowering women in agriculture. By providing access to crucial information, improving agricultural productivity and enhancing market linkages, technology can act as a catalyst for change, fostering greater resilience to climate change, promoting sustainability and advancing gender equality in farming [72, 118].

2.1. Mobile Technologies and Apps

One of the most transformative technological innovations in agriculture, especially for women farmers, has been the widespread use of mobile technology. Mobile phones have become a vital tool in rural areas, providing access to information, resources and services that were previously unavailable. For women farmers, mobile technology offers numerous advantages, ranging from agricultural advice to financial services [35].

2.1.1 Weather Forecasting and Climate Information: Access to timely and accurate weather forecasts is essential for making informed decisions about planting, irrigation and pest control. Mobile apps that deliver weather information directly to farmers' phones help them plan agricultural activities more effectively [11]. For instance, platforms like Farmers' Hub, WeatherFlow and iFarmer provide real-time weather updates, allowing women to anticipate and mitigate the effects of adverse weather conditions such as droughts or heavy rainfall [73].

2.1.2 Agricultural Advisory Services: Many mobile platforms offer advice on crop management, pest control and sustainable farming practices. For instance, *Digital Green* and *eSagu* provide extension services, delivering expert advice on agricultural practices through videos and mobile messages [46]. Women farmers can access this information on their phones, which helps them make decisions about the best farming techniques, pest management or crop varieties suitable for the changing climate. Mobile platforms can also help women stay informed about the latest research on climate-resilient crops, improving their ability to adapt to climate change [85].

2.1.3 Market Information and Financial Services: In many rural areas, women farmers face difficulties accessing markets and financial services. Mobile technology is helping to bridge this gap by providing real-time market prices and connecting women farmers with buyers. For example, platforms like *M-Farm* in Kenya enable farmers to access updated market prices and connect directly with buyers, eliminating the need for intermediaries and ensuring better prices for their produce [86]. Additionally, mobile banking and mobile money services like *M-Pesa* have empowered women by providing access to savings, credit and insurance. With access to mobile money, women can safely save money, receive remittances and access financial products tailored to their needs. This enables them to invest in agricultural inputs, such as seeds or irrigation systems, which are necessary to improve productivity and cope with the impacts of climate change [60, 114].

2.2. Remote Sensing and Data-Driven Agriculture

Remote sensing technologies, which include satellite imagery, drones and sensors, have opened new frontiers in data collection and analysis for agriculture. These technologies enable farmers, including women, to monitor crop health, soil conditions and weather patterns, leading to more informed decision-making. Remote sensing and data-driven approaches to agriculture are revolutionizing farming by increasing efficiency, reducing costs and improving resilience to climate-related risks [4].

2.2.1 Satellite Imagery for Crop Monitoring: Satellite imagery allows farmers to monitor large areas of farmland without the need for physical inspection. This is particularly useful for women farmers who may not have the time or resources to conduct regular field visits. Through remote sensing, farmers can assess the health of their crops, detect pests or diseases early and identify areas that require intervention [28]. For example, *AgriDigital* uses satellite data to provide farmers with information on crop health, soil moisture and potential yield. This helps women make timely decisions on irrigation, pest control and crop management, which are critical in a changing climate [29].

2.3.2 Drones for Precision Agriculture: Drones are increasingly being used in agriculture to gather high-resolution images and data about crops and soil. These drones can identify issues such as pest infestations or nutrient deficiencies and help farmers apply inputs like water, fertilizer and pesticides more precisely [93]. For women farmers, drones offer a practical solution for monitoring large or remote areas of farmland. Drones also provide data on soil health and water usage, which is particularly valuable in regions affected by water scarcity. Precision farming techniques enabled by drones help farmers optimize their resources, reduce waste and improve yields—making agriculture more sustainable and climate-resilient [74].

2.2.3 Sensor Technology for Improved Irrigation: Water scarcity is one of the most significant challenges for farmers in the context of climate change. Smart irrigation systems equipped with sensors can help optimize water usage, ensuring that crops receive the right amount of water at the right time [107, 87]. These systems can be controlled via mobile apps, giving women farmers the ability to manage irrigation efficiently. Sensors that monitor soil moisture levels can reduce water wastage and improve crop yields, especially in drought-prone areas [103]. By integrating remote sensing technologies into everyday farming practices, women can improve the efficiency and sustainability of their agricultural activities, thus enhancing their resilience to climate change and boosting productivity [94].

2.3. Climate-Smart Agriculture (CSA)

Climate-smart agriculture (CSA) refers to farming practices that increase agricultural productivity, enhance resilience to climate change and reduce greenhouse gas emissions. CSA is essential for adapting to the changing climate and many technological innovations are helping women farmers' transition to climate-smart practices [27]. These include agroforestry, crop diversification, conservation tillage and sustainable water management.

2.3.1 Agroforestry and Crop Diversification: CSA practices promote the integration of trees with crops, which can improve soil health, conserve water and enhance biodiversity. For women farmers, agroforestry offers multiple benefits, including increased food security, improved nutrition and additional income streams [36]. For example, women can grow fruit trees alongside staple crops, providing both food and income. Technology can support these practices by offering training, resources and market information for selling the diverse products grown in agroforestry systems [17].

2.3.2 Sustainable Water Management: Water is a key resource in agriculture and climate change is leading to more frequent droughts and erratic rainfall patterns. Technologies that promote efficient water use, such as drip irrigation and rainwater harvesting systems, are vital for women farmers in regions facing water scarcity [47]. These systems ensure that water is used efficiently, reducing wastage and enhancing the resilience of crops to drought conditions. In addition, mobile apps and sensors that monitor water levels and soil moisture can help women make data-driven decisions about irrigation, improving water management and reducing the effects of water scarcity [5].

2.3.3 Soil Health and Conservation Practices: Climate change leads to soil degradation, which can reduce agricultural productivity. CSA practices such as conservation tillage, mulching and crop rotation help restore soil health and mitigate the effects of climate change [48]. Technological tools that provide information on soil health and nutrient management can help women adopt these practices more effectively. By integrating technology with sustainable farming practices, women can improve soil fertility, increase crop yields and reduce the environmental impact of farming [61].

2.4. Women as Innovators in Agricultural Technology

While technology has traditionally been designed with male farmers in mind, there is a growing recognition of the need for gender-sensitive innovations. Women farmers are not only consumers of technology but also innovators who are adapting existing technologies to meet their needs and the specific challenges they face [26].

In some regions, women have been involved in the development of locally appropriate technologies, such as low-cost irrigation systems, efficient cooking stoves and affordable seed storage solutions [95, 113]. These innovations are often designed to ease the burden of labor and time-consuming tasks, allowing women to focus on improving productivity and adapting to climate change. By involving women in the design and development of agricultural technologies, we can ensure that the tools meet their needs and contribute to greater empowerment [62].

2.5. Overcoming Barriers to Technology Adoption

While technology holds immense potential to empower women farmers, several barriers hinder its widespread adoption. These include:

1. **Digital Literacy and Education:** Many women, especially in rural areas, lack the digital literacy needed to navigate new technologies effectively. Bridging this gap through training programs that build digital skills and knowledge is crucial for enabling women to fully benefit from technological innovations [37].
2. **Access to Resources and Infrastructure:** Access to reliable electricity, internet and mobile networks remains a challenge in many rural areas. Governments, development organizations and the private sector must invest in infrastructure that supports the use of technology in agriculture [75].
3. **Affordability and Financial Constraints:** High costs associated with technology adoption, including the purchase of smartphones, data plans and devices, may be prohibitive for women farmers. Subsidies, loans and grants tailored to women farmers can help make these technologies more accessible [88].
4. **Cultural and Social Barriers:** In many societies, women face cultural norms that restrict their access to decision-making power, land or financial resources. Gender-sensitive policies that promote women's access to land, credit and technology are essential for ensuring that women can take full advantage of technological advancements [96].

Technology has the potential to be a powerful catalyst for change, especially for women farmers facing the challenges of climate change. By improving access to information, resources and markets, technology can help women farmers enhance their productivity, resilience and economic independence [25]. Innovations such as mobile apps, remote sensing and climate-smart practices are transforming agriculture, making it more sustainable, inclusive and adaptable to a changing climate. However, for technology to truly empower women, efforts must be made to address the barriers that limit their access to these tools [49]. Investments in digital literacy, infrastructure and gender-sensitive policies are essential for ensuring that women farmers are not left behind in the technological revolution. By empowering women with the tools and knowledge they need, we can create a more equitable, resilient and sustainable agricultural system that benefits everyone [6].

3. Case Studies: Technology Empowering Women Farmers

The following table presents case studies from various regions where technology has been implemented to empower women farmers, enabling them to adapt to climate change, increase productivity and improve their livelihoods [108, 18, 50, 62, 76].

Table 1: Case Studies on Technology-Driven Solutions Empowering Women Farmers in Africa and Beyond

Case Study	Location	Technology Used	Description	Impact on Women Farmers	Challenges
1. M-Farm	Kenya	Mobile platform	M-Farm is a mobile platform that provides farmers with real-time market prices and connects them directly with buyers, eliminating middlemen. It also offers weather updates and agricultural advice.	Women farmers can access updated market prices, ensuring fair compensation for their produce. The platform empowers women by providing financial literacy and access to better market linkages.	Limited internet access in rural areas and digital literacy barriers for older women.
2. Digital Green	India, Ethiopia, Ghana	Video-based training platform	Digital Green uses videos to deliver agricultural extension services to farmers. These videos cover topics such as improved farming practices, pest management and climate-smart agriculture techniques.	Women benefit from practical, visual training that they can access at their convenience, enhancing their agricultural skills and productivity.	The need for community-based facilitators to effectively engage women and bridge the digital literacy gap.
3. eSagu	India	SMS-based advisory service	eSagu offers personalized agricultural advice through SMS, allowing farmers to get tailored guidance on crop management, pest control and soil health.	Women farmers receive expert advice directly to their phones, reducing the need to travel long distances for agricultural extension services.	Access to mobile phones and reliable network connectivity in rural areas.
4. Agri-Tech Startups	Uganda	Mobile apps, IoT devices	Companies like *AgriTech* provide mobile apps that offer weather forecasts, agronomic advice and digital marketplaces for farmers. IoT sensors track soil moisture and weather conditions.	Women can make data-driven decisions on irrigation, fertilization and pest management. These technologies also help improve productivity and reduce water usage.	High cost of technology for smallholder farmers, limited understanding of advanced tools.
5. M-Pesa	Kenya	Mobile money platform	M-Pesa is a mobile banking and financial service that allows farmers to send and receive money, pay bills and access microloans.	Women farmers use M-Pesa to manage finances, receive payments for their products and access small loans for purchasing agricultural inputs.	Limited access to mobile networks in remote areas, low digital literacy among women.
6. Ceres Imaging	USA (California)	Drone and satellite imaging	Ceres Imaging uses drones and satellite imagery to provide farmers with data on crop health, irrigation and soil moisture.	Women farmers gain valuable insights into crop conditions, enabling them to optimize water usage, manage pests and enhance yields.	High upfront costs for drone technology and the need for proper training to interpret data.
7. Women in AgTech (WIA)	Global	Agri-Tech networking platform	Women in AgTech is a global initiative that connects women working in agricultural technology, offering mentorship, networking opportunities and resources.	Provides women in agriculture with access to mentorship, training and funding opportunities, helping them scale their businesses and adopt innovative technologies.	Gender biases and limited funding opportunities for women in the tech space.
8. iCow	Kenya	Mobile-based dairy farming platform	iCow provides information on livestock management, including animal health, breeding cycles and feeding practices via SMS.	Women dairy farmers benefit from tailored advice on improving milk production, animal health and marketing, leading to increased income and improved livelihoods.	Limited access to smartphones for all women, especially those with low income.
9. Climate-Smart Agriculture (CSA) Tools	Zambia, Malawi, Tanzania	Climate-smart tools (weather apps, soil sensors, crop management apps)	Climate-smart tools help farmers manage water, reduce soil degradation and improve productivity in changing climates. Women farmers use these tools to enhance soil health, water use and crop yields.	Women gain access to timely weather data, learn climate-resilient farming techniques and improve productivity.	Training and awareness programs to educate women on using the tools effectively.
10. Farm Radio International	Sub-Saharan Africa	Radio and mobile platform	Farm Radio International provides agricultural advice through radio broadcasts and integrates mobile platforms for interaction and feedback.	Women farmers in remote areas gain access to practical agricultural information that helps them improve their farming practices and adapt to climate challenges.	Low literacy levels among women and challenges in radio signal reception in certain areas.

1. **Access to Information:** Many of the technologies empower women farmers by providing them with timely information on weather, market prices and best agricultural practices. This leads to informed decision-making, increased productivity and better adaptation to climate change [38].
2. **Financial Inclusion:** Technologies like mobile money platforms (e.g., M-Pesa) and digital marketplaces (e.g., M-Farm) have improved financial inclusion, enabling women to manage finances, access loans and sell their products at fair prices [51].
3. **Barriers to Adoption:** Despite the success of these technologies, challenges such as poor internet connectivity, digital illiteracy, high upfront costs and cultural barriers remain. Overcoming these barriers through infrastructure development, targeted training and affordable solutions is crucial for maximizing the impact of technology on women farmers [19].
4. **Sustainability and Scalability:** For these technological innovations to be sustainable and scalable, ongoing support, training and integration with local communities are essential. Empowering local leaders, especially women, to act as facilitators of technology adoption can help overcome

barriers and ensure broader reach [63].

3.1 Challenges and Barriers to Technology Adoption

While technology has the potential to greatly empower women farmers, numerous challenges and barriers hinder their ability to fully adopt and benefit from technological advancements [101]. These barriers stem from a combination of socio-economic, cultural, infrastructural and gender-specific factors that limit women's access to, knowledge of and ability to use agricultural technologies effectively [77]. Understanding and addressing these challenges is crucial for enabling women farmers to harness technology for increased productivity, climate change adaptation and economic independence [7]. In this section, we explore the key challenges and barriers women face in adopting technology and how they impact their agricultural practices.

3.2 Limited Access to Resources

3.2.1. Financial Constraints: One of the most significant barriers to technology adoption is the lack of financial resources. Many women farmers, especially in rural and developing areas, face economic challenges that make it difficult to invest in agricultural technology.

- **Explanation:** Technologies such as drones, smart irrigation systems or even smart phones require significant upfront investments. Women farmers often lack access to credit, loans or grants, especially since they are less likely to own land or have formal economic assets required for collateral [24].
- **Impact:** Without access to funding, many women cannot afford the initial costs of purchasing or implementing technological tools. As a result, they are unable to adopt technologies that could enhance their productivity and resilience to climate change [20, 112].

3.2.2. Limited Access to Land and Property Rights In many cultures, women have limited or no access to land ownership. In some regions, land ownership is a key factor in securing credit or loans to invest in technology.

- **Explanation:** Women may farm land that they do not own, which makes it difficult for them to justify long-term investments in technology. Many financial institutions require land titles as collateral for loans, which women often do not have [88].
- **Impact:** Without secure land tenure, women farmers face challenges in adopting technologies that would require long-term investment, such as irrigation systems or soil health management tools [64].

3.2.3 Digital Illiteracy and Education Gaps

3.2.4. Lack of Digital Literacy In many rural areas, women may not have had the same opportunities as men to acquire digital literacy skills. This lack of digital knowledge hampers their ability to use mobile applications, internet-based platforms and advanced technology such as sensors or drones [89].

- **Explanation:** Women, especially in low-income countries, are less likely to have access to formal education and digital literacy programs. As a result, they may struggle to understand how to use smartphones, mobile apps or even basic technological interfaces [39].
- **Impact:** Digital illiteracy prevents women from effectively using mobile technology for weather forecasts, market prices, agricultural advice or financial transactions. Even if technologies are available, women may not benefit from them due to their inability to use them [65].

3.2.5. Gendered Education Gaps In many societies, girls have less access to education than boys, leading to a gender gap in knowledge, including in areas related to technology and agriculture [52].

- **Explanation:** Girls are often expected to help with household chores or caregiving duties instead of attending school, which can limit their exposure to technology and practical agricultural knowledge [78].
- **Impact:** This educational disparity perpetuates a cycle of underrepresentation of women in the technology space, preventing them from learning how to effectively integrate technology into their agricultural practices [109, 21].

3.3. Cultural and Social Norms

3.3.1. Gender Roles and Norms In many communities, rigid gender roles dictate that women focus primarily on household duties, caregiving and subsistence farming [97]. These cultural expectations limit women's opportunities to explore and engage with new technologies.

- **Explanation:** In some societies, men are seen as the primary decision-makers when it comes to agricultural innovations, while women's contributions are often undervalued. Technologies that require decision-making power, such as investing in irrigation systems or pest management tools, may be controlled by men, leaving women with fewer opportunities to engage with new technologies [40].
- **Impact:** Women are often excluded from the decision-making processes regarding the adoption of technology and may lack the support needed to implement new tools, even when those tools could reduce labour and improve productivity [53].

3.3.2. Lack of Support from Male Household Members In some contexts, women may face resistance from male family members, who may see new technologies as a threat to traditional power dynamics or as unnecessary investments.

- **Explanation:** Men, particularly in patriarchal societies, may be reluctant to allow women to make independent decisions related to technology adoption, fearing that it might undermine their authority or disrupt gendered divisions of labour [65].
- **Impact:** Even if women are willing to adopt technology, they may encounter resistance from male family members, preventing them from using or benefiting from technological innovations [79].

4. Infrastructural Barriers

4.1. Limited Access to Internet and Mobile Networks In many rural areas, especially in developing countries, access to reliable internet and mobile networks is often limited or non-existent [98]. This is a critical barrier to accessing digital platforms, online agricultural advisory services or weather forecasts.

- **Explanation:** Rural regions often lack the infrastructure needed to support consistent internet or mobile service. Women in these areas may struggle to use mobile-based apps for market prices, weather updates or agricultural training due to poor network coverage [80].
- **Impact:** Without internet access, women are unable to take full advantage of mobile platforms, rendering digital technologies largely ineffective. This exacerbates their exclusion from digital agriculture solutions and climate

change adaptation strategies [66].

4.2. Lack of Electricity In remote areas, especially in off-grid communities, a lack of electricity can hinder the use of technologies such as mobile phones, computers and irrigation systems that require power [90].

- **Explanation:** Many women farmers in rural areas rely on basic, low-cost technologies that do not require electricity. However, more advanced technologies, such as solar-powered irrigation systems, mobile phones or agricultural drones, require a reliable electricity supply, which is often unavailable [54].
- **Impact:** Without a stable power supply, women farmers are unable to operate advanced technological tools that could increase their productivity and resilience to climate-related risks [99].

5. High Costs of Technology and Maintenance

5.1. Expensive Initial Investment: Many agricultural technologies, such as precision farming tools, irrigation systems or climate-smart tools, require significant initial investment, which is often out of reach for women farmers, particularly in low-income regions [8, 9].

- **Explanation:** Technologies that provide high value in terms of productivity and climate adaptation, such as automated irrigation systems, sensors and drones, come with high upfront costs. Additionally, there may be hidden costs for installation, maintenance and training [81].
- **Impact:** High costs prevent women from adopting these technologies, as they may lack the financial resources or credit access needed to make such investments. This results in women being left behind in the technological revolution in agriculture [22].

5.2. Lack of Training and Support: Even when technologies are affordable, there may be insufficient training or technical support to help women use and maintain these technologies effectively.

- **Explanation:** Many technologies require training on how to use them, troubleshoot issues and understand the data they generate. Inadequate or absent training programs limit the ability of women farmers to utilize technology to its full potential [67].
- **Impact:** Without the necessary skills and support, women may struggle to integrate technology into their agricultural practices and fail to reap the benefits that could improve productivity and sustainability [55].

6. Limited Access to Extension Services

6.1. Gender Bias in Agricultural Extension: Agricultural extension services, which provide training and support to farmers, are often biased toward male farmers. Extension agents may prioritize male farmers or may not be trained to address the specific challenges faced by women.

- **Explanation:** Agricultural extension services may be more readily available to male farmers, who are often seen as the heads of households and primary breadwinners. Additionally, extension agents may not have the expertise or training to engage with women effectively, especially in patriarchal communities [82].
- **Impact:** Women may not receive the same level of support in adopting new technologies or improving their agricultural practices, which affects their ability to increase productivity and build resilience to climate change [41].

To overcome the barriers to technology adoption, it is essential to develop targeted strategies that address these challenges. Key actions include:

1. **Increasing financial access:** Providing low-interest loans, grants or subsidies tailored to women farmers, especially for purchasing and implementing technologies [111, 68].
2. **Promoting digital literacy:** Offering training programs for women to build digital skills, enabling them to use mobile apps, websites and other technologies effectively [91].
3. **Breaking cultural norms:** Encouraging gender-sensitive policies that promote women's participation in decision-making about agricultural technologies [100].
4. **Improving infrastructure:** Investing in rural infrastructure such as reliable internet, electricity and mobile network coverage to support technology use [102].
5. **Affordable technology:** Designing and subsidizing low-cost, simple-to-use technologies that are specifically tailored for smallholder women farmers in developing countries [110, 70].
6. **Inclusive extension services:** Ensuring agricultural extension services are accessible, gender-sensitive and tailored to the specific needs of women farmers [56].

6.2 Policy Recommendations

To ensure that women farmers can fully benefit from technological innovations, several policy actions are necessary:

- **Promote Gender-Sensitive Technology Design:** Technologies should be designed with women's needs in mind, considering their roles in agriculture and the specific challenges they face. For instance, mobile apps should be available in local languages and the design of platforms should be user-friendly for women with varying levels of literacy and digital skills [23].
- **Invest in Digital Literacy and Training:** Governments and development organizations should invest in training programs to build digital literacy among women farmers. This includes offering courses on how to use mobile phones, access online platforms and apply technological innovations to agriculture [42].
- **Ensure Equal Access to Resources:** Governments should work to remove legal and cultural barriers to women's access to land, credit and agricultural inputs. Policies that promote women's ownership of land and access to finance can enable women to invest in technology and improve their agricultural productivity [69].
- **Enhance Connectivity in Rural Areas:** To bridge the digital divide, efforts should be made to improve internet and mobile network infrastructure in rural areas. This would provide women farmers with the connectivity they need to access vital agricultural information and market opportunities [10].

7. Conclusion

The gendered impact of climate change on agriculture highlights the need for a more inclusive and gender-sensitive approach to climate adaptation and mitigation. Women farmers are disproportionately affected by the changing climate and their unique needs and challenges must be addressed in climate policies, agricultural practices and development programs. By promoting gender equality in access to resources, information and decision-making, it is possible to reduce women's vulnerabilities and empower them to play a more active role in

climate change adaptation. Policies that prioritize women's access to land, credit, education and technology are essential for building their resilience to climate change. Furthermore, addressing the cultural and social barriers that prevent women from participating in decision-making processes is crucial for ensuring that their voices are heard and their needs are met. By empowering women, we can not only enhance their capacity to adapt to climate change but also contribute to broader goals of food security, poverty reduction and sustainable development.

Ultimately, achieving gender equality in agriculture and climate change adaptation will require coordinated efforts from governments, international organizations and civil society to dismantle the barriers that prevent women from fully realizing their potential in the face of climate change. Technology has immense potential to empower women farmers in the context of climate change. By improving access to information, enhancing productivity and promoting climate-resilient agricultural practices, technology can help women overcome the challenges posed by climate change and improve their socio-economic status. However, to realize this potential, it is essential to address the gendered barriers to technology adoption and ensure that women have equal access to resources, training and opportunities. Through inclusive policies and gender-sensitive technological interventions, we can empower women farmers to become agents of change in the fight against climate change, thereby fostering a more equitable and sustainable agricultural future.

8. References

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