
RESEARCH ARTICLE

Gender Integration in Climate-Smart Agriculture (CSA) Education in Saudi Arabia: A Review

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ABSTRACT

Climate-Smart Agriculture (CSA) aligns directly with the goal of Saudi Vision 2030 by optimising resource use and building climate resilience for environmental resilience, economic diversification and sustainable development. As technological agriculture becomes more advanced, an effective education and capacity-building system is vital for promoting adoption and sustainable CSA practices. The participation of women in agriculture in Saudi Arabia is getting more recognition through small livestock rearing, beekeeping, nurseries, greenhouse production and value addition, information on gender integration in CSA education and training program is limited. The article synthesises peer-reviewed literatures, policy documents, and institutional reports to examine the gender integration of CSA education in Saudi Arabia. The article identifies the possible transformation and agricultural development through feminist theory, gender-responsive pedagogy, intersectionality, and Agricultural Knowledge and Information Systems (AKIS). Additionally, the persistent gendered barriers which include male-dominated knowledge systems, limited representation of women's, agricultural roles, unequal access to extension and digital tools, and weak institutional coordination was highlighted in this review. Simultaneously, the article shows the emerging opportunities for gender-responsive and transformative CSA education that aligns with national policy. Conclusively, women's agency, learning, and leadership in climate-resilient agricultural systems could be enhanced through integrating gender in CSA education.

KEYWORDS

Agricultural education, gender, Saudi Arabia, climate smart, pedagogy, women participation

ARTICLE INFORMATION

ACCEPTED: 01 January 2026

PUBLISHED: 15 February 2025

DOI: 10.32996/jeas.2026.7.1.2

1.0 Introduction

Saudi Arabia's Vision 2030 drives sustainable agriculture through investments in agricultural technology, water-saving technologies, and biotechnology (Eyad 2024). The rapid transformation in agricultural sector is driven by the Vision 2030, which seeks to diversify the economy, increase food security, and modernize natural resource management. The agricultural sector in the Kingdom faces with significant threats from the complex impacts of climate change, such as rising temperatures, unpredictable rainfall patterns, recurring floods, prolonged droughts, and more frequent of extreme weather events (Wang *et al.*, 2025). As a result, agricultural productivity has been adversely affected, while food and nutritional security as well as the livelihoods of millions of rain-fed smallholder farmers have become increasingly vulnerable (Wang *et al.*, 2025). In this regard Climate-Smart Agriculture (CSA) has gained policy attention due to its emphasis on improving productivity, strengthens resilience to climate impacts, and promotes sustainable resource management (Alotaibi and Kassem, 2021).

Climate Smart Agriculture (CSA) is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change (FAO, 2022). It contributes to the achievement of national food security and development goals with three objectives: Sustainably increase agricultural productivity and income, adapt and build resilient to climate change and reduce/ or remove greenhouse gas emission where possible (FAO, 2022). CSA in Saudi Arabia includes technologies and practices such as smart irrigation systems, hydroponics and vertical farming, protected agriculture, sustainable livestock management, and the use of digital tools for monitoring and decision-making (Alotaibi *et al.*, 2024; FAO, 2016). CSA becomes central to national agricultural strategy, education, training, and capacity-building have emerged

as enablers of successful implementation. New technical skills, updated agronomic knowledge, and digital competencies are essential for farmers to engage effectively with modern climate-resilient systems (Olabanji and Chitakira, 2025). These innovations require technological investments and strong educational systems capable of equipping current and future agricultural workers with the skills, knowledge, and adaptive capacities necessary for climate-resilient (Aldosari, 2018; Sajid *et al.*, 2018). However, CSA is significantly important for women farmers because it empowers them and enhances their economic independence, food security and resilience by providing access to training, resources and innovations that reduce the impacts of climate change (UN Women, 2022).

Women have been shown to influence the agriculture and rural economies across the developing countries, they play a role as employed paid or unpaid labourers on other farmers farms and agricultural businesses, as well as self-employed and also labourers on family farms (Gautam *et al.*, 2023). Their contributions vary widely within and among regions, evolving rapidly due to economic and social shifts in the agricultural sector (Gautam *et al.*, 2023). In Saudi Arabia women play an important role in livestock rearing, small scale farming and food processing. They are also active in greenhouse production, home-based farming, plant nurseries, and value addition (FAO, 2024; Meeran, 2023). Education and capacity-building programs are essential for expanding women's agricultural productivity and supporting their participation in national sustainability goals (FAO, 2024). Education has also been recognised as key pathway through which women's empowerment can be advanced across economic, social, and political dimensions (Kusum and Shweta, 2024). Women's empowerment has shown to influence the foundation for sustainable development and societal progress. In global development discourse, it has increasingly been positioned as both a social justice concern and a strategic requirement for attaining the Sustainable Development Goals (Kusum and Shweta, 2024). Moreover, education and capacity-building programs are also essential for women's empowerment, which leads to the enhancement of agricultural productivity and support national sustainability goals such as food security, climate action and gender equality (FAO, 2018).

Education, therefore support the national shift towards sustainable agricultural development, align with the Saudi vision 2030 goals. CSA related learning occurs through a diverse ecosystem of institutions, which includes: vocational training centres, universities programs, government research organisations, and NGO supported programs (FAO, 2018). Agricultural e-learning platforms have also provided online training to support farmers with access to educational resources and training to help them understand and apply the latest technologies and best practices, and this promotes the dissemination of knowledge and contributes to the modernization of agriculture (Anja, 2024). Sophia *et al.* (2024) highlighted the importance of gender-responsive agricultural education and emphasised inclusive pedagogy, access to a good training environment, and curricula that addressed women's specific knowledge needs. Because when women receive agricultural training tailored to their needs, it will increase the adoption rates of climate-smart technologies, strengthen household resilience, and expand their community knowledge networks (Beuchelt and Badstue, 2013; Jost *et al.*, 2016).

Despite the kingdom's commitment to advancing women's empowerment under the Saudi Vision 2030, there is no consolidated review examining gender integration in CSA education, and most of the academic literature is fragmented and lacks cohesion as well as sufficient data availability. However, such evidence is sparse in the Saudi context. Most of the existing literature focuses on technical aspects of CSA, specifically the drivers of adoption and the outcomes of technical interventions such as irrigation technologies; however, it does not adequately address gender integration. Also, some studies focus on women's participation in a specific agricultural activity, such as post-harvest activities (cleaning, sorting, packaging), livestock management, and small-scale agribusiness/entrepreneurship, rather than support for agricultural education systems. Reports from government and developmental agencies offer helpful information about training initiatives, but they do not report gender-disaggregated outcomes or curriculum content in detail (FAO, 2023; Meeran, 2023). Consequently, there is a limited comprehensive synthesis specifically addressing how CSA education in Saudi Arabia either supports or restricts women's access to climate-resilient agricultural knowledge.

Therefore, the review aims to examine the integration of gender in CSA education in Saudi Arabia, with a focus on analysing the pedagogical approaches and assessing the available evidence on women's learning outcomes, and identify the gender-related barriers and enablers to access to education. The review highlights key gaps in the design, delivery, and evaluation of CSA learning initiatives and offers recommendations for creating more inclusive and gender-responsive agricultural education.

2.0 Theoretical and Conceptual Framework

The theoretical perspectives of this review are based on the interrelations that highlight the influence of gender on access to agricultural knowledge, participation in training, and the adoption of Climate-Smart Agriculture (CSA). This review aims to provide a critical lens for understanding educational systems, policies, and institutional arrangements that may reinforce gender inequalities in the agricultural transformation of Saudi Arabia.

2.1 **Feminist Theory and Gendered Structures of Knowledge**

Feminist perspective emphasizes the need for a more equitable educational environment that recognizes and nurtures the individual potential of all, regardless of gender (Wienclaw, 2021). Feminist theory also asserted that knowledge system such as training, agricultural education and extension delivery is deeply intertwined with and fundamentally shaped by the surrounding of social, cultural and institutional context that privilege male experiences, expertise and authority (Shivi, 2023). This highlights the historical and ongoing biasedness shape and considered the knowledge, potentially marginalised the contribution of women and understanding of agricultural practices (Pritismita and James, 2025). This is driven by the patriarchal norms and lead to unequal access to resources, economics opportunities and decision-making power (FAO, 2023). Furthermore, many feminists claim that most educational systems prepare females poorly for higher paying, more prestigious jobs. The reasons for this phenomenon are complex, although hidden curriculum, teacher expectancy effect, and gender stereotyping by guidance counsellors all seem to contribute to this situation (Wienclaw, 2021).

Gender segregation is evident within Saudi Arabia, Men hold the most authority and are responsible for the primary income, security and safety of the family. They are expected to work outside the home, earn money and provide for their family. Women have traditionally taken responsibility for the domestic space as the nurturers and bedrocks of the family. Gender biasness restricts women in availing resources and opportunities (Safdar *et al.*, 2021; Urooba *et al.*, 2023). Proper policies and legislation for the ownership of land and property by the women should be developed and must be acknowledge and secured and communicated to the people through rising awareness among the people (Urooba *et al.*, 2023). Women farmers' access to financial services is prevented by cultural values, norms and legal policies and they cannot develop enterprises or start business and increase production by their own (Safdar and Pervaiz, 2020; Urooba *et al.*, 2023). In the agricultural sector, in Saudi Arabia most of the agricultural extension personnel were men and agricultural training programs, especially at the higher institution levels have historically offered to men/men only settings, even though recently under Saudi vision 2030 initiative promotes coeducation and program to both men and women. In the context of agricultural extension and advisory, both local and organizational gender norms shape the different expectations and experiences of extension workers (Badstue *et al.*, 2020; Maulida *et al.*, 2025). Also, the agricultural curricular and extension programs prioritizing mobility and farm ownership opportunity to men, because agriculture has traditionally been viewed as a men-dominated field, with a lack of gender equality in the workplace (Shisler & Sbicca, 2019; Maulida *et al.*, 2025). This has created a unique organizational culture for both men and women as extension workers and shows marginalised women's significant contributions to agriculture (Maulida *et al.*, 2025). This explain the reason for women remain invisible in agricultural education even with the essential roles played in real-life production system, and it is historical pattern of men agricultural authority and gender power relations.

2.2 **Gender-Responsive Pedagogy (GRP)**

Gender-responsive pedagogy and gender sensitive attitude are crucial elements in fostering inclusion and gender equality in the educational environment, and education has traditionally placed a high priority on gender concerns (Lopez and Andal, 2024). GRP are increasingly recognised as an effective strategy for creating a more equitable and inclusive educational experience within the classroom, where the specific learning and social needs of girls and boys are taken into account (Mekonnen and Cherinet, 2020; Walsh *et al.*, 2025). It also involves the employment of teaching and learning strategies that challenge these dynamics to allow for the more equitable participation of girls. It requires a reform of the curricula and teaching practices towards ones that challenge established gender hierarchies (Mekonnen and Cherinet, 2020; Walsh *et al.*, 2025). The learning environment should be the one that acknowledge and address the specific life circumstances, needs, and systematic barriers faced by the female farmers. Moreover, the approach to gender integration into agriculture extension programs vary from gender-blind to gender-aware, which acknowledges differences, inequalities, and barriers among men and women of different ages and social identities (David *et al.*, 2024). Women make significant contributions to agriculture and livestock production in Saudi Arabia; it is important extension service planning and delivery is gender responsive and account for the differential information needs and constraints of women and men farmers. The gender responsiveness of extension services can improve women's knowledge to make informed decisions and increase their ability to apply appropriate farm productivity practices (CGIAR, 2024).

The national modernization efforts increasingly emphasize capability-building and participation in Saudi Arabia, these include rising women's labour force participation under Vision 2030 reforms (Saudi Vision 2030, 2025). Additionally, agriculture remains shaped by regionally specific rural livelihoods, labour arrangements, and gendered participation patterns. For instance, evidence from small-ruminant systems in Najran highlights gender-differentiated participation shaped by social context (Aldosari, 2018). GRP is therefore theoretically useful because it explains how gendered learning barriers are reproduced (through pedagogy and institutions) and how they can be disrupted through intentional instructional design and learning environments. Furthermore, agricultural learning ecosystem in Saudi Arabia includes public-sector service delivery and digitization pathways, for example, MEWA's unified e-services portal, alongside extension activities and training provision (MEWA, 2025). Research on Saudi extension and training indicates that extension agents' knowledge sources, attitudes, and training needs shape what and how is delivered,

for example, studies of extension agents and sustainable/organic agriculture in Saudi regions (Bader et al., 2019; Alotaibi et al., 2021). Within this system, GRP functions as a framework for diagnosing and redesigning CSA learning in ways that are gender-responsive.

2.3 Transformative and Social Learning Theory

The theory is based on the idea that people learn from their interactions with others in a social context; by observing others' behaviours, they develop similar behaviours, assimilate and imitate them, especially if their observational experiences are positive or include rewards related to the observed behaviour (Rachmad, 2025). Behaviourism conceptualizes learning as observable change in behaviour, produced through processes of reinforcement and repetition, with a strong emphasis on rote learning (Rumjaun and Narod, 2025). Social learning theory provides critical foundation for driving social change and achieve an effective outcome by transforming individuals' perspective into shared, collective action, stakeholder participation (Asare-Nuamah *et al.*, 2025). The literature on social learning highlights that social relationships and networks are responsible for mediating the diffusion of agricultural knowledge and technologies among farmers (Li *et al.*, 2024). This approach has been adopted as a key framework for advancing sustainable development, and strengthening inclusive natural resource management, and address the complex societal challenges (McNaught *et al.*, 2024; Soto *et al.*, 2021; Asare-Nuamah *et al.*, 2025). Social learning has been identified as a key mechanism for influencing farmers' adoption of new agricultural technologies, as in the case of Ethiopia indicating learning from neighbouring farmers significantly influence the adoption of improved seeds and fertilizers (Krishnan and Patnam, 2014). However, social interactions and network promote farmers' adoption of innovative agricultural practices through exchange of information and observation of other farmers decision (Wang and Xu, 2024).

Climate-smart agriculture education goes beyond learning technical skills but at as a transformative process that shift farmers mindset, values, and professional identities to promote sustainability and resilience in response to climate change and encourages to know how people think and see themselves (Tambe *et al.*, 2023; Olabanji and Chitakira, 2025). Transformative learning theorists argue that adult learning is a process of perspective transformation, which involves questioning assumptions and creating new frames of reference (Papathanasiou, 2023). This theory emphasizes a fundamental shift in consciousness, where individuals move to develop more critical, reflective, permeable, and inclusive perspectives, a process often initiated by a disorienting dilemma that challenges core beliefs (Papathanasiou, 2023). CSA education programs aim to promote critical reflection on social norms and develop agents of change through targeted interventions, training, and inclusive policies that focus on gender, water, risk, and innovation (Sophia *et al.*, 2024).

Modern agricultural extension approaches are experiential and social learning, aimed at empowering farmers through farmers' field schools and digital tools, facilitating the adoption of sustainable practices and shifting from a top-down approach to participatory methods (Wang and Xu, 2024). Demonstration plots, farmer field schools, and peer networks encourage the adoption of improved agricultural practices by providing them with practical learning and social support, which strengthens their self-esteem (Franz *et al.*, 2019). These approaches are relevant for women, who may benefit from collective and supportive learning environments, particularly where mobility or public participation is limited, and usually incorporate feminist pedagogical principles, community-driven initiatives, and accessible digital tools. These aim to build confidence, provide relevant skills, and foster collective agency despite external barriers (Miller and Morrison, 2025). Therefore, this theory suggests that CSA is most effective when it adopts participatory and gender-aware pedagogies, rather than viewing learners as passive recipients. These promote social and individual transformation for a necessary understanding of climate resilience.

2.4 Intersectionality and Rural Women's Agricultural Identities

Social categories, such as gender, ethnicity, and class, which an intersectional perspective recognises, do not operate independently. Instead, their interaction shapes different experiences and unequal power relations within society (Adaptation Fund, 2022). It emphasises that gender intersects with other social markers such as geography, age, marital status, and socio-economic position to shape lived experience (Katie *et al.*, 2022). The agricultural landscape in Saudi Arabia is regionally diverse with varying topographies and climates that allow for specialized regional production; pastoral livestock systems in the borders especially northern region, greenhouse and date production in Al-Qassim, encompassing terraced farming in Asir, beekeeping and tropical crops production in Jazan, and grain and fodder systems in Hail (PIF, 2025). Regional diversity is central to the national food security strategy, as it leverages unique geographical conditions despite the country's predominantly desert climate (PIF, 2025). From an intersectional viewpoint, rural women's experiences are affected by the interaction of multiple social identities and systems of privilege and oppression; therefore, they cannot be treated as a homogeneous group (Adaptation Fund, 2022). It is important to understand how different forms of discrimination interact and exacerbate inequality (Steliana, 2023). Women with a higher level of education or greater household bargaining power may experience greater autonomy and visibility in agricultural decision-making. Intersectionality thus provides a framework for analysing differentiated outcomes and avoids treating rural women as a homogeneous category (Katie *et al.*, 2022).

Agricultural knowledge systems, particularly extension service delivery, training and innovation platforms acts as a powerful and usually top-down, inherently influence and legitimize specific agricultural identities while marginalizing others through the promotion of particular technologies, practices, and definitions of success that favour specific approaches and social groups over others (Slavova and Karanasios, 2014). Intersectionality further reveals that institutional barriers are unevenly distributed; women in rural areas often experience mobility constraints compared to men in the same areas and to their counterparts in urban areas due to socio-cultural norms, and those women with low literacy levels experience exclusion from formal agricultural education and innovation systems (Ruth *et al.*, 2019). These intersecting constraints not only limit access to material but also restrict women's ability to construct identities as skilled, modern, or innovative agricultural actors within dominant post-developmental theory. This study adopts intersectionality as a theoretical framework to support gender transformative approaches, sustainability, and agricultural development. Research shows that women play a vital role in agriculture, which is essential for food security, environmental protection, and climate change adaptation; however, their contributions are frequently underutilised, and insufficient policy and practice support (Kipchumba *et al.*, 2025). Intersectionality provides a conceptual tool for understanding gender-neutral or narrowly targeted "women's empowerment" interventions that often fail to address structural inequalities.

This framework encourages a transformative shift that focus from instrumental approaches to relational and structural which treat gender as a simple variable to enhance productivity. Recognition of the intersectional nature of rural women's agricultural identities promotes the development of more inclusive policies, equitable knowledge systems, and sustainable development outcomes (Katie *et al.*, 2022). Intersectionality serves as an analytical framework and a basis for reimagining agricultural systems that recognise diversity, equity, and justice. By emphasising these intersecting dimensions, it reveals multiple and overlapping barriers to women's participation in climate-smart agriculture (CSA) education, thereby highlighting the inadequacy of uniform approaches.

2.5 Agricultural Knowledge and Information Systems (AKIS) and Epistemic Inequalities

Agricultural Knowledge and Information Systems (AKIS) refer to the network of people, organizations (like researchers, farmers, advisors, governments, businesses), and their interactions that generate, share, and use knowledge for agricultural innovation and development, shifting from simple tech transfer to collaborative, system-wide learning for sustainable practices (COMCEC, 2022). AKIS describe the institutional networks through which agricultural knowledge circulates among farmers, universities, research organisations, and extension services, it is also important in modern policies like the EU's CAP for achieving sustainability goals (Gavin, 2022). The approach is most often demand driven via the empowerment of farmers who "own" their role and in doing so it ensures their individual needs are met. By creating an interface between the range of stakeholders, it fosters collaborative input to directly meet the needs of the farmers that are involved (Gavin, 2022).

In Saudi Arabia, AKIS are shaped by male-dominated extension services with male staffs often being the primary point of contact (Al-Asfour *et al.*, 2017) cultural norms and religious interpretations that have historically enforced significant gender segregation in public and private life, limiting mixed-gender interaction to family members and married couples. These norms are gradually evolving due to recent government-led social and economic reforms under Vision 2030 (Alqahtani, 2025). Low female representation in agricultural technical professions is primarily due to a combination of socio-cultural norms, limited access to technical education and resources, and structural barriers. (UN Women, 2022).

This framework draws on feminist epistemology and the ethics of knowledge to analyze inequality within Saudi Arabia's AKIS, especially the idea that epistemic injustice, which occurs when systematic patterns lead to certain individuals or groups being discounted as credible knowers or having their knowledge obscured (Sirri, 2024). In agricultural systems, epistemic inequality is often produced when the dominant scientific or industrial model of knowledge is systematically valued over the practical, traditional, and indigenous knowledge of marginalized communities (Sirri, 2024). Gender lens is necessary in Saudi Arabia to enhance women engagement in agriculture, even though they are institutionally under-recognized, which is also depend on region, farming system, and the social organization of agricultural labour. Empirical work from Saudi contexts illustrates that gendered participation patterns are shaped by socio-cultural and structural factors rather than individual preference and biological differences (Aldosari, 2018).

Extension is not merely a delivery channel; it is a knowledge-authorizing institution that authorised knowledge which can reproduce epistemic hierarchies through what it teaches, who it targets, and how it evaluates the adoption of new innovations. Studies from Saudi show that farmers' benefit from extension activities varies and is shaped by the accessibility and relevance of services (e.g., regional analyses of extension activities and farmer outcomes). (Khodran *et al.*, 2021). Women are positioned as secondary audiences when extension and training systems are organized for male or as a particular type of producer, and they are primary managers of specific agricultural tasks. This is consistent with broader global evidence that gendered institutional designs in agriculture often distribute learning opportunities unevenly across women and men (Doss *et al.*, 2015). Recently sustainability research also points to the role of extension/training pathways in enabling women's adoption of specific sustainable livelihood practices (e.g., beekeeping), reinforcing the idea that learning infrastructures can either mitigate or intensify inequality depending on inclusion and design (Almutlaq *et al.*, 2025).

Finally, this framework situates epistemic inequality within Saudi Arabia's ongoing institutional transformation agenda. Vision 2030 and NTP aligned reforms emphasize modernization and performance in public services, which can expand digital delivery and institutional reach (Kingdom of Saudi Arabia, 2016; MEWA, 2025). Yet, from an AKS perspective, modernization can still reproduce epistemic inequality if it digitizes existing hierarchies (e.g., privileging already-visible producers or already-authorized knowledge forms). Therefore, this study treats "effective agricultural transformation" not as only technological change but also epistemic change a shift toward knowledge pluralism and co-production in which farmers' experiential expertise (including women's situated knowledge) is institutionally recognized and built into research priorities, extension content, and evaluation criteria (Saymore, 2025). Analysing CSA education through an AKIS lens helps to identify the institutional pathways that enable or constrain women's access to learning and innovation.

3.0 Context of Climate-Smart Agriculture, Agricultural Education, and Gender in Saudi Arabia

3.1 Climate Smart Agriculture in Saudi Arabia

In Saudi Arabia, the agricultural sector is facing growing vulnerability as a result of multiple impacts of climate change, including rising temperatures, variability in rainfall, recurrent flooding, prolonged drought conditions, and an increasing incidence of extreme weather events. (Wang *et al.*, 2025). As a result, climate-related pressures have adversely affected agricultural productivity while simultaneously increasing risks to food and nutritional security and threatening the livelihoods of millions of smallholder farmers who depend on rain-fed agriculture (Wang *et al.*, 2025). Sustainable agricultural methods and climate-smart practices are widely viewed as complementary approaches for mitigating greenhouse gas emissions and improving productivity in agricultural systems (Alotaibi *et al.*, 2024). Climate-smart agriculture is an approach for transforming and reorienting agricultural systems to support development and ensure food security in the face of new realities of climate change (Lipper *et al.*, 2014). It combines several sustainable farming practices adapted to local conditions to reduce the impacts of climate change (Timothy *et al.*, 2015). Although it is built on existing agricultural knowledge, technologies, and sustainability principles (World Bank Group, 2024). The approaches advocate integrating climate change into the planning and implementation of sustainable agricultural strategies, thereby identifying synergies and trade-offs across the three pillars of CSA (food security, adaptation, and mitigation) to support policy and decision-making (Paul *et al.*, 2021). This assesses the performance of alternative technologies and practices in relation to national development priorities and food security goals under changing climatic conditions (Paul *et al.*, 2021). Furthermore, Climate-smart agriculture (CSA) draws on accumulated knowledge and experience from sustainable agricultural development while incorporating participatory, community-driven approaches (Paul *et al.*, 2021; Nagothu *et al.*, 2016), while prioritizing sustainable intensification as a core pathway for enhancing on-farm productivity and income, alongside existing measures aimed at protecting agricultural land (Paul *et al.*, 2021).

The implementation of CSA in Saudi Arabia increasingly combines advanced digital technologies, such as IoT-enabled systems, drones, and smart greenhouses, with broader national strategies, including the Saudi Green Initiative and the National Food Security Strategy (TOME, 2023). The main focuses are to enhance water efficiency, increase crop yields, and improve food security. Other important areas include promoting drought resistance, precision agriculture, and effective resource management to address the impacts of climate change and support the objectives of Saudi Vision 2030. Saudi Arabia has launched a global initiative to advance climate-smart agricultural solutions. These practices support gains in food production, strengthen farmers' resilience, and advance low-emission strategies, with advanced agricultural. ERP systems playing an enabling role in optimizing planning and resource management (TOME, 2023). Brazil, Ethiopia, and New Zealand leading the way in the implementation of these strategies, followed by some countries. In Saudi Arabia, the focus is on enhancing the resilience and productivity of farming systems (Swati *et al.*, 2026), paving the way for a sustainable future in agriculture (TOME, 2023).

Gender Integration into climate-smart agriculture (CSA) projects, programmes, and policy frameworks is essential for the effective implementation of CSA initiatives (FAO, 2019). Studies indicate that improved access to climate change information and CSA knowledge among women encourages the adoption of CSA technologies by both women and men, thereby strengthening the resilience of households and communities to climate-related shocks (FAO, 2023). Reducing gender-based disparities in access to productive resources, agricultural services, and inputs has the potential to lower global hunger by an estimated 150 million people (FAO, 2019). Women's ownership of asset and control positively linked to the uptake of some climate-smart practices (FAO, 2018; Kristjanson, *et al.*, 2017). The integration of gender into climate change initiatives at the policy level is facilitated through frameworks that require gender-responsive adaptation and mitigation measures (FAO, 2019).

3.2 Gender and Agricultural Education

Women play an important role in agriculture, for been responsible for 60% to 80% of food production globally. They can be empowered through access to productive resources, including land, agricultural inputs, education, and financial services, as a means of enhancing agricultural performance and food security (Jayakumar and Surudhi, 2015). Despite women's vital roles, their contribution is considered invisible, they are also not giving attention in agricultural education and extension services, leading to

less female leadership in policy and research. Thus, this gap is as a result of historical men's dominance. Limited access to agricultural education reduces women's likelihood of occupying decision-making and managerial roles within agricultural systems. As a result, women's perspectives and knowledge are often underrepresented in agricultural policy processes, constraining innovation along the value chain and negatively affecting multiple dimensions of food and nutrition security (FAO, 2017). Educating women in agriculture would lead to greater adoption of new techniques, diversified crops, entrepreneurship, better nutrition, and improved family well-being in general.

The CSA outcomes depend heavily on institutions, access, and social relations. In the case of gender issues, adoption of CSA practices requires timely access to training, extension services delivery, decision-making authority over resources and farm management, and recognition of agricultural actors within formal programs. The World Bank Group *et al.* (2015) reported that the difference between men and women in how they can receive information, training, services, and productive resources affects the path of agricultural innovation and the distribution of benefits. They emphasise the importance of integrating gender into agricultural services and institutions rather than treating it as an additional or secondary concern.

In Saudi Arabia, the gender lens for agricultural systems is becoming more recognised and supported. According to Aldosari (2018), who reported gender disparities in participation and access to agricultural information channels, women benefited from fewer services, such as veterinary clinics and media information sources. This issue is important for CSA, since livestock resilience, animal health, rangeland pressure, and other climate-related shocks are strongly mediated by knowledge access and service responsiveness; access to all those resources by women is structurally weaker, and resilience investments may be uneven and less effective at the household or community scale. The extension and learning systems are key determinants for the uptake of sustainable practices among women producers in the Hail region of Saudi Arabia (Almutlaq *et al.*, 2025). Despite not always being associated with CSA, beekeeping directly contributes to climate adaptation and sustainable livelihoods, particularly in arid and semi-arid contexts. CSA needs an institutional and socio-technical transition operating under severe climatic and resource constraints and facilitated through national systems of governance, research, and extension (MEWA, 2025). The effectiveness of the climate-adaptive capacity depends on whether women have equitable access to knowledge systems, services, and recognition as agricultural decision-makers. The participation and adoption of sustainable practices by women in Saudi Arabia should be through extension services, which provide concrete evidence that gendered dynamics are not hypothetical but already observable within rural production systems (Aldosari 2018; Almutlaq *et al.*, 2025).

3.3 Barriers and Enablers for Women's Participation in CSA Education

CSA is a comprehensive approach aimed at increasing agricultural incomes and sustainable productivity, building resilience against climate change, and lowering or eliminating greenhouse gas emissions and addresses some of the problems of food security (Mohanty *et al.*, 2024). It's a technical innovation that stresses the importance of social differentiation, particularly gender, which shapes who can adopt, benefit from, and sustain the CSA practices (Ruth *et al.*, 2019). The participation of women is understood through an institutional and socio-structural lens, by their access to resources, knowledge systems, decision-making authority, and recognition as agricultural actors.

Some of the key barriers to women's participation in CSA are the : Unequal access to extension, training, and knowledge systems in Saudi Arabia and some Gulf countries; women have limited access to agricultural extension and training services, the extension systems have historically focused on the male farmers who are considered as the key farmer without concern of the needs of women farmers (Aldosari, 2018; World Bank *et al.*, 2015). Water-efficient irrigation, soil management, and climate-risk management are among the CSA practices that require inclusive learning and advisory support, as insufficient knowledge has direct implications for women's adaptive capacity.

CSA requires upfront investment to improve irrigation systems, implement climate-controlled production, and rehabilitate soil: Access to land, credit, and productive assets by women remains uneven and shaped by legal frameworks, customary practices, and institutional norms across the Gulf (Doss *et al.*, 2015). Women in Saudi Arabia are relatively active in agriculture, particularly in livestock-related activities, beekeeping, and home-based or informal agricultural activities, which often lack official recognition, a support system, and asset ownership that would enable participation in CSA programs or financing schemes.

To address the gender inequality in CSA training requires inclusive interventions, decision-making power and access to resources that can able to overcome participation barriers. In Saudi Arabia, accessible training and extension services has been shown to influence the adoption of sustainable practices by gender, as demonstrated by women beekeepers in Hail (Almutlaq *et al.*, 2025). World Bank *et al.* (2015) highlighted that modification of extension services with consideration of women-friendly schedules, adopting the use of participatory approaches and inclusive curricula enhances women's capacity to engage in climate-smart innovations education. Saudi Vision 2030 enables CSA education environment for gender-inclusive in the program that promotes women's economic participation. Ministry of Environment, Water and Agriculture (MEWA) and the National Center for Sustainable Agriculture Research and Development (Estidamah) integrate gender to enhance women's access to CSA knowledge and resources

for sustainability, innovation, and capacity-building. Gender inclusion should be treated as a core performance dimension of CSA, rather than as a secondary social objective. These would align climate adaptation with broader national goals of inclusive development and expansion of human capital in Saudi Arabia.

4.0 Conclusion and Recommendations

The review analyses gender integration in Climate Smart Agriculture (CSA) education in Saudi Arabia. Saudi Vision 2030 goals that are relate to sustainable resource management, food security, and rural development can be achieved through the adoption of CSA practices. The educational system of CSA remains insufficient for gender inclusion, with structural, institutional, and cultural barriers that restrict their participation in training. Even with the agricultural rapid modernisation, gendered assumptions rooted in traditional hierarchies persist in CSA curricula and learning environments. This gender blindness limits the opportunities for women to adopt CSA practice and weakens the potential for actual resilient and inclusive agricultural transformation. This review shows how feminist theory, gender-responsive pedagogy, transformative and social learning theory, intersectionality and agricultural knowledge and innovation systems (AKIS) analysis contribute to the effectiveness of CSA education in Saudi Arabia. The theoretical lenses reveal how gender norms shape the access to knowledge, how institutional structure inclusively reinforces these norms and how digital innovations can either empower or marginalise women. Achieving climate and agricultural goals in Saudi Arabia requires a shift from gender-neutral to gender-responsive CSA education; this involves the reform of curricula, the expansion of women-focused training, the enhancement of digital accessibility, and the institutionalisation of gender-disaggregated evaluations. Integration of national climate resilience, agricultural innovation, and sustainable development with inclusive CSA education enhances women's empowerment and commitment.

Climate Smart Agriculture (CSA) education in Saudi Arabia should integrate gender for a systematic and multi-level approach that could address curriculum design, pedagogy, institutional structures and digital accessibility. This is across the TVET institution, MEWA training and community programs to reflect women's roles and learning needs. The training environment should consider the cultural settings and be accessible and comfortable for women to participate. Women's learning outcomes evaluation is essential for understanding and for refining CSA education programs, by publishing an annual report on gender in agriculture in order to improve transparency and policy responsiveness.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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