Bridging the Gender Divide in Climate Action: Enhancing Resilience and Reducing Methane Emissions in Smallholder Goat Production

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ABSTRACT

Smallholder goat production is a vital livelihood strategy for millions of people, particularly women, in developing countries. However, it also contributes significantly to greenhouse gas emissions, particularly methane, which has a global warming potential 28 times higher than carbon dioxide over a 100-year time frame. Climate change is a pressing issue with far-reaching consequences for the environment, human health, and agrarian rural economy. Smallholder goat farmers, particularly women, are among the most vulnerable due to their limited resources, lack of climate information, disparity in access to credit and markets, and dependence on natural resources. This study aims to enhance the resilience of smallholder goat production systems, reduce methane emissions, and improve livelihoods for women smallholder farmers by addressing their specific needs and challenges. A gender-sensitive approach is needed to enhance resilience and reduce methane emissions in smallholder goat production. Women face significant barriers to adopting climate-resilient practices, such as limited access to information and training on climate-resilient practices, and cultural and social barriers. These factors make it difficult for women to invest in these practices, adopt new technologies, and control over resources, which can hinder their ability to adapt to changing environmental conditions. There is a significant research gap on the specific needs and challenges of women smallholder farmers in the context of climate change. This study aims to address this gap by exploring the intersections between gender, climate change, and smallholder goat production, and identifying strategies for enhancing resilience and reducing methane emissions. In conclusion, policies that consider gender in small-scale goat farming are crucial for advancing the rural development, enhancing resilience, and lowering emissions from ruminants. These approaches simultaneously work to narrow the gender gap and promote climate-friendly practices. Key recommendations include supporting women's participation in decision-making, providing access to information for women smallholder farmers to adopt climate-resilient practices, and monitoring and evaluating the impact of climate-resilient practices on resilience and methane emissions in smallholder goat production systems.

Keywords: Gender, Climate Change, Methane, Goats, Small Scale Farming.

INTRODUCTION

Smallholder livestock owners, comprising 20% of the global population, occupy most agricultural lands in Sub-Saharan Africa (SSA) despite high poverty levels (McDermott et al., 2010). They produce 70-80% of the world's food and contribute significantly to global greenhouse gas emissions (Ricciardi et al., 2018), with livestock accounting for 50-65% of global emissions in developing nations (Herrero et al., 2013). Small-scale, women-managed farms in the developing world have an increased goat population, potentially increasing methane output. To reduce methane emissions, supportive policies and investments in institutional capacities and technologies are required (Olczak et al 2023). The relationship between climate change and agriculture is characterized by gender-specific factors, with the small-scale livestock industry contributing significantly to climate change (Assan, 2021). Gender-inclusive approaches and gender-neutral animal species, such as goats, are essential in efforts to mitigate methane emissions. Smallholders in developing countries could play a crucial role in climate mitigation through methane reduction (O'Mara, 2011). Over 80% of the world's farms operate on less than two hectares, yet they provide approximately 80% of the food produced in Asia and sub-Saharan Africa (Modi et al 2024; Lowder et al. 2014).

The global goat population is approximately 1.1 billion and has grown significantly since the 1960s due to changing human incomes, food preferences, and climate change (Miller and Lu, 2019). In 2013, the goat herd reached over one billion heads, an increase of 34% from 2000. The global dairy goat population was estimated to be 218 million in 2017 (FAO 2019). The sheep population only increased by 10% during the same period, while the cattle population remained relatively constant at approximately one billion heads. Asia has the highest goat population, with China, India, Pakistan, and Bangladesh being the most populous (USAID, 2019). Goats are known for their hardiness and grazing ability, making them a vital resource for small-scale farmers (Kumar et al., 2013). The global goat population is increasing to over one billion, with a growing number of goats raised for milk production owing to increasing demand. Goats, a rapidly growing livestock population in low- and medium-income countries, are a crucial animal model for climate change because of their high thermal and drought resilience, ability to survive on limited pastures, and disease resistance (Erdaw and Beyene, 2022). Goat rearing is vital in developing countries' rural economies, aiding landless, marginal, and small farmers (Kumar et al., 2013).

Goats, previously considered inferior to cattle, can be profitable with low investment under semi-intensive and extensive management systems (Sharma et al., 2018). They provide quick returns owing to short generation intervals, high prolificacy, and related products. Goat production is a critical component of global livestock production and is gaining prominence because of the increasing demand for goat milk, meat, and other products (FAO, 2015). Developing countries are experiencing growth in goat milk and meat production as these commodities are crucial for sustaining millions of smallholder farm families (Lohani and Bhandari, 2021; Thornton, 2010). Given the increasing goat populations, scientific studies on methane reduction in goats should become a global and mainstream subject in climate change research (Darcan, 2000). Goats are a preferred choice for small-scale farmers in developing nations due to their unique characteristics, which may enhance their adaptability to climate change (Nair et al 2024). Their capacity to adapt to unforeseen climate pressures with minimal infrastructure and effort ensures a higher production system with reduced input. However, as ruminants that emit methane are associated with climate change, the rate of population growth worldwide is a significant concern.

Ruminant livestock contribute to half of global warming and reduce feed efficiency due to dietary energy loss (Arndt et al. 2021). Livestock, accounting for 8.5%-18% in developing nations, is particularly significant in Southern Sahara, where small ruminants make up 16% of total tropical livestock units (Otte and Chilonda, 2002). Supporting smallholders is crucial for sustainable development and climate change (Ricciardi et al. 2021). Although methane mitigation efforts have been implemented, a comprehensive exploration of sustainable methods is lacking in developing countries (Cobellis et al., 2016). Goats emit less methane per unit body weight than cattle and sheep, but their emissions vary based on diet, management systems, and environmental conditions (Pragna et al., 2018). Dietary manipulation can alter fermentation patterns, reduce emissions, and improve feed efficiency (Haque 2018). Younger plants such as clover, vetch, and chicory can reduce methane production due to their fermentable carbohydrates (Boadi et al. 2011). Enhancing feed quality in smallholder goat production can effectively reduce methane release from goats.

Gender inequality, climate change, and food and nutrition insecurity are significant socioeconomic and environmental challenges in low- and middle-income countries (Assan, 2021). Climate change and livestock production are gendered, necessitating gender equality for addressing these issues. Socioeconomic and gender analyses are crucial for developing gender-equitable agricultural policies that promote goat resilience farming systems (Huyer et 2021a). The sociocultural aspect of climate action should guide the agenda in these countries, recognizing the roles of men, women, and youth in methane reduction (Assan, 2015). Gender inequalities often hinder these efforts, but strategies based on sociocultural, economic, and environmental variations can mitigate their effects (Huyer, 2021). Research indicates that nearly two-thirds of poor livestock farmers are rural women, and their role in livestock development is complex (Aklilu et al., 2008). Research and interventions in goat farming are crucial for women's development and climate mitigation, despite challenges in prioritizing these efforts (Livestock in Development (LID) 2004). Collaboration between public and private sectors is necessary to find innovative, cost-effective, and gender-inclusive methods in climate mitigation efforts (Assan, 2022).

THE SIGNIFICANCE AND STATE OF GLOBAL GOAT PRODUCTION: TRENDS AND INSIGHTS

Goats significantly impact human socio-economic life, particularly in rural and less favored regions, as they convert low-quality natural resources into protein sources (Lohani and Bhandari, 2021; Dubeuf et al 2004). In developing countries, goats are increasingly vital for human nutrition, with their population growing more rapidly than that of sheep, indicating their increasing importance in food production. Goat production contributes significantly to sustainable food security, especially in low-income areas and marginal habitats (Erdaw and Beyene, 2022). Worldwide, the estimated goat population exceeds 860 million (Azizi, 2010), and recent trends indicate a growing demand for goat dairy products, especially in developing countries, where they serve as a substitute for dairy products from large ruminants to meet human dietary needs (Lérias et al., 2013). Goat milk is highly valued by both the poor and the rich, with Haenlein (2004) stating that 20 years ago, more people consumed goat milk than cow milk globally.

Goat production is a significant global livestock industry, with Asia leading the way, with 59.4% of the world's total goat population, followed by Africa (31.6 %). Asia also contributes to 58.35% of goat milk production Between 2000 and 2013, the global goat population grew by 33.8%, with an average annual increase of 2.6% (Chetroiu et al., 2013). Goat milk production also saw a significant increase, increasing by 39.2% between 2000 and 2012. Meat production from goats also increased by 41.66% between 2000 and 2012. Small ruminants constitute 6% of the total tropical livestock units (TLU) in sub-Saharan Africa (SSA) (Otte & Chilonda, 2002). Robinson et al. (2014) reported that the goat population in SSA reached 182.0 million heads. Between 2000 and 2013, global goat numbers increased by 33.8%, with Asia consistently maintaining the top position, accounting for approximately 59.4%. Owing to their high heat stress tolerance, goats can survive and produce in the world's most marginal regions (Danso et al 2024). Since the 1960s, there has been a steady increase in the global goat population, particularly in low-income countries or less-favored regions. In these nations, 54.50% of the total goat population was in 2000 (Erdaw and Beyene, 2022).

The world goat populations are classified into two those which are meant for meat production and those for dairy production (FAO, 2020). There are 1145.5 million goat heads (Mh) worldwide; of this amount, 214.01 Mh are classified as dairy goats (DGs). The goat population is five times larger than that of buffaloes, pigs, sheep, cattle, and chickens. From 2010 to 2020, the global goat population experienced the sharpest growth, increasing by 29.0% (Olmo et al., 2024). The global DG inventory (GDGI) showed a significant increase from 1970 to 2022, with the number of goat heads rising from 76.07 Mh in 1970 to 214.01 Mh in 2022 (FAO, 2020). The goat population was concentrated in Asia (51.4%) and Africa (43.3%), with the majority in southern Asia (56.3%) and eastern Asia (28.6%). Only 6.5% of Asia's 579 million goats are found in Southeast Asia. The rate at which goat populations are expanding is a major concern as a ruminant animal species that produces methane.

Goats as a small ruminant play a crucial role in income generation and households' social and financial security in developing countries (Assan 2022; Monau et al 2020; Omotosho et al 2020. They are an integral component of the pastoral production system, offering economic, managerial, and biological advantages (Kerven, 2024). They are conveniently cared for by women and children, occupy little housing space, lower feed requirements, and supply meat and milk in quantities suitable for immediate family consumption. They are kept for various reasons, including savings, investment, security, insurance, stability, and social functions. Goats are better able to withstand drought and have a short reproductive cycle, making them the most important component of livestock in pastoral and agro-pastoral production systems (Joy et al 2020). In contrast, large ruminants like cattle are concentrated and remain in the hands of a restricted number of producers, highlighting the legacy of sub-Saharan Africa's rural economy (FAO, 2020).

Goats are expected to meet the increasing demand for animal-sourced proteins and potentially increase methane production. The Food and Agriculture Organization of the United Nations (FAO) predicted an 88% global increase in sheep and goat meat consumption from 2000 to 2030, higher than beef (81%) and pork (66%) but lower than poultry (170%) (FAO 2011). The African continent has the world's second-largest inventory of dairy goats, with an annual average of 37%. The global imbalance in goat distribution highlights the link between the physiological benefits of goats and peasant or pastoral agriculture in challenging climatic regions (Kerven, 2024); Haenlein, 2004). This could have significant implications for methane production, despite their lower production compared with sheep and other ruminants (Soren et al. 2017; 2015).

Goats have historically significantly impacted human socio-economic lives, particularly in rural and less-favored regions (Dhanda et al 2003)). They provide a protein source and convert natural resources of low quality, making them a valuable source of protein in these regions. The high tolerance of goats to heat stress allows them to survive and produce in marginal areas (El Aich and Waterhouse 1999). When managed well, goats contribute to ecosystem preservation, weed control, wildfire incidence reduction, and rangelands and wildlife habitat improvement. Global goat populations have increased since the 1960s, particularly in low-income or less-favored regions (Erduran, et al 2024). However, goats and sheep face environmental challenges, such as the degradation of rangelands, competition for land use, and limited water availability. Climate change also poses additional difficulties for small ruminant farming, necessitating an increased policy for research, organization, and extension (Dubeuf, 2011).

The increasing global commercialization of goat products raises the question of how keeping goats contributes to climate change (Kerven, 2024). Livestock greenhouse gas emissions, including methane (CH4), were first recognized in 2006 with Livestock's Long Shadow report by the UN Food and Agriculture Organization scientists. Goats, domesticated by humans 10,000 years ago, are now raised worldwide (Amills et al., 2017; Hermes et al., 2020), With an estimated 1.1 billion goats, they are the third most common ungulate livestock after cattle (1.6 billion) and sheep (1.3 billion) (FAOSTATS, 2024). Goats are useful to humans and are one of the first animal species domesticated by humans (Lu 2023). Goats are highly adaptable because of their efficient use of fibrous woody material and resilience to extreme climates, making them crucial for poor farmers in Africa and Asia (Kerven, 2024; Peacock and Sherman, 2010).

THE NEXUS BETWEEN GOAT PRODUCTION AND METHANE EMISSIONS: IMPLICATIONS FOR CLIMATE CHANGE.

Methane gas produced during livestock production is a substantial source of greenhouse gas (GHG) emissions that have been linked to climate change. Methane is predicted to contribute 18% of global warming by the next 50 years, with livestock accounting for 9% of emissions (Milich, 1999). Domestic animals account for 94% of global emissions. Although emissions have decreased per unit of animal product, total emissions have increased due to a vast animal population. By 2050, ruminant livestock emissions are expected to increase significantly due to the growing demand for milk and meat (IPCC, 2007). Methane (CH4) is the second most significant greenhouse gas emitted from anthropogenic sources, with ruminants contributing to about 25% of all emissions (Wuebbles & Hayhoe, 2002; IPCC, 2006). Goat production is a significant contributor to methane (CH4) emissions, a potent greenhouse gas (GHG) that contributes to climate change (Kerven, 2024). With an estimated 1.1 billion goats in the world, goat farming is the third most common ungulate livestock after cattle and sheep (FAOStats, 2024). Goats generate 4.9% of total EME emissions from livestock, resulting in approximately 4.61 million tonnes of enteric methane. Methane is produced in the rumen of goats as part of the digestive process, where microorganisms break down cellulose and other complex carbohydrates (Cottle et al 2011). This process, known as enteric fermentation, produces methane as a byproduct, which is subsequently released into the atmosphere through goat manure, flatulence, and exhalation. Methane has a global warming potential (GWP) 28 times higher than that of carbon dioxide (CO2) over a 100-year period. Reducing methane emissions from livestock production can contribute to climate change mitigation efforts due to methane's shorter atmospheric lifetime compared to CO2 (Zhang et al 2023).

Ruminants are known to emit greenhouse gases through "enteric fermentation," a process where microbes break down food, releasing methane as a by-product (Pragna et al 2018). Enteric fermentation is the largest source of GHG emissions from ruminant production, accounting for 47% of total CH4 emissions, exceeding 90% of total emissions (Opio et al 2013). The rate of emission in terms of carbon footprint at the product levels is 6.5 kg CO_2-eq/kg FPCM for milk production from small ruminants. However, with regard to meat from ruminants, the carbon footprint for small ruminant meat is 23.8 kg CO_2-eq/kg meat. Methane production, a natural byproduct of anaerobic respiration, serves as the primary electron sink in the rumen and reduces enteric CH4 production, potentially improving feed efficiency (Li et al 2018; Ibáñez et al 2015; Johnson and Johnson 1995; Boadi et al. 2004). Numerous studies have examined the nutritional effects on CH4 production and developed models to predict CH4 emissions based on diet composition (Nedelkove et al 2024; Hristove et al 2022; Alem et al 2021). Goats emit less methane per unit bodyweight than cattle and sheep, but their GHG emissions vary based on diet, management system, and environmental conditions (Kerven, 2024). Extensive systems, where goats forage naturally, may result in low emissions due to carbon sequestration, while intensive systems utilize more cultivated energy feed, resulting in lower emissions but incurring carbon costs. For goats, this is particularly significant due to animal population trends and high demand for global goat milk consumption, resulting in higher methane emissions during production (Koluman Darcan, 2023).

Beauchemin et al (2008) reported various nutritional management strategies to reduce enteric methane (CH4) production in ruminants. These include increasing grain intake, lipid inclusion, and supplementation with ionophores. Improved pasture management, maize silage replacement, and legume use also hold promise for CH4 mitigation. New strategies like saponins, tannins, yeast cultures, and fiber digesting enzymes require further research. Most studies on CH4 reductions are short-term, highlighting the need for long-term sustainability and greenhouse gas budget impact. Feed management can decrease methane emissions from goats by improving feed quality and quantity (Goopy et al 2020). Goat grazing and browsing behavior decrease the consumption ratio of roughage to concentrated protein sources, suggesting that extensive pastoral livestock management may lower methane emissions per unit of output or animal head (Kumari et al 2020). Goat feeding is crucial for mitigating climate change's negative effects.

Reducing CH4 production ensures optimal economic returns from goat farming and minimizes its impact on global warming (Koluman- Darcan, 2023). In fact, goats emit less enteric methane per unit body weight than all other domestic ruminant animals. However, due to their tremendous increase in population, goats might increase their methane contribution especially in developing countries. Research is needed to understand goat productivity, especially nutritional interventions, which can impact rumen function and enteric methane emissions (Pragna et al 2018). Feed composition influences CH4 production, which can be reduced by increasing concentrate levels in diets (Beauchemin et al., 2008; Johnson & Johnson, 1995). Sauvant & Giger-Reverdin (2009) found that 35% to 40% grain incorporation in rations can lead to significant improvements in methane emissions, influenced by food intake. Hammond et al. (2011) found no significant differences in CH4 production between sheep fed fresh ryegrass or white clover, despite a two-fold higher difference in the ratio of easy fermentable carbohydrate: NDF. Sun et al. (2011) reported similar emissions from chicory and ryegrass.

Enteric CH4 can be reduced through three mechanisms: targeting digestion end products to propionate, providing alternative hydrogen sinks, and selectively inactivating rumen methanogens (Zhang et al 2023). Implementing nutritional interventions in goat diets can help mitigate enteric CH4 in smallholder farming sectors (Benchaar et al., 2001). However, elevated ambient temperatures may negatively affect these processes and ultimately influence CH4 production levels in goats, necessitating appropriate mitigation strategies to maintain goat production in changing climate scenarios (FAO, 2016). Efficient feed utilization in large goat populations can positively impact methane reduction, contributing to climate change mitigation (Soren et al 2015).

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THE INTERPLAY BETWEEN SMALLHOLDER GOAT FARMING CHARACTERISTICS AND RESILIENCE: LESSONS FOR CLIMATE CHANGE ADAPTATION

Goats have shown remarkable resilience in the face of climate change, thriving even in the most challenging agro-ecological zones (Parsad et al 2024). This adaptability suggests their potential as a sustainable livestock option in the current climate-induced environmental conditions. Encouraging goat rearing, known for its low methane emissions, is believed to have multiple benefits. Goat rearing has a multifaceted benefit such as reduce gender disparities, increase women's involvement in climate-smart agriculture, and consequently improve productivity and food security (Assan, 2022). The substantial population of goats, combined with their deep-rooted presence in rural communities, has consistently supported the livelihoods of resource-poor farmers in numerous ways, often making significant contributions. This discussion presents an overview of the potential for promoting gender-inclusive, climate-smart goat husbandry practices as a means of community empowerment. This approach offers a comprehensive solution to address the interconnected challenges of gender inequality, methane production, and climate change impacts, while simultaneously tackling food insecurity in developing countries.

Goats exhibit remarkable adaptability to various agro-climatic conditions and are exceptionally easy to manage compared to other livestock (Nedumaran and Muthuveni. 2023). These animals demonstrate greater resilience to climate changes than other ruminants and are well-suited for small-scale farming operations (Feleke et al 2016). A significant portion of the global goat population resides in arid and semi-arid regions prone to droughts and famines (Kumar and Roy, 2013). Nevertheless, goats are less affected by harsh climates than other ruminants, which are highly sensitive to subtle environmental changes (Agossou, et al 2017). The morphological versatility and unique browsing capabilities of goats enable them to adapt more readily to changing climates, making them a crucial source of livelihood for many impoverished and marginal farmers worldwide (Feleke et al 2016). Additionally, goats serve as a primary means of sustenance for women, children, and the elderly in tropical and subtropical areas (Bezabih and Berhane, 2014). Their small size requires less space and feed, allowing for easy integration into various farming systems (Kumar and Roy, 2013). In India, goat farming, often referred to as the "poor man's cow," is an essential component of dryland agriculture (Nedumaran and Muthuveni. 2023). It is particularly suitable for marginal or uneven terrains, making it an economical choice for small and marginal farmers.

Goats are ideal for smallholders due to their low capital requirements, adaptability to harsh climates, and higher consumption in rural households (Castella et al.2013; They are more often owned by women and have the potential to reproduce twins and triplets twice per year, making them more fertile than cattle, which produce single calves up to once per year (Hedge 2020). Goat farming holds considerable potential for boosting employment and reducing poverty among economically disadvantaged small-scale farmers in rural areas, as goats are easily managed and bred by men, women, and youth alike (IFAD 2021). Over the past decade, Southeast Asia, has seen a significant rise in goat demand, with even small per capita consumption impacting the total demand (Nguyen et al. 2023). This presents opportunities for rural development, as goats are primarily produced by smallholder farmers (FAO 2020).

Climate-smart goat farming for small-scale farmers in low and high incomes countries can be targeted in an effort to reduce methane emissions, improve productivity, and achieve gender-inclusive socio-economic benefits (Darcan and Silanikove, 2018). Methane, a potent greenhouse gas, is significantly emitted by goat farming (Kerven, 2024). Innovative practices and technologies can lower these emissions in goats, contributing to global temperature control efforts and air quality improvement (Sintori and Tzouramani, 2015). Strategies typically focus on enhancing animal nutrition, which improves health, productivity, and lowers mortality rates, all of which have a bearing on reducing CH_4 (IPCC, 2006). Goats, as low enteric methane emitters and resilient to climate impacts, are valuable for mitigation and adaptation (Kerven, 22024). Goat farming facilitates women and youth entrepreneurship due to minimal investment requirements and small herd sizes, supporting women's empowerment (Assan, 2015). At the global symposium on climate action, deliberations continue regarding strategies to mitigate methane emissions from ruminants, with the objective of developing environmentally sustainable livestock systems for small-scale agricultural producers (Koluman, 2023).

EXPLORING THE POTENTIAL OF NUTRITIONAL INTERVENTIONS TO DECREASE ENTERIC METHANE PRODUCTION IN SMALL-SCALE GOAT FARMING SYSTEMS

Nutritional interventions through dietary manipulation can reduce CH4 emissions by up to 40%, depending on the intervention and degree of change (Benchaar et al 2001). Better nutrition can potentially reduce CH4 emissions by up to 75% (Hammond et al 2013). Dietary strategies can be divided into improving forage quality and changing diet proportions, and supplementing feed additives to inhibit methanogens or alter metabolic pathways, reducing substrate for methanogenesis (Boadi and Wttenberg, 2002). Dietary manipulation is a practical and straightforward approach to CH4 mitigation that can enhance goat productivity and decrease CH4 emissions (Kerve 2024). Climate-smart goat farming has the potential to reduce goat methane emissions via dietary manipulation, emphasizing the dual advantages of improved production and reduced GHG emissions. This strategy will be effective if it encompasses forage management, feed preservation, and feeding techniques to reduce methane emissions, increase productivity, and enhance carbon sequestration through forage production. The type of feed allowed to goats can have a major effect on methane production. Forage to concentrate ratio of the ration has an impact on the rumen fermentation and hence the acetate to propionate ratio (Olijhoek and Lund, 2017). It would therefore be expected that methane production would be less when high concentrate diets are fed (Finlay et al 1994).

Diet composition and intake of feed are main factors affecting CH4 production by ruminants (Sauvant and Giger-Reverdin, 2009). Ruminant fed forages rich in structural carbohydrates produce more CH4 than those fed mixed diets containing higher levels of non-structural carbohydrates per unit of fermented material in the rumen (Haarlem et al 2008). The composition of feed or the quality of forage influences CH4 production in ruminants. Digestion in the rumen is dependent on the activity of microorganisms, which need energy, nitrogen and minerals (Chianese et al 2009). Therefore, the quality of forage affects the activity of rumen microbes and CH4 production in the rumen. Forage species, forage processing, proportion of forage in the diet, and the source of the grain also influence CH4 production in ruminants (Johnson and Johnson 1995). Methane production tends to decrease as the protein content of feed increase and increases as the fiber content of feed increases (Boadi et al. 2004). Methane production is positively related to diet digestibility and negatively related to dietary fat concentration, whereas dietary carbohydrate composition had only minor effects (Sauvant and Giger-Reverdin, 2009). Production of CH4 has a negative impact on animal productivity, resulting in lost energy ranging from 2% to 12% of the animal's GEI (Haarlem et al 2008).

Generally, as the daily feed intake increases, CH4 production also increases (Shibata and Terada, 2010). Most studies agree that dry matter intake (DMI) is the main driver of daily methane output although methane output per kilogram of DMI decreases with increasing feeding level, diet digestibility, and with increasing proportions of concentrates or lipids in the diet (Grainger et al 2007; Beauchemin et al 2009). The diet of ruminants significantly influences the intensity and yield of enteric methane emissions (Bosher et al, 2024; Tseten et al, 2022; Getiso and Mijena, 2021). Dietary factors, such as feed quality, fiber content, concentrate vs. forage ratio, starch content, fat content, and protein content, are the main cause of variation in methane production between animal populations or individuals (Lileikis et al, 2023). Understanding these dietary factors can help create measures for reducing methane generation in ruminants, such as improving ingredient combinations and nutritional management approaches (Beauchemin et al., 2019). Rumen composition and digestibility significantly impact methanogenesis, affecting H2 concentrations and substrate availability for fermentation.

Diets with higher energy availability or digestibility can decrease methane output per energy-corrected milk yield (Patra, 2013). High-starch diets can increase methane production due to starch fermentation by rumen microbes, while high-fat diets can reduce methane production as fat inhibits methanogenesis. Poor quality feed can lead to increased methane production due to reduced digestibility and fermentation (Huang et al, 2021). Certain feed additives, such as ionophores, can reduce methane production by inhibiting methanogenic microbes (Tseten et al, 2022). The impact of an animal's digestive physiology on its methanogenic output is significant (Smith et al., 2022). The availability of substrates for methanogenesis is essential for ruminant metabolism, as the fermentation of carbohydrates into volatile fatty acids and microbial protein synthesis releases CH4 (Goopy et al., 2013, 2014). Low levels of methane emissions in livestock result in physiological differences, such as smaller rumens, altered microbial fermentation profiles, and a greater ratio of propionate to butyrate in volatile fatty acids (Bain et al., 2014; Pinares-Patiño et al., 2011; Jonker et al., 2018).

Supplementing forages whether of low or high quality, with energy and protein supplements, is well documented to increase microbial growth efficiency and digestibility (McAllister and Newbold, 2008). Milk and meat production will increase as a result. The direct effect on methanogenesis is still variable and unclear, but indirectly, methane production per unit product will decline. Increasing the level of non-structural carbohydrate in the diet (by 25%) would reduce CH4 production by as much as 20%, but this may result in other detrimental effects including acidosis, laminitis and fertility problems. In addition, many other factors which affect CH4 production like season, age of animal, management of animal, and population of protozoa in the rumen (Forster et al 2007). Grazing animals produce more methane than indoor-fed animals due to differences in feed quality and composition (Danielsson et al., 2017). Dietary supplements, like essential oils and plant extracts, can reduce methane production by modulating rumen fermentation (Beauchemin et al, 2008). Factors influencing methane production from enteric fermentation include feed intake, feed composition, and energy consumption. Improving the nutritional quality of grazed forage can enhance animal growth rates and reduce lifetime emissions (Quninton et al., 2018).

GENDER, CLIMATE ACTION, AND METHANE REDUCTION: UNDERSTANDING ROLES, RESPONSIBILITIES, AND OPPORTUNITIES

Research has demonstrated that approximately two-thirds of the world's billion impoverished livestock farmers are rural women (Staal et al., 2009); consequently, any adaptation intervention, such as minimizing methane production in animal production, is likely to be effective if gender concerns are addressed. The role of livestock in women's livelihoods is complex, making it challenging to generalize their economic contributions to livestock development (Bravo-Baumann, 2000; Njuki et al., 2001; Herath, 2007). Nevertheless, there are key aspects that support the role of women in livestock production and climate adaptation, particularly their involvement in feeding and watering animals and fodder production in mixed crop and livestock systems and agroforestry technologies. Prioritizing livestock research and interventions for women's development presents challenges; however, there is evidence for the significant role of livestock in women's development (Livestock in Development (LID), 2004; Aklilu et al., 2008) and climate change adaptation in livestock production. Data from several developing countries indicates that impoverished women may and do keep livestock, encompassing a range of small-scale livestock and farming practices and animal types. It is evident that if climate change initiatives pertaining to livestock farming are to be successful, women must be included (Deshingkar et al., 2008; Flintan, 2008; Niamir-Fuller, 1994; Rangnekar, 1998).

A gender-focused, climate-smart approach centered on goats has the potential to transform rural agrarian food systems by reducing methane emissions, fostering climate change adaptation in agriculture, addressing gender inequality, and improving food security and nutrition in developing nations (Assan, 2015). The intertwined challenges of gender disparity in agro-food production systems and methane-induced climate change have been largely overlooked in small-scale agriculture and food systems, indirectly affecting climate mitigation efforts (Huyer, et al 2021). This goat-centered strategy can enhance resilience in vulnerable communities, which is crucial given the escalating impacts of climate change (Herrero et al 2011). The changing climate poses significant threats to goat production systems in Africa and Asia, where goats are predominantly raised, endangering food security and livelihoods, especially in rural areas (Herrero et al 2009). Traditional goat farming practices are being challenged by extreme weather events, altered precipitation patterns, and rising temperatures (Thornton and Herrero, 2010).

The influence of gender dynamics on goat management affects breeding stock availability and productivity, and incorporating these factors may lead to improved breeding outcomes (Assan, 2021). Research by Amole et al (2024) highlights gender roles in feed production and management, with men and youth more involved in most activities. This concept can be extended to climate action, such as reducing methane emissions. The interconnection between gender roles and climate change action provides a foundation for more sustainable and multifaceted approaches to addressing climate issues (Huyer et al 2021). A gendered climate-smart goat-centered approach empowers men, women, and youth in agriculture to meet household food needs (Assan, 2021). This strategy maintains animal production due to goats' adaptability to harsh climate-induced conditions (Paudyal et al 2019) and reduces methane production through efficient feed utilization (Getiso and Mijena, 2021). It serves as an effective component of climate action for low and medium income countries, addressing the interconnected socio-economic and environmental challenges of climate change. Promoting gender-inclusive climate-smart goat husbandry practices empowers communities, reduces methane production, mitigates food and nutrition insecurity, and capitalizes on opportunities to offset climate change adversities (Rao and Moharaj, 2023). Women are often more susceptible to climate change's effects on agricultural production, which can compromise food and nutrition security (Acosta et al 2021).

Worldwide, both governmental agencies and non-governmental organizations have advocated for goat rearing as a means to alleviate rural poverty, particularly in harsh dry or semi-arid tropical regions (Vries 2008). Women play a vital role in various aspects of animal husbandry, including goat care, feed collection, birthing assistance, and management of diverse livestock such as poultry, pigs, dairy cattle, fish, and ducks (Assan, 2022). Climate-smart goat rearing is instrumental in eliminating systemic barriers that hinder women's equal participation in agriculture by expanding their socio-economic opportunities, thus playing a significant role in agricultural value chains and climate action (Kerven, 2024). The concept of climate-smart goat rearing and sustainability is predicated on establishing and maintaining conditions where men, women, youth, and nature can coexist productively, enabling the fulfillment of social, economic, and other requirements for present and future generations through reduced methane production.

When developing strategies to enhance feed utilization and reduce methane emissions in goats, it is crucial to consider gender dynamics within households. While women are recognized as key players in goat production, there is a paucity of information on climate change initiatives targeting methane reduction that also promote gender equality. Studies on gender roles in the goat value chain, including how gender relations affect access to resources for methane reduction and the benefits of mitigation strategies, are often poorly integrated or absent from goat development and husbandry practices (Kristjanson et al., 2010). To address this gap, research and development partners in smallholder projects should create an analytical climate action framework and implementation guidelines to promote gender equity in methane reduction efforts for smallholder goat farming. This article aims to emphasize the importance of bridging the gender gap in climate-smart goat farming to decrease methane emissions.

Ayoade et al., (2009) noted similar findings, with women generally managing animal feeding, which is crucial for minimizing methane production. Research by Amole et al (2024) highlights gender roles in feed production and management, with men and youth more involved in most activities. Developing effective and sustainable solutions to feed scarcity requires evaluating existing and potential feed resources, their utilization, associated challenges, and gender roles in goat husbandry at the household level. Feed availability fluctuates seasonally, with scarcity during dry periods. The study found that most livestock feed-related constraints affect both male and female households. To effectively impact animal management, interventions in areas where women are responsible (such as milking, young stock care, and poultry feeding) should target women, regardless of animal ownership. Kristjanson et. al., (2010) suggest that women should be more involved in technology design, testing, and dissemination processes which are critical for enhancing adaptive capacity in any livestock production system.

Understanding gender roles in goat farming is essential for enhancing goat nutrition and productivity using local feed resources which can impact on methane production. This includes examining goats as assets, production systems, gender dynamics within households, and decision-making processes which are critical offset vulnerability and impart resilience in local farming communities. Women primarily gather feed for goats, which consists of natural pasture, crop residues, and other resources that vary based on geography, topography, season, and climate. These activities have a bearing as coping strategies in goat farming. The growing population's demand for animal-derived foods is challenged by climate risks, erratic precipitation, and environmental limitations in semi-arid regions, leading to feed scarcity and reduced productivity. To tackle these challenges and enhance goat farmers' adaptability, a gender-sensitive diagnostic approach is necessary to assess feed availability at the household level. This approach aims to develop site-specific solutions for improving feed supply and utilization, recognizing that technological or organizational interventions are crucial for climate adaptation. The main goal is to boost goat production and nutrition by leveraging locally available feed resources, acknowledging women's pivotal role in managing feeding strategies essential for climate adaptation.

IMPLICATIONS

A comprehensive, sustainable, gender-inclusive, and cost-effective mitigation strategy for small-scale livestock systems remains elusive and needs consideration in climate action. While methane reduction efforts have become central to goat production systems in developed countries, there is a lack of comprehensive or consolidated studies assessing methane emissions reduction from small-scale livestock systems, particularly those involving goats, and their impact on climate change in developing countries. To combat climate change and variability, efforts to reduce gender disparities and intersectional differences in smallholder goat production systems should include minimizing methane emissions from small-scale ruminant farming. Gender inequality has been a primary factor in the low productivity of small-scale food systems in developing countries, and this issue may extend to attempts to decrease methane emissions from rural agricultural economies' small-scale ruminant production systems.

Women, due to their roles and numerical advantage in low- and middle-income countries' small-scale goat production systems, should be included in strategies to reduce methane emissions from small-scale ruminant production. Targeting equitable smallholder goat production systems for methane reduction is crucial for achieving SDG 5, which focuses on gender equality and supports progress across all other SDGs. Implementing gender-transformative change in goat-food systems requires a holistic, inclusive approach to dismantle barriers and mitigate climate change by reducing methane emissions. Advancing gender equality and women's empowerment in goat food systems will help close productivity gaps and reduce methane emissions, thereby addressing intersecting social differentiation.

Fostering a climate-smart goat farming industry that aims to reduce methane emissions from small-scale agricultural operations while simultaneously promoting gender equality and enhancing food security to achieve MDGs in developing nations is essential. Addressing gender inequalities is crucial for effective methane reduction strategies, and bridging the gap in small-scale goat systems can make a substantial contribution to tackling climate change. Achieving sustainability smallholder livestock systems requires addressing social and environmental carbon footprints and targeting gender-inclusive, cost-effective methane mitigation strategies with positive socio-economic returns. Gender-responsive climate action that monitors and evaluates the goat production value chain can achieve this, addressing gender roles, responsibilities, and benefits that support methane reduction in smallholder goat production and identifying unintended consequences. It is imperative to note that any methane reduction strategy in ruminant-based enterprises within low- and middle-income countries must take into account sociocultural, economic, and environmental specificities; without such a comprehensive approach, no endeavor can be deemed successful.

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