Women Empowerment through Climate Resilient Agricultural Technologies for Sustainable Food Systems

2025

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Programme Coordination

ICAR- Central Institute for Women in Agriculture, Bhubaneswar
&
National Institute of Agricultural Extension Management, Hyderabad

03-07 February, 2025

Published By

ICAR-Central Institute for Women in Agriculture
Bhubaneswar, 751 003, Odisha

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Citation: Tania Seth, N. Balasubramani, Arpita Mohapatra, Mridula Devi (2025). *Women Empowerment through Climate Resilient Agricultural Technologies for Sustainable Food Systems* [E-book]. ICAR-Central Institute for Women in Agriculture, Bhubaneswar, Odisha.

Published by:

The Director
ICAR- Central Institute for Women in Agriculture
ISO 9001-2008 certified
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ISBN Number: 978-81-985291-0-7

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Foreword

In India, women farmers rely deeply on agri-allied sectors for their livelihood and socio-economic needs. Women produce, procure and prepare majority of the food, offer ecosystem services and manage natural resources. Women farmers involved in agri-food system are more vulnerable to climate change as compared to men for several social, cultural, technological and economical issues, like poor access and control over resources, inadequate social contacts, poor technological knowledge and decision making ability as well as high reliance on rainfed agriculture and other non-climatic barriers. Therefore, agri-food system needs women-led transformation through climate resilient interventions so that with limited resources the food and nutritional security of burgeoning population can be addressed in a sustainable way to achieve all the dimensions of sustainability. Climate smart interventions in agriculture and animal husbandry sectors like conservation agriculture, crop diversification, stress resistant varieties, rain water harvesting, soil carbon sequestration, precision farming, integrated nutrient management, integrated pest management, waste management, livestock genetic improvement, digital management of animal for climate smart diets will enhance the food production and improve the livelihood of farmers. ICAR-Central Institute for Women in Agriculture (ICAR-CIWA) is an institution, exclusively devoted to gender related research in agriculture. ICAR-CIWA has a mandate of undertaking research on gender issues in agriculture and allied fields, gender-equitable agricultural policies/ programmes and gender-sensitive agricultural-sector responses and coordinating research through its 13 AICRP on WIA centres. ICAR-CIWA also stressed upon creating awareness among farm women about climate smart technologies through various sensitization programs under OIIPCRA, NICRA and ICAR-ILRI collaborative projects. The publication on 'Women Empowerment through Climate Resilient Agricultural Technologies for Sustainable Food Systems' documented the recent advances in climate resilient technologies in agri-allied sectors and devising appropriate women friendly strategies for sustainable food systems.

I appreciate the team of ICAR-CIWA, Bhubaneswar for organizing this collaborative training program with MANAGE, Hyderabad, Telangana on 'Women Empowerment through Climate Resilient Agricultural Technologies for Sustainable Food Systems' from 03-07 February 2025 and bringing out the publication which would prove beneficial to the stakeholders for developing and refining the climate resilient agricultural technologies with women perspective for wider scale adoption in the agrarian families.

(Dr. Mridula Devi)

Preface

Agriculture is the backbone of Indian economies, particularly in rural areas where women play a critical role in ensuring household food security, nutrition and livelihoods. Despite their substantial contributions, women often face significant challenges, including limited access to resources, climate change threats and socio-economic barriers. To address these challenges, empowering women through climate-resilient agricultural technologies is essential for fostering sustainable food systems.

The compendium, *Women Empowerment through Climate-Resilient Agricultural Technologies for Sustainable Food Systems*, is designed to equip women farmers, extension workers, researchers and policymakers with the necessary knowledge and skills to enhance agricultural productivity, adapt to climate change, and build resilient communities. It provides practical insights into climate-smart agricultural practices, innovative farming techniques, and gender-responsive strategies that promote sustainable development. This e-compendium covers key topics such as climate change adaptation strategies, sustainable farming methods, efficient resource management, and the integration of digital tools in agriculture. Special attention is given to fostering women's leadership, decision-making capabilities and access to financial and technological resources to bridge the gender gap in agriculture. By adopting the principles outlined in this manual, stakeholders can contribute to creating inclusive and resilient food systems that empower women and ensure a sustainable future for all. It is our hope that this resource serves as a catalyst for positive change, inspiring individuals and communities to champion women's empowerment in agriculture as a means to achieve food security and climate resilience.

We extend our sincere gratitude to all contributors who have played a pivotal role in the development of this manual. We also acknowledge the women farmers whose invaluable experiences and agricultural researchers whose dedication and insights help to develop women friendly climate smart technologies that can drive progress in sustainable agriculture. Together, let us work towards a future where women’s empowerment in agriculture is not just an aspiration but a reality that strengthens food systems and enhances community resilience in the face of climate change.

03 February 2025 **Editors**

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Role of Women in Sustainable Food System

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Food is a central element of the United Nations' Sustainable Development Goals (SDGs), which define the global development agenda for the 21st century. SDG 2 specifically focuses on ‘ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture’. In India, the situation is dire, with the highest child "wasting" rate globally at 18.7%. Over 35% of children in the country are stunted, and around 16.6% of the overall population suffers from undernourishment. More than 50% of women and adolescents are anaemic, highlighting severe under-nutrition (NFHS 5).

The issue is not confined to India alone. Worldwide, food insecurity is rising, with nearly 9% of the global population experiencing food insecurity (FAO, 2020). To achieve the SDG target by 2030, a fundamental transformation of the global food and agriculture system is required to ensure universal food security. Achieving food security is impossible without sustainability. In today's world, sustainable food security necessitates a comprehensive approach that addresses emerging global challenges, such as climate change, population growth, economic inequality, rising energy costs, and technological advances in resource-efficient agricultural practices (Berry et al., 2015). Over time, the definition of food security has broadened to include not only the availability of food but also its accessibility, affordability, and acceptability (nutritional value) (Faizan et al., 2023). To build a sustainable food production system, it is crucial to implement resilient agricultural practices that increase productivity while protecting ecosystems. These practices must be adaptable to the challenges posed by climate change and extreme weather events, such as droughts, floods, and other natural disasters. Additionally, they should improve soil and land quality over time, promote social and gender equity, ensure equal opportunities for all, and support the economic viability of all stakeholders involved in the food system.

Key features of sustainable food system

A sustainable food system is one that produces, processes, and consumes food in ways that are environmentally responsible, socially equitable, and economically viable, ensuring the well-being of both current and future generations. Its core objective is to meet the nutritional needs of all individuals while minimizing environmental harm and promoting social equity. A sustainable food system should be resilient to climate change, technologically advanced, accessible, and affordable, while also prioritizing nutritional security and inclusivity for all communities. It integrates sustainability at every stage of the food value chain, from input sourcing to production, processing, marketing, and consumption (Christophe et al., 2019).

Input Source: Inputs such as seeds, water, fertilizers, and energy are essential to agricultural systems. These should be organic or regenerative, minimizing the use of chemical inputs, and designed to reduce and conserve natural resources, thereby minimizing environmental impact. Sustainable input practices help preserve ecosystems and contribute to overall food system sustainability.

Production Practices: Sustainable agriculture focuses on eco-friendly practices such as crop diversification, soil conservation, crop rotation, and water-efficient farming techniques. These practices help reduce carbon emissions, promote biodiversity, and improve land and soil health over time. They also support social equity by ensuring fair wages, good working conditions, and social justice for agricultural workers (Coulibaly et al., 2021).

Processing: Sustainable food processing emphasizes reducing waste, conserving energy, and preserving the nutritional value of food while minimizing environmental harm. This includes using eco-friendly packaging, energy-efficient machinery, and implementing waste reduction strategies that improve the efficiency of food processing systems.

Marketing and Consumption: In the marketing phase, sustainability is promoted through transparent labeling that educates consumers about the environmental and social benefits of products. Sustainable consumption encourages consumers to make informed choices by supporting local and sustainable food options, reducing food waste, and opting for products with minimal environmental impact (Varžinskas and Markevičiūtė, 2020).

The key features of sustainable food system include following aspects

1. ***Climate-Resilient Practices***

Climate variability has a significant impact on food security. Droughts, floods, heatwaves, and changing precipitation patterns threaten crop yields and food production (Mirzabaev et al., 2023). Climate-smart agriculture practices such as drought-resistant crops, water-efficient irrigation systems and agro-forestry can help to reduce vulnerability to climate shocks. Ecological farming principles, such as crop diversification, intercropping, and conservation tillage, can enhance resilience while reducing dependency on synthetic chemicals (Jones et al., 2023). Sustainable land management practices like rotational grazing and reduced tillage also help protect soil health and prevent desertification, contributing to long-term food production.

2. ***Technological Firmness***

Technologies such as GPS, sensors, and data analytics are transforming agriculture through precision farming, optimizing resource use and improving crop yields (Getahun et al., 2024). Genetically modified organisms (GMOs) or gene-edited crops designed to withstand pests, diseases, or extreme weather conditions offer a more stable food supply and can reduce crop losses. Innovations in plant-based proteins, lab-grown meat, and edible insects present new, more sustainable protein sources, addressing concerns about the environmental and ethical impacts of traditional meat production.

3. ***Accessibility and Affordability***

Ensuring food is affordable for all, especially vulnerable populations, is fundamental to achieving food security (Pérez-Escamilla, 2017). Policies aimed at reducing poverty, providing subsidies for nutritious foods, and promoting equitable economic growth are essential to making healthy food accessible. Enhancing transportation, storage, and market infrastructure is crucial for reducing food losses, particularly in rural or underserved areas. Shifting from monoculture farming to more diversified, plant-based diets can also enhance food security by reducing dependence on a few staple crops that are vulnerable to pests, diseases, and climate shocks. Promoting indigenous and underutilized crops can boost dietary diversity and improve overall food security. Strengthening local food systems, supporting smallholder farmers, and fostering food sovereignty can enhance resilience to global disruptions and reduce dependency on international trade.

4. ***Nutritional Security***

Sustainable food security goes beyond calorie availability; it emphasizes access to a balanced and nutritious diet, including essential micronutrients such as vitamins, minerals, and protein. Increasing the nutritional value of staple crops through fortification or bio-fortification can help combat deficiencies in critical nutrients like iron, zinc, and vitamin A. Nutrition education and policies that promote healthy eating habits, particularly in low-income communities, are essential for addressing poor diets that often correlate with food insecurity.

5. ***Inclusive Empowerment***

Women play a crucial role in food production and distribution, particularly in developing countries. Ensuring women have access to land, credit, education, and decision-making opportunities enhance agricultural productivity and food security (Dwomoh et al., 2023). Smallholder farmers are pivotal to food systems, and providing them with financing, technology, services, and market access can reduce poverty and boost food security. Incorporating indigenous knowledge alongside modern technologies promotes sustainable practices tailored to local conditions, helping to ensure that food systems are inclusive and locally relevant.

6. ***Waste Reduction***

Food waste is a major challenge, with approximately one-third of all food produced globally being lost or wasted. Reducing food waste at the consumer, retail, and household levels is critical for improving food security and sustainability. Strategies to minimize waste include improving food storage, enhancing distribution networks, and encouraging consumers to reduce waste through education and behavior change initiatives. Reducing food waste not only conserves resources but also helps ensure that food produced reaches those who need it most, contributing to a more sustainable food system.

So, building a sustainable food system requires a holistic approach that integrates environmental, social, and economic considerations at every stage of the food value chain. Through resilient practices, technological innovation, equitable access, nutritional security, and waste reduction, we can create a food system that supports the needs of current and future generations while minimizing harm to the planet.

Role of women in building and maintaining food security

Women play essential roles in maintaining all four pillars of food security: availability, access, utilization, and stability. Their contributions are critical in ensuring food security at both household and community levels, as they take on multiple responsibilities in food production, household management, and the preservation of food systems, particularly in times of economic and environmental challenges.

1. Food Availability through Food Production

Major Contributors to Labor Force: In India, women make up 33% of the agricultural labor force and 48% of the self-employed farmers. With increasing urban migration of men, the agricultural sector is increasingly managed by women. These women contribute to agriculture in various roles as cultivators, entrepreneurs, and laborers. It is estimated that 60–80% of the food produced in India can be attributed to the efforts of rural women. They are involved in various stages of food production, from planting and harvesting to post-harvest activities such as processing and marketing.

Diverse Roles: Rural women are also involved in allied fields such as livestock rearing, horticulture, dairying, post-harvest operations, fishing etc. They carry out the most labor-intensive manual tasks in agriculture, including cattle management, fodder collection, milking, threshing, and winnowing. Additionally, rural women play a crucial role in community management, ensuring the dissemination of information and agricultural extension services at the local level. Their work contributes significantly to household food security and the local economy.

2. Food Access

Health and Well-being: Women are often primarily responsible for household food preparation and ensuring the nutritional quality of meals. Their decisions around food choices, including selecting diverse, nutritious crops and ensuring the proper storage and processing of food, directly impact family health and food security. The value-added food products created by women can also contribute to improved health and well-being. They often serve as health educators within their households, teaching family members about nutrition, hygiene, and the importance of a balanced diet. Their knowledge and management of food utilization directly impact the overall health and well-being of the family, particularly in terms of preventing malnutrition and diet-related diseases. By focusing on nutritious and local ingredients, women help promote healthy diets within their communities.

Resource Management: Women often manage the household's income, allocating resources for food purchases, healthcare, and education. Their ability to wisely allocate limited resources is essential in ensuring that families can consistently access adequate food, even in times of financial constraint.

3. Food Utilization through Processing and Preservation

Women are typically responsible for the preparation of meals and ensuring that food is nutritious and safe for consumption.

Post-Harvest Activities: In many rural areas, women are responsible for post-harvest activities such as cleaning, sorting, drying, and packaging crops. These tasks are essential for preserving the quality of food and extending its shelf life, which helps in ensuring food security, especially during off-seasons.

Traditional Preservation Techniques: Women are at the forefront of adding value to primary agricultural products. They often use traditional methods such as fermenting, drying, pickling, and canning to preserve food. These techniques not only reduce food waste but also ensure that food are available year-round, contributing to sustainability. Women often use sustainable and environmentally friendly methods in food processing. For example, solar dryers, eco-friendly packaging, and energy-efficient cooking techniques can help reduce the environmental footprint of food production and processing.

Small-Scale Food Processing: Women are frequently involved in small-scale food processing businesses, such as making jams, sauces, pickles, dried fruits, and beverages. In case of milk they prepare dahi, cream, ghee, paneer, sweets etc. This adds value to raw agricultural products, improves household incomes, and fosters local food systems.Through innovative processing and preservation techniques, women also play a significant role in reducing food waste. By utilizing excess harvests, imperfect produce, or food by-products, women contribute to a more sustainable food system. For example, turning fruit peels or vegetable scraps into snacks, jams, or animal feed.

4. Food Stability through Sustainable Practices

Food Stability is a crucial aspect of food security, referring to the ability of a food system to consistently provide adequate quantities of nutritious food over time, even at the time of shocks or disruptions. This concept encompasses the stability of food production, food access and food utilisation ensuring that people are not exposed to fluctuations in food availability, prices, or quality that could jeopardize their nutritional needs. Women can play a crucial role in ensuring food stability by granting them decision-making power and empowering them in all aspects of the food system. When women have the ability to make decisions about food production, distribution, and household nutrition, they are better equipped to enhance food security for their families and communities. Empowering women through access to resources, education, and leadership opportunities not only improves agricultural productivity but also strengthens the resilience of food systems, leading to greater stability in times of crisis or uncertainty.

Knowledge of Sustainable Practices: Women are often caretaker of traditional agricultural knowledge, including sustainable farming methods such as agroecology, crop rotation, seed saving, and organic farming. They contribute to sustainable agriculture by applying these practices to improve soil health, conserve water, and protect biodiversity. Women often preserve local, indigenous food knowledge, which includes the cultivation of native and climate-resilient crops that contribute to diverse diets and sustainable food systems. They often safeguard and pass down the knowledge of food preservation methods and nutritional practices that support long-term food sovereignty. Women are at the forefront of developing strategies to adapt to climate change.

Crisis Management and Resilience: Women are crucial in ensuring food stability, particularly during times of economic hardship, food price inflation, or natural disasters. They manage household food supplies by carefully planning meals, storing food for lean seasons, and often engaging in income-generating activities to cope with economic shocks.

Adaptation and Risk Management: Women are often on the frontlines of managing the stability of food supplies, utilizing their knowledge of local food systems and coping strategies to adapt to changing circumstances. This may involve diversifying crops, practicing sustainable farming techniques, or engaging in food preservation practices to minimize losses during tough times.

The Gender Division of Labor

The roles, responsibilities, and activities assigned to women and men based on gender are often shaped by cultural, social, economic, and historical factors. These roles, commonly referred to as gender roles. Recent comparative research on the 'feminisation' of agriculture and natural resource management, undertaken by ICIMOD and supported by IFAD, illustrates this trend, whereby in some mountain regions in India women undertake 4.6 to 5.7 times the agricultural work men carry out.n agriculture, women play a vital role in**food production**, particularly in small-scale and subsistence farming, where they handle tasks like planting, weeding, harvesting, and managing crops and livestock. Women are also primarily responsible for **livestock care**, including milking, feeding animals, and maintaining animal health. Additionally, they are deeply involved in **post-harvest activities**, such as sorting, cleaning, drying, processing, and preserving food through methods like drying, canning, and pickling. Women often engage in **agro-processing and value addition**, creating products like jams, pickles, juices, and handicrafts.

Men, on the other hand, typically take on physically demanding tasks like **land preparation** and **crop management**, including ploughing and using heavy machinery. They are usually responsible for **marketing and selling** agricultural products and managing financial transactions. In many communities, men hold **decision-making power** over land ownership, crop selection, and other major agricultural decisions, reinforcing traditional gender roles in agriculture.

Due to gender division of labour women often bear the brunt of unpaid and less-recognized work. It limits their decision making ability, forced to do labour intensive works, gets limited access to technology and remain vulnerable even after their exhaustive contribution in agriculture.

Addressing Gender Disparities in Food Systems and Value Chains

Gender mainstreaming is the process of assessing the implications for women and men of any planned action, including legislation, policies or programmes, in all areas and at all levels. It is a strategy for bringingequality for women and men. For addressing gender disparity gender related issues need to be identified.

1. **Access to Resources and Assets**: Ensuring women have equal access to land and a property right is fundamental to closing gender gaps in food systems. Policies that recognize women as landowners and grant them legal rights to land are essential. This includes protecting women's rights to inherit and control land.

2. **Access to Credit and Finance**: Women often lack access to credit, loans, or financial services, which limits their ability to invest in agriculture or food-related businesses. Financial institutions and government programs should be designed to support women's access to capital, with loans and grants targeted toward female farmers and entrepreneurs.

3. **Access to Technology and Inputs**: Providing women with access to modern farming technologies, high-quality seeds, fertilizers, and irrigation systems can boost agricultural productivity. Additionally, promoting gender-sensitive extension services and training programs can empower women to adopt new agricultural innovations.

4. **Gender-sensitive agricultural education programs and capacity building (Gender-Inclusive Training and Extension Services)**: Agricultural education programs and capacity building should be developed to equip women with skills in modern farming practices, crop management, livestock care, and agro-processing. Promoting leadership training for women in agricultural and food systems will help ensure they take on influential roles. This could include creating mentorship programs and offering platforms for women to engage in decision-making around food security, land use, and market strategies.

5. **Women friendly technologies**: Introducing labor-saving technologies and practices can help reduce the time women spend on manual agricultural and household tasks. This allows women to engage more effectively in other income-generating activities, such as value-added processing or selling agricultural products.

6. **Improving Market Access and Economic Opportunities**: Women's participation in agricultural value chains often faces barriers to accessing markets due to limited networks or lack of information. Strengthening women's market access, including support for women's cooperatives, trade fairs, and digital platforms, can improve their market participation and income generation.

7. **Addressing Social and Cultural Norms**: Gender norms and stereotypes often perpetuate inequality in food systems and value chains. Promoting cultural change through education and awareness campaigns can challenge these stereotypes, encourage men and boys to take on shared responsibilities, and promote women's agency in food production and related activities.

8. Multi-Stakeholder Collaboration: Addressing gender disparities in food systems requires collaboration between governments, non-governmental organizations, banks, research institutes, and other grassroots organizations. Partnerships can mobilize resources, share knowledge, and create synergies for more effective solutions.

9. **Promoting Gender-Responsive Policies**: Governments should design policies that address the specific needs of women farmers and entrepreneurs in food systems. This includes ensuring gender-sensitive budgets, providing targeted agricultural subsidies for women, and creating a favorable regulatory environment for women's participation in food systems and markets.

Empowering Women for Sustainable agricultural practicesby Gender-Sensitive Agricultural Innovations

1. Labor-Saving Technologies

Labor-saving technologies are innovations that reduce the amount of time and physical effort required for agricultural tasks, especially those tasks that women typically perform. By providing women with tools and technologies that make agricultural work easier and more efficient, these innovations can significantly increase productivity and allow women to engage in other income-generating activities or household responsibilities. These technologies also help reduce the physical burden of manual labor, which is often gendered in rural farming systems.

Mechanical Weeding Tools: Hand-weeding is labor-intensive and time-consuming. Mechanical weeding machines, such as powered weeders or simple hand-held weeders, can help women reduce the time spent on weeding, leading to higher crop yields and reduced physical strain.

Multi-purpose Grinders and Mills: Agro-processing tasks, such as grinding grains, are often performed by women. Multi-purpose grinding mills reduce the time and energy required for these tasks, allowing women to process larger quantities of crops more efficiently and produce value-added products like flour, spices, and pastes.

Solar-Powered Drying Systems: Traditionally, women are responsible for drying harvested crops, which is often done manually under the sun. Solar-powered drying systems can significantly reduce labor and improve the quality of dried produce, helping women preserve crops for longer periods and access new markets for processed foods.

2. Access to Information and Communication Technology

Information and Communication Technology (ICT) is a powerful tool that can empower women in agriculture by providing them with the knowledge, resources, and opportunities to enhance their agricultural practices.

Mobile-based Extension Services: Mobile apps can deliver expert advice on crop management, pest control, and sustainable agricultural techniques. For example, women can receive instant tips on organic farming, water management, and soil conservation, helping them adopt environmentally friendly practices and improve crop yields.

Online Agricultural Communities: ICT platforms allow women to connect with other farmers, experts, and agricultural organizations. These communities provide a space for sharing knowledge, discussing challenges, and finding solutions to common problems, which enhance learning and collective problem-solving.

E-Learning Platforms: Online training platforms offer courses on various aspects of farming, from soil health to agro-processing and marketing. Women can learn at their own pace, gain certifications, and acquire skills that directly contribute to sustainable and profitable agricultural practices.

3. Access to Sustainable Inputs

Inputs in agriculture such as high-quality seeds, fertilizers, water-efficient irrigation systems, good quality animal breeds are crucial for promoting environmentally friendly, resilient, and productive agricultural practices. However, women farmers, especially in rural areas, often face challenges in accessing these resources due to gender disparities in access to land, credit, education, and market opportunities. By integrating gender-sensitive agricultural innovations, women can be better empowered to adopt sustainable farming practices, contributing to both their economic empowerment and the overall sustainability of agriculture.

a. Seed

•**Gender-Sensitive Seed Distribution Programs**: Seed companies and cooperatives can tailor programs to address women's specific needs, ensuring that high-quality, drought-resistant, less labour involved and pest-resistant seeds are available to women farmers. Such programs can prioritize local, indigenous varieties, which are better adapted to local environments and are often more sustainable.

•**Seed Banks and Community Seed Networks**: Women farmers can benefit from community-based seed banks and seed exchange programs, where they can access diverse seed varieties and share knowledge on seed-saving practices. These programs often involve women as key players in the management and distribution of seeds.

b. Organic Fertilizers and Soil Health Inputs

Sustainable agriculture relies heavily on maintaining and enhancing soil fertility while reducing the environmental impact of chemical fertilizers. Women farmers can be empowered by having access to organic fertilizers and soil-enhancing inputs that are safer, more affordable, and better for the long-term health of their land.

- **Soil Health Training and Support**: Providing gender-sensitive training on soil conservation techniques, such as crop rotation, mulching etc. can help women maintain the health of their land and improve productivity sustainably. Women can also be empowered to manage soil erosion, improve soil moisture retention, and reduce degradation through integrated land management practices.
- **Promotion of Organic Fertilizers**: Women can be trained and supported in the use of organic fertilizers, such as compost, manure, and green manure, which improve soil fertility and structure without the harmful effects of chemical inputs. Providing easy access to organic fertilizers can also reduce dependency on expensive, synthetic alternatives.

c. Water-Efficient Irrigation Systems

Access to efficient irrigation systems is critical for sustainable farming, especially in regions facing water scarcity. Women often bear the responsibility of water collection, and inefficient water use can undermine agricultural productivity and sustainability. Gender-sensitive innovations in water-efficient technologies can empower women to manage water resources more effectively.

- **Drip Irrigation and Micro-Irrigation Systems:** These systems deliver water directly to plant roots, reducing water wastage and improving crop yields. Women farmers, particularly in water-scarce areas, can benefit from these technologies, which use less water and are more efficient compared to traditional irrigation methods.
- **Rainwater Harvesting:** Women can be trained to set up and maintain rainwater harvesting systems, which capture and store rainwater for use in irrigation. These systems can reduce dependence on unreliable external water sources, increase crop resilience to droughts, and ensure a steady supply of water for farming.
- **Water-Saving Technologies for Small-Scale Farms:** Access to small-scale, affordable irrigation tools like hand-held pumps, sprinkler systems, and water-efficient hoses can help women manage irrigation more effectively and reduce the labor intensity associated with manual water collection.

d. Agrochemicals and Bio-pesticides

The excessive use of chemical pesticides and fertilizers has negative environmental and health impacts. Women, who are often responsible for crop protection, are disproportionately exposed to the harmful effects of these chemicals. Gender-sensitive innovations in bio-pesticides and natural pest control solutions offer safer, more sustainable alternatives for women farmers.

- **Biological Pest Control**: Introducing women to biological pest control methods, such as using beneficial insects (e.g., ladybugs for aphids) or biopesticides (e.g., neem oil, garlic spray), can reduce the need for harmful chemical pesticides. These practices are safer for women and the environment while effectively controlling pests and diseases.
- **Integrated Pest Management (IPM):** Training women in IPM strategies, which combine biological, mechanical, cultural, and chemical control methods in a sustainable manner, can help manage pests and diseases more effectively while minimizing environmental harm.
- **Eco-Friendly Crop Protection Products:** Providing access to affordable, eco-friendly pesticides and herbicides allows women to protect their crops without compromising their health or the environment. These products can be less toxic and more sustainable than conventional chemicals.

e. Access to Sustainable Livestock Inputs

Women are often the primary caretakers of livestock, and their success in raising animals depends on access to sustainable livestock management inputs, such as animal feed, health care products, and breeding technologies.

- **Sustainable Animal Feed and Supplements**: Providing women with access to affordable, locally available, and sustainable animal feed options can enhance livestock productivity while reducing costs. Feed made from local by-products or agro-industrial waste can be both cost-effective and environmentally friendly.
- **Animal Health Services**: Women can benefit from gender-sensitive veterinary services and training, which teach them how to care for their animals, prevent diseases, and implement biosecurity measures. Providing women with training on animal nutrition, vaccination schedules, and disease management empowers them to increase livestock productivity and improve their economic returns.
- **Sustainable Breeding Programs**: Supporting women in accessing high-quality breeding stock, such as improved poultry or dairy breeds, can lead to better productivity and income generation. These programs should also promote genetic diversity and the conservation of indigenous breeds, which are more adapted to local environments.

f. Climate-Smart Inputs and Innovations

Women are key players in implementing climate-smart agriculture (CSA) practices, which help mitigate and adapt to climate change. Access to CSA inputs enables women to build more resilient farming systems.

- **Drought-Tolerant Seeds**: Providing women with access to drought-resistant and heat-tolerant crop varieties enables them to better withstand changing climatic conditions, ensuring food security and sustainable livelihoods.

- **Carbon-Reducing Practices**: Introducing women to sustainable farming practices like agro-forestry, cover cropping, and no-till farming can reduce carbon emissions, enhance soil health, and improve farm resilience to climate change.
- **Climate-Resilient Infrastructure**: Providing access to infrastructure, such as shade nets or greenhouses, can help women manage extreme weather conditions, such as heat waves, storms, and heavy rainfall, which can threaten crop yields.

Conclusion

Women are the key player in farming sector, particularly in developing countries, are responsible for a significant proportion of food production.Food loss and waste (FLW) occurs at each and every stage of the food supply chain. Their roles in food production, nutrition, food processing, preservation and climate change adaptation highlight the centrality of gender equality in food system transformation. To fully harness the potential of women in driving sustainability, it is crucial to address the gender disparities that hinder their access to resources, decision-making power, and economic opportunities. Supporting women through policies that promote equality, access to resources, and representation in decision-making processes can significantly contribute to a more sustainable, resilient, and equitable food system.

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Crop Diversification for Food and Nutritional Security of Women under Changing Climate Scenario

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Growing of diversified crops covering cereals, millets, pulses, oilseeds, vegetables, fruits, spices, condiments, medicinal and aromatic plants as well as including mushroom, honey bees, poultry, goatery, dairy etc. provide diverse foods, fullfill the nutritional requirement of farm family, generate additional income, reduce risk under climate change scenarios of increased temperature, high rainfall and natural calamities such as floods, droughts, cyclones and tsunami. In this paper the crop diversification strategies including benefits and precautions are discussed. To achieve crop diversification, different management practices such as adjusting the sowing or planting time, selection of appropriate crop establishment/planting method, land modification, rain water harvesting, crop residue recycling and efficient irrigation practices are essential.

Crop Diversification

Crop diversification is the addition of new varieties, species, crops or cropping systems to the existing cropping plan in a farm. Addition of crops and varieties depend on the production technology, climatic conditions, soil types, market facility and other socio-economic factors. Diversification plan in most cases consider replacing the low-value crops or commodities with high-value crops or commodities, such as medicinal plants, cash crops, vegetables and fruits. Farm diversification include an integration of crops and livestock, defined as mixed farming. Crop diversity encompasses several aspects, such as crop species diversity, varietal diversity within crop species, and genetic diversity within crop species. It is recognized as one of the most feasible, cost-effective, and rational ways of developing a resilient agricultural cropping system.

The commonly used methods for measuring crop diversification are the Herfindahl Index (HI), Simpson Diversity Index (SDI), Ogive Index (OI), Entropy Index (EI) and Modified Entropy Index (MEI) (Johns et al., 2022). SDI is estimated using the following formula,

$$SDI = 1 - \sum_{i=1}^{n} P_i^2$$

where, Pi is the proportion of i^{th} crop/crop sector in the gross cropped area. Thediversification index ranges between 0 and 1. Higher values indicate high degree of cropdiversification. SDI values of 0.00 – 0.30 indicate low diversification (Punjab and Haryana in food crops; Odisha, Madya Pradesh and Chhattisgarh in non-food crops). Medium crop diversification values of 0.31-0.60 are found in Uttar Pradesh, Odisha, Bihar, West Bengal, Assam, Madhya Pradesh, Rajasthan, Maharashtra, Gujarat, Andhra Pradesh, Tamil Nadu and Chhattisgarh in food crops and Punjab, Rajasthan, Gujarat, Andhra Pradesh, Telangana, Karnataka, Tamil Nadu and Kerala in non-food crops. High crop diversification (0.61-1.00) are observed in Kerala and Karnataka states for food crops and Uttar Pradesh, Haryana, Bihar, West Bengal, Assam and Maharashtra for non-food crops.

Crop Diversification Benefits

1. *Lower risk and higher earnings*: By spreading over a wider variety of crops, agricultural households can lower production and economic risks through crop diversification. Financial risks brought on by unfavorable weather or market shocks are also covered. By increasing the market potential, growing a variety of vegetables may also be beneficial financially. Through crop diversification, producers can introduce new goods, foods, and medicinal plants to both domestic and foreign markets.
2. *Better nutrition for farm family and animals*: Better nourishment for the family and farm animals is made possible by the addition of new crops and improved varieties. Protein nutrition for the family is enhanced when quality protein maize (QPM) is introduced to diversify the rice-wheat system by substituting some wheat area. Similarly, by switching to legume fodder from current fodder crops, animals can receive green feed that is high in protein. Cultivation of diverse vegetable crops and fruits in the farm supply the requirements of vitamins, minerals and fibre requirement (**Table 1**).

Table 1: Diversevegetables and fruits as sources of vitamins and minerals for farm family

Vegetables	Major source	Fruits	Major source
Spinach	Calcium, vitamins, iron and antioxidants	Amla	Vitamin C
Broccoli	Vitamin K, Vitamin C	Banana	Carbohydrate, Potassium, Magnesium, Ascorbic acid and Vitamin A
Peas	Protein, Vitamin A, C and K and fibre	Apple	High in soluble fibre and pectin
Sweet potato	Vitamin A, C, B6, Beta carotene	Guava	Vitamin C, Carotenoid
Beets	Potassium, Folate	Lemon	Potassium, Vitamin C, Soluble fibre and pectin
Carrots	Vitamin in the form of beta carotene	Mango	Provitamin A, C and Carbohydrate
Tomato	Vitamin C, Potassium	Orange	Vitamin C, Fibre, Potassium, Folate, B-Complex Vitamin

Garlic	Natural antibiotic	Papaya	Enzyme (pepsin), Vitamin C, A, Calcium and Carbohydrate
Onion	Vitamin C, B6, Manganese	Pineapple	Vitamin C and Fibre
Cauliflower	Vitamin C, K, Fibre	Pomegranate	Potassium and Flavonoids
Cabbage	Vitamin C, Fibre, Folate, Provitamin A	Straw berry	Calcium, Magnesium, Potassium, Vitamin C
Capsicum	Vitamin C, Provitamin A	Jamun	Fibre, Vitamin C and antioxidants
French bean	Provitamin A, Vitamin C, Fibre, Potassium, Folate and Phytochemicals	Watermelon	Potassium, Carbohydrate, Fibre and Vitamin C

3. *Agronomic benefits*: Inclusion of crops of different growth habits, utilize the natural resources such as irrigation water, nutrients, vertical space efficiently. Crop diversification also reduce the incidence of insect pests and diseases by breaking insect and disease cycles, reducing weeds and soil erosion, and conserving soil moisture. Land modification allows crop diversification in the low-lying coastal region, digging of farm pond facilitate harvesting of rain water and the dugout soil is used for raising the embankment for cultivation of vegetables and fruit crops.
4. *Ecosystem services*: Inclusion of diverse crops in an agro-ecosystem have several environmental benefits such as improved pollination by honey bees, less pollution due to better use of carry-over applied nutrients, providing space for beneficial insects and predators. Conservation of biodiversity and enhanced ecosystem services achieved by crop diversification.
5. *Better adaptation to climate change scenario*: The synergistic mixing of field crops, horticultural crops, dairy enterprise, fisheries, poultry, etc. is necessary for the integrated agricultural system approach. This diversified system has better potential in terms of climate change adaptation. Improved gender-friendly agronomic approaches, methods and package of practices also helpful to handle biotic and abiotic stressors, high temperatures, moisture stress, saline effects, and waterlogging.
6. *Crop diversification as a component of conservation agriculture*: Reduced tillage, diverse crop rotation and crop residue recycling are the most important principles of conservation agriculture. By growing diverse crops, residues are generated for use in the subsequent crops. In rice-based cropping system, rice straw is recycled as thick mulch over soil surfacealong with zero tillage planting for potato cultivation to conserve soil moisture, reduce salinity, and increase the yield and quality of potato (Sarangi et al., 2021). Irrigation water can be saved by introduction of pitcher

irrigation in vegetable cultivation, which is less labour intensive and gender-friendly (Sarangi et al., 2024c).

7. *Crop diversification leads tocropping system intensification*: The number of crops in a rotation can be increased by implementing shorter duration crops and better agronomic techniques like paddy straw mulching and zero tillage. Improved agro-technology makes it feasible to cultivate rice, zero-tillage potatoes, and green grams in coastal regions of India (Sarangi et al., 2024a). Other crop diversification options for coastal region are rice-maize, rice-mustard-green gram, rice-garlic, rice-onion and rice-vegetables.

Precautions for crop diversification

Market demand as well as additional elements like government regulations and subsidies should be taken into consideration while choosing diverse crops. For the chosen crops or types, appropriate infrastructure for transportation and storage may be set up. Tools, machinery, and equipment that reduce drudgery and are appropriate for both gender should be employed. It is important to guarantee that the necessary inputs for the introduced crops or types are available. It is important to have the most up-to-date technical information and references about production methods.

Gender-friendly integrated farming system models for crop diversification

Gender-friendly farming system models are those that allow both male and female farmers to embrace farming methods without any obstacles. By bridging the gender gap, it addresses the needs of both genders and encourages women's empowerment and gender sensitization. The following are some models of gender-friendly farming systems those could be followed.

1. *Integrated fodder crops-based goat farming*: The investment in goats and fodder crops is a profitable farming system for the coastal region. Black Bengal goat breeds with diverse fodder crops including cereal (maize, sorghum, sudan grass, oat, hybrid napier, nandi grass, guinea grass and para grass) and legume fodders (Alfalfa, berseem, rice bean and cowpea) result higher income to the farmers. The goat unit produce manure, which arecomposted along with other crop residues and applied to the soil for growing vegetable crops. There is significantpotential to reduce the fertilizer costs for crop production by substituting manure and composts for costly inorganic fertilizers (Sarangi et al., 2024b). Alfalfa, berseem, nandi grass, sorghum, oat and rice bean are suitable fodder crops for goat farming andthese fodder crops are easily grown by women farming community.
2. *Integrated Paddy + Vegetable + Fish + Honey bees farming*: The low-laying waterlogged paddy land could be converted into a diverse farming system by placing soil and manure filled bags for growing climbing types of vegetables (Maniruzzaman et al., 2024). The soil and manure filled in bags at 3 m × 3 m spacing are placed in paddy field for growing climbing types of vegetables such as cucumber, bitter gourd, ridge gourd which grow on a netted structure 2 m above the paddy canopy. Growing of diverse vegetable crops also provides opportunity for rearing of honey bees in the bee hives placed nearby. The waterlogged paddy field also provides an environment for rearing of fish in the standing water.
3. *Back-yard poultry farming*: One possible gender-friendly farming strategy is encouraging rearing of poultry birds in the homestead area together with other crop-based enterprises. Poultry birds that can produce eggs and meat are kept in small

houses because they are inexpensive, profitable, and a good source of sustenance for families. Turkeys, guinea fowl, geese, ducks, and chickens may be a part of this system. Through employment and revenue, it is one of the most successful ways to raise the socioeconomic standard of marginalized women farmers. For backyard chicken production, CARI-Nirbheek and Giriraja are suggested birds.

4. *Millets based cropping system*: Encouraging women to grow millet increases their income and advances food security and sustainability. Because finger millet is high in calcium and other minerals, it helps to maintain healthy bones. A high antioxidant concentration promotes general health and immunological function. Little millet's rich nutritious content encourages health advantages like better digestion and increased vitality. Because of the short maturity period and hardiness of millet crops, women farmers can gain economically from cultivation of these crops. Foxtail millet due to its high fiber and mineral content, can help with weight management and heart health. It is appropriate for diabetes individuals due to its low glycemic index. **Table 2** lists millet-based cropping systems that are appropriate for the various Indian states. The majority of the nutrients needed for the human body to operate normally are found in millets (**Table 3**).It is easier to digest, non-allergic, non-acid-forming, and higher in protein, antioxidants, dietary fiber, iron, magnesium, and calcium than cereals. In addition to lowering iron deficiency, maintaining body weight, and improving hemoglobin levels, it also helps prevent anemia, diabetes, heart disease, cancer, and a number of other non-communicable disorders. In addition to being climate resilient, the crop is simple to grow, uses less water, and contributes to better soil health.

Table 2: Millet-based gender-friendly cropping systems

State	**Millet-based system**
Karnataka, Tamil Nadu and Andhra Pradesh	Finger millet + Pigeon pea 8-10:2
	Finger millet +Filed bean 8:1
	Finger millet + Soybean 4:1
Bihar	Finger millet + Pigeon pea 6:2
Uttaranchal	Finger millet and Soybean mixed together in 90:10 per centproportion by weight basis
North hilly areas	Finger millet + Soybean in Kharif and oats in rabi is an ideal remunerative sequence
Maharashtra (Kolhapur)	Finger millet + black gram / moong bean 6-8: 1 (Sub montane regions)

5. *Homestead farming system*: The proximity to the dwelling house, the appropriate area and soil for producing a variety of crops, enterprises, water harvesting in small pond, compost preparation, and storage make this the most gender-friendly agricultural system. This system could incorporate cutting-edge technologies like protected cultivation, vertical farming, hydroponics, etc. to produce nutrient-rich fruits,

vegetables, flowers, and medicinal plants that would meet household nutritional needs and be sold in the market to generate revenue for the women farmers.

Table 3: Nutrition composition of millet per 100g of edible portion

Parameter	Protein (g)	Fat (g)	Minerals (g)	Total dietary fiber (g)	Insoluble dietary fiber (g)	Soluble dietary fiber (g)	CHO* (g)
Finger	7.20	1.90	2.00	11.20	9.50	1.70	66.80
Proso	12.50	1.10	1.90	-	-	-	70.40
Foxtail	12.30	4.30	3.30	-	-	-	60.90
Little	10.40	3.90	1.30	7.70	5.50	2.30	65.60
Kodo	8.90	2.60	1.70	6.40	4.30	2.10	66.20
Barnyard	6.20	4.40	2.20	-	-	-	65.50
Brown top millet	11.5	-	4.2	12.5	-	-	-
Pearl	11.00	5.40	1.40	11.50	9.10	2.30	61.80
Sorghum	10.00	1.70	1.40	10.20	8.50	1.70	67.70

*CHO: Carbohydrate

6. *Mushroom farming*: Cultivation of mushroom is a women-friendly enterprise as it requires less land, labour and women can utilize spare time. It is an excellent women-friendly enterprise for self-employment and converting agricultural byproducts to nutritious outputs such as paddy straw mushroom, oyster mushroom and button mushroom. With the increasing demand for mushroom in the urban and peri-urban areas, formation of women self-help groups (SHGs) to adopt such enterprises has a great potential to diversify the income of small marginal and landless rural households.
7. *Natural farming*: This method encourages the use of readily available, reasonably priced, environmentally friendly, and gender-sensitive botanical items and extracts, as well as cow dung and urine. To encourage natural farming throughout the nation, the Indian government established the National Mission on Natural Farming (NMNF). It has equal advantages for the farming community's men and women. The limitations of resource acquisition are overcome because natural farming inputs are readily available and produced on-farm.Women have used agro-ecological techniques that emphasize use of traditional seeds and a variety of crop types. Their involvement in natural farming will help the country's sustainable development plan, assure the practice's sustainability and growth, and advance fairness and economic well-being. Natural farming benefits all farmers and the community by avoiding or minimizing the use of externally acquired inputs and utilizing local resources in accordance with agro-ecological principles, encouraging community engagement, and focusing on shared resource management (Sharma et al., 2023).

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Impact of Climate Change on Livelihood of Women Farmers

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Climate change is one of the most pressing global challenges, with far-reaching consequences for agriculture and food security. The escalating challenges brought on by the climate crisis are grappling the rural communities worldwide. The impact of climate change on the livelihoods of women farmers is profound and multifaceted, affecting agricultural productivity, economic security, and social well-being. Women play a crucial role in agriculture, especially in developing countries where they contribute significantly to food production, household nutrition, and economic stability. Climate change has a significant impact on the livelihoods of women farmers, especially in low-income areas. Women farmers, particularly in developing regions, are disproportionately affected due to pre-existing gender inequalities, limited access to resources, and the critical roles they play in agriculture and household management.

The Role of Women in Agriculture

Women play a crucial role in agriculture, contributing significantly to food production, livestock management, and natural resource conservation. According to the Food and Agriculture Organization (FAO), women constitute nearly 43% of the agricultural labor force in developing countries. Despite their substantial contributions, they face unequal access to land, credit, education, and decision-making processes. These disparities exacerbate their vulnerability to climate change.

Effects of Climate Change on Women Farmers

Over 50% of global food is produced by female farmers, with women comprising 43% globally and nearly half of the agricultural labor force in developing nations (Akter et al., 2017).Climate change is a global challenge that has affected many lives and livelihoods; however, women and children are arguably the most affected (UN Women, 2014). Some of the major effects of climate change on women farmers are describe below.

- **Declining Agricultural Productivity:** Climate change leads to unpredictable weather patterns, including erratic rainfall, prolonged droughts, and extreme temperatures. These changes affect crop yields, making it difficult for women farmers to sustain their agricultural activities. Reduced productivity directly impacts their income, food security, and overall well-being.

- **Water Scarcity and Resource Depletion:** Water scarcity is a significant consequence of climate change, affecting irrigation and household water supply. Women, who are primarily responsible for fetching water in many communities, face increased workloads and health risks due to prolonged water collection journeys. Limited water availability also hinders agricultural activities, reducing crop and livestock productivity.

- **Soil Degradation and Land Depletion:** Rising temperatures and extreme weather events contribute to soil erosion, desertification, and reduced soil fertility. Women farmers, often working on marginal lands, struggle to adapt to these changes due to inadequate knowledge of soil conservation techniques and limited access to agricultural extension services.

- **Increased Pests and Diseases:** Higher temperatures and changing precipitation patterns create favorable conditions for pests and diseases, affecting both crops and livestock. Women farmers, who typically engage in small-scale farming with limited access to pesticides and veterinary services, face significant losses, further threatening their livelihoods.

- **Food Security Challenges:** Climate change exacerbates food insecurity by reducing agricultural output and disrupting food supply chains. Women, who are often responsible for household food preparation, struggle to provide nutritious meals, leading to malnutrition and adverse health effects, especially among children and pregnant women.

- **Economic Hardships and Financial Constraints:** Reduced agricultural productivity translates to lower incomes for women farmers. Many women lack access to financial services, credit, and insurance, making it difficult to recover from climate-induced losses. Without financial support, they are unable to invest in adaptive technologies or alternative income-generating activities.

- **Increased Workload and Labor Burden:** As climate change disrupts traditional farming practices, women face increased workloads. They must work longer hours to maintain agricultural productivity while also fulfilling domestic responsibilities. This additional burden affects their health, well-being, and ability to participate in community decision-making.

- **Displacement and Migration:** Extreme weather events, such as floods and droughts, force many rural communities to migrate in search of better living conditions. Women farmers, often tied to their land and family responsibilities, face displacement and loss of livelihoods. Migration also exposes them to new vulnerabilities, including exploitation and social exclusion.

Adaptive Strategies and Solutions

Climate change poses significant challenges to global agriculture, disproportionately affecting women farmers, who often have limited access to resources, education, and decision-making power. Women play a crucial role in food production, yet they are highly vulnerable to climate variability. Some of the adaptive strategies and solutions that enhance the resilience of women farmers against climate change are

- **Climate-Resilient Agricultural Practices:** Encouraging the adoption of climate-smart agriculture (CSA) can enhance resilience among women farmers. Techniques such as agro-forestry, crop diversification, conservation agriculture, and improved irrigation systems help mitigate the effects of climate change.

- **Access to Education and Training:** Providing women farmers with education and training on climate adaptation techniques, sustainable farming, and financial literacy can empower them to make informed decisions. Agricultural extension services should be tailored to address the specific needs of women farmers.

- **Improved Access to Resources:** Governments and organizations must facilitate women's access to land, credit, and farming inputs. Legal reforms ensuring land ownership rights for women can significantly enhance their economic security and ability to invest in sustainable agriculture.

- **Strengthening Women's Cooperatives and Networks:** Women's cooperatives and self-help groups provide a platform for knowledge-sharing, collective bargaining, and financial support. Strengthening these networks can enhance resilience and improve access to markets and resources.

- **Gender-Inclusive Policies and Interventions:** Policymakers must integrate gender perspectives into climate adaptation strategies. Women should be actively involved in decision-making processes at local, national, and international levels to ensure their voices are heard in climate action planning.

- **Technology and Innovation:** Providing women farmers with access to innovative technologies, such as drought-resistant seeds, mobile-based weather forecasts, and efficient irrigation systems, can help them adapt to changing climatic conditions.

- **Social Protection and Financial Inclusion:** Expanding microfinance programs, insurance schemes, and social protection policies tailored to women farmers can enhance their financial security and ability to recover from climate-related losses.

Conclusion

Climate change poses a severe threat to the livelihoods of women farmers, exacerbating existing gender inequalities and socio-economic challenges. Addressing these issues requires a multi-faceted approach, including policy reforms, education, access to resources, and community-driven solutions. By empowering women farmers with the necessary tools and support systems, we can build more resilient agricultural communities and ensure food security for future generations.

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Climate Resilient Urban Horticulture: A Gender Perspective

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Climate is the average weather of a given area over a period of time, defined by the average temperature, rainfall, and sunshine in different seasons in a region resulting in small or big environmental events. Climate change indicates change in climate variables like extreme temperatures (high and low), excessive sunlight, and elevated CO_2, change in rainfall pattern in terms of frequency, periodicity, quantity, distribution, affecting the life cycle, existence, survival, of living beings on this planet. As the concentration of greenhouse gases increases, the planet's ability to trap heat also increases, leading to a rise in global average temperature. A direct relationship exists between the quantity of greenhouse gases released and the severity of climate change, meaning higher emissions result in more significant warming. It is a fact that the climate is warming during the past decades the cause has been mainly anthropogenic. There has been an increase in average global air and ocean temperatures, variations resulting in a variety of problems including increased frequency of extreme weather events, widespread melting of snow and ice, and increase in ocean water levels (IPCC 2007a). High temperature is a single aspect of climate change can make food less safe. Rising temperatures directly contribute to climate change by altering weather patterns, causing more extreme weather events like heat waves, heavy rainfall, droughts and intensified storms, potential threats to human populations and horticulture.

Climate change is a global threat to sustainable development and food security. In developing countries, dependence on rain-fed agriculture and natural resources as a principal livelihood source is leaving millions of smallholders vulnerable. For farmers, climate change has the potential to increase the frequency and intensity of weather extremes, including droughts and floods, along with attacks from crop and livestock pests and diseases. These changes will have direct effects upon agriculture and natural resources at organism, farm and broader landscape levels, as well as direct impacts on human health, infrastructure and non-agricultural livelihoods. There are also a range of non-climate stressors affecting smallholders. These could include things like market instability, lack of access to credit, poor infrastructure, disease outbreaks, political instability, population pressure, and limited access to education and technology. The interactions between climatic and non-climatic stressors will also be important as effects may be compounded and amplified (FAO, 2015).

The uncertainty of the annual weather pattern over the year has forced many farmers to reconsider the choice of crops, cropping patten, and other mitigation strategies. However, a significant chunk of landless farmers has suffered immensely due to lack of assured engagement enforced by climatic aberrations, and forced them to migrate to urban regions for menial engagements. The climatic uncertainties, lack of field level workforce, coupled with fast paced expansion of the urban areas to peri-urban farm lands have not only reduced the cultivable areas and their production levels, but also forced farmers to increase the modern synthetic chemical fertilizers and pesticides in their fields. This has resulted in the increase in food cost in both rural and urban areas, besides increase in the residual effects of chemical fertilizers and pesticides in the fresh produce. Increases movement of agricultural produce from different areas to cater to the increased consumption demand dure to ever increasing urban population has resulted in increased food miles and resultant pollution.

Climate resilient horticulture

Climate change poses unprecedented challenges to global food security and agricultural practices. As temperatures rise, weather patterns become more erratic, and extreme events become more frequent, the horticulture industry faces significant risks. However, the adoption of climate- resilient practices in horticulture is crucial for ensuring the availability of nutritious food, sustaining livelihoods, and preserving the environment. Horticulture, which includes the cultivation of fruits, vegetables, flowers, and ornamental plants, plays a vital role in human well-being. Fruits and vegetables are rich sources of essential nutrients, contributing to a healthy diet and reducing the risk of chronic diseases. Moreover, horticulture provides economic opportunities for farmers, contributes to rural development, and fosters local and global trade. Climate change impacts horticulture in several ways. Rising temperatures can affect crop growth and development, leading to reduced yields and compromised quality. Changes in precipitation patterns and increased water scarcity pose challenges for irrigation, a critical component of horticultural practices. Extreme weather events, such as storms, floods, and droughts, can cause substantial damage to crops and infrastructure. Additionally, pests and diseases can proliferate under changing climatic conditions, affecting plant health and productivity.

By adopting climate-resilient practices, horticulture can adapt to the changing climate while minimizing risks and maximizing productivity. Climate-resilient horticulture focuses on strategies that enhance the capacity of plants and farming systems to withstand climate stresses. This includes the use of climate- resilient crop varieties, efficient water management techniques, improved soil health practices, and integrated pest management. Climate-resilient horticulture not only safeguards food production but also contributes to environmental sustainability. Increased crop yields and resilience to climate change contribute to reliable food production enhanced food security with reduced greenhouse gas emissions, minimized water usage, and improved soil health. Improved resource efficiency can lead to cost savings for growers, while promoting local food production and sustainable practices can empower communities.

Climate smart horticulture is an approach that aims to enhance the resilience and productivity of horticultural systems in the face of climate change. The climate-smart management of orchards and plantations involves the efficient use of water and energy for farm operations. Adaptation to local conditions can be enhanced by using grafting technology, whereby the rootstock can bring specific resistance to biotic and abiotic factors. Climate-smart orchard and plantation crops, once established, require no-tillage and minimal fossil fuel inputs. On average, they can sequester more carbon in their biomass and in the soil than annual crop production system while producing nutritious food and sequestering carbon, orchards and plantations stabilize slopes and help build soils.

Conservation, development, improvement, and dissemination of climate-resilient, market-driven crop varieties that provide a crucial defense against extreme temperatures, water scarcity, the emergence of new pests and diseases, and nutritional insecurity. The growth, health, and geographical distribution of fruit-bearing plants are influenced by several non-living components of an ecosystem, such as temperature, humidity, rainfall, wind speed, evaporation, and changes in atmospheric CO_2 level. Climate-smart fruits are fruits can be grown in changing climate conditions and are a potential solution to ensure various nutritional securities. There are many trees and palms worldwide that produce crops that are rich in carbohydrates (in starchy fruits, seeds, nuts, pods, tubers), provide fats (in fruits, seeds, nuts), and some proteins (in nuts, beans and leaves). Fruits like Jackfruits, Dragon fruit, Phalsa, Avocado, Passion fruit, Rambutan, Mangosteen, Durian, Longan, Karonda, Kokum, Soursop, Jamun, etc can be deployed strategically for diverse and climate resilient fruit production.

Climate resilient urban horticulture holds immense importance in addressing climate change, ensuring food security, and promoting micro-environmental sustainability. It is also crucial for improving long-term livelihoods and enhancing urban climate litheness. Various benefits of climate resilient urban horticulture include enhanced food security, environmental sustainability, economic viability, and community empowerment. In a gender prospective urban horticulture mainly empowers women in family to promote gender equitable and gender-sensitive cultivation and production of horticulture produce. The ability of urban community, and ecosystem to prepare and respond to the effects of climate change strengthens their climate resilience. By determining the risks and vulnerabilities associated with climate change, and then implementing risk management strategies, the urbanites can mitigate most of the climate change risks. Climate-resilient urban horticulture integrates climate adaptation, mitigation, and sustainable agriculture. It aims to increase productivity, enhance resilience, and reduce greenhouse gas emissions.

There are many components promoting climate-resilient horticulture, especially the crop selection wherein choosing climate-resilient varieties that can withstand extreme weather events like heat waves and water scarcity, plays a very important role. Promoting soil organic matter content through composting and its application, and reduced tillage enhance carbon sequestration and soil fertility. Utilizing efficient irrigation systems like drip irrigation, rainwater harvesting, and growing drought-tolerant varieties minimize water usage. Biological controls methods and minimal pesticide usage to protect crops minimize environmental hazards. Growing crops in stacked layers to maximize production in space crunched urban and peri urban areas, reduce water and land requirements.

Protected cultivation for Climate- resilient Horticultur

Protected cultivation, which embraces a broad range of practices, 'protect' the plants against external factors. These practices are meant to ensure consistent productivity under various and variable, sometimes unpredictable, climate variables. In protected cultivation, controlled environment system creates a microclimate that optimizes plant growth by regulating factors like temperature, humidity, light, and CO_2 levels. The structures used in protected cultivation safeguard crops from extreme weather events like heavy rain, frost, strong winds, and excessive sunlight. Protected cultivation can facilitate better pest and disease management strategies, ensuring year-round production outside of typical growing season of some of the crops in many regions. Furthermore, the controlled environment minimizes the need for pesticides, decreasing chemical runoff and its detrimental effects on surrounding ecosystems.

Vertical farming in protected structures maximize production in limited space, especially in urban areas, while reducing water and land requirements thanks to advanced hydroponic and aeroponic systems that circulate water enriched with nutrients directly to plant roots. When powered by renewable energy sources, protected farms have the potential to be almost entirely self-sufficient, further reducing their environmental impact. Weather patterns and soil quality become non-issues, making protected vertical farming using a soilless media a reliable food source regardless of climatic conditions. In urban areas, the scalability of vertical farming structures can be set up in urban rooftops and balconies. Arka Vertical Garden designed and developed by the ICAR- IIHR, Bengaluru, with soilless medium aids in the production of safe to eat vegetables ensuring food and nutritional security in space crunched urban areas. The basic component of an Arka vertical garden is a base frame spread over one sq. m. on four wheels, with inbuilt irrigation system. Each of the vertical garden has 16 pots, 80 kg of growing medium, seed kit, and inputs for plant nutrient management and plant protection.

Gender and climate change impacts

More clarity is needed on the different vulnerability factors between men and women. Evaluation and documentation of current mitigation and adaptation strategies that have been effective could help to identify any gender focus. Extensive research and understanding are needed on why, how and to what extent women in urban areas are vulnerable to climate change as the majority of the literature and research focuses on poor women of the rural south. Impacts are socially and culturally specific. Appropriate coping strategies and adaptation priorities for women in peri-urban and urban areas are needed. Women tend to be represented as a homogeneous group and in fact different characteristics will shape and affect their vulnerability and ability to cope (Nellemann *et al.* 2011). Therefore, how does climate change impact urban women from different backgrounds, including culture, age, race, ethnicity, marital status, profession, etc.? What are, or should be, the coping strategies and adaptation priorities for each different group? Generalizations make it challenging to meet the highly specific needs of groups of women or men. More research is needed into how agricultural productivity and food security affects urban women and what adaptation strategies would improve their ability to cope.

Urban and peri-urban horticulture

Urban horticulture is gaining in popularity. It is practiced in small to medium-sized holdings within cities. It can be done in flowerpots, growbags, small gardens, or larger fields. Also, can be done using traditional, high-tech, or innovative practices. The objective of urban and peri-urban horticulture is to improve the availability of fresh horticulture produce in cities and increase the access of urban populations to this nutritious food. As proximity food production systems with short supply chain, urban and peri-urban horticulture can save energy and reduce greenhouse gas emissions by cutting down on transport, packaging, and conservation. Furthermore, a green and dense rooftop garden cools a home by acting as a natural insulator, absorbing sunlight, and releasing moisture through transpiration, which cools the surrounding air, effectively lowering the temperature inside the house, particularly during hot summer months, as essentially the plants on the roof are naturally cooling the air around the building through evaporation and improving the urban microclimate. Creating a diverse garden can attract beneficial insects and enhance biodiversity in local ecosystems in cities.

Urban and peri-urban horticulture has emerged as a preferred activity for small-scale producers, who can grow different horticulture specialty crops within and around cities. Crops are grown either in peri-urban green belts, plots within the cities, home gardens or micro-gardens. Home gardens are container-based small-scale production units that can be used to cultivate a wide range of vegetables, roots, tubers and condiments in small spaces, such as patios, balconies and rooftops. They are adapted to densely populated urban environments, where space is limited and water scarce. Rooftop home gardens are a good example of producing more with less, delivering higher yields and greater diversity than larger-scale production per unit of surface area, water used and labour expended. Not only do they require less space, water and labour, they also use less pesticides and mineral fertilizers and need less transport and packaging to reach consumers. They are also less affected by pest and diseases due to lower plant population and continuous monitoring due to proximity.

Localized food production in home gardens is likely to result in a rise in the consumption of fresh organic foods with lesser pesticide residues, improving diet and health of urban families. Plant exchange, sharing of seeds and planting material, educative community gatherings in home gardens will result in strengthened, cordial and cohesive social cohesiveness. Bhubaneswar based Kitchen Garden Association organizes such regular "*aso bulijiba chata*" programs, which are highly effective due to physical knowledge sharing, demonstration of effective tricks and tips in the gardens of the hosts, and community cooking of vegetable dishes from home garden grown vegetables brought by the participants of these programs. Furthermore, turning underused urban landscapes into green spaces would immediately impact property value and aesthetic appeal while also helping to mitigate climate change.

Rooftop and home gardening can be utilized as leisure time especially by elders, women, and children by providing an avenue for being physically active through various gardening activities. Home gardening is a mentally stimulating activity that allows you to connect with nature through cognitive stimulation, while cultivating plants, and creating a beautiful space, besides potentially reaping benefits like improved mood, reduced stress, increased physical activity and a sense of accomplishment, making it a valuable way to spend free time. In addition to creating a channel to connect to nature, the potential for growing fresh produce, and a space for social interaction home gardens provide both mental and physical well-being through relaxing and productive gardening and associated activities.

Food miles and essence of growing food in home gardens

Food miles is the distance food travels from place of production to place of consumption, signified with the quantum of greenhouse gases emitted towards logistics, transport, consumption of electricity in cold chains, and many other activities during this travel from the farm to the wholesale market or the processing center, the retail market or local shop, and then to your home. Food miles contribute to climate change, pollution, and energy consumption primarily by burning fossil fuels by various mode of transportation used to move the food, such as trucks, ships, trains, or airplanes. It is an indication of the environmental impact of caused by emissions of greenhouse gases into the earth's atmosphere when fossil fuels are used in their transport. Global food miles account for around 19% of total food system emissions, primarily due to the carbon footprint of road transport used to move food across long distances (Li *et al*., 2022). Food miles can also lead to wastage due to spoilage and/or damage in transit. Thus, food miles have a significant environmental impact, contributing to climate change, air pollution, and greenhouse gas emissions. The further food travels, the greater its environmental impact.

A locally produced food would have a lower carbon footprint. Home gardens contribute by providing a small amount of the total food required the family especially the fresh vegetables. The home gardens primarily nurtured by the women, and the elderly can reduce food miles by growing fruits and vegetables. The women folk reduce food miles by planning their garden planting schedule for regular availability of fresh and organic vegetables, and minimizing food waste at home. Prioritizing consumption locally grown seasonal food produce from local farmers' weekly bazaars would not only reduce food miles but also promote peri-urban horticulture.

Gender implications in climate sensitive urban areas

Women-led initiatives have been playing a crucial and integrative role in promoting sustainable horticulture and empowering rural communities. Women play an important role in horticulture, contributing to production, post-harvest management, and other aspects of the field. Under the climate change regime women are also subjected to uncertainties and are often underrepresented and face gender disparities in resource access and control as especially as a subordinate in any enterprises in mainstream horticulture.

Women in urban areas too are vulnerable to climate change due to factors like limited access to resources, pre-existing gender inequalities, restricted mobility, and specific roles within households. Even though research often focuses on rural women, as the impacts of climate change are socially and culturally specific, meaning the vulnerabilities vary depending on the context. Not much research has been done on why, how and to what extent women in urban areas are vulnerable to climate change as most of the literature and research focuses on poor women of the rural background.

Women are often primarily responsible for household chores and childcare, which can limit their ability to respond to climate-related exigencies like evacuations or securing essential supplies. In many societies, women have less influence in household and community decisions related to climate adaptation strategies, leaving them with fewer options to protect themselves under climatic emergencies. Lower income levels and limited access to employment opportunities can make urban women more vulnerable to the economic impacts of climate change like daily food composition.

Stress and anxiety related to climate change and family issues can be exacerbated by gender inequalities and limited coping mechanisms. Densely populated urban areas experience higher temperatures due to the "urban heat island" effect, which can disproportionately affect women's health, especially pregnant women, due to increased heat stress. Further, inadequate congested urban housing conditions like lack of ventilation, increased risk of heat-related illnesses, respiratory problems, and reproductive complications may happen due to extreme heat. Home gardens provide and excellent outlet to relax and spend relaxing and calming sessions of garden tending. Regular gardening activities in open rooftops exposing to fresh garden air, sunlight, and green landscape provides numerous physical and mental health dividends. The presence of greenery and exposure to natural light enhance mental health. Spending time outdoors gardening allows for increased exposure to sunlight, which is crucial for vitamin D synthesis. Engaging in gardening activities promotes mental well-being, reduces stress, and improves overall mood. Spending time in a garden has been shown to reduce stress, anxiety, and depression. The act of tending to plants can be a form of mindfulness that helps promote relaxation and mental clarity.

Most of the homebound women in nucleus families with office going spouse and school going children lack midday engagement drawing them to engage on the unproductive social media indulgence and addition to the daily soaps in television and OTT platforms. Such indulgence not only has huge risk of harming the individual physically, mentally, and socially but also there is wasteful expense of electricity for running these devices, fans, air conditioners, etc. Home gardens provide productive engagement to home bound women in gardening, waste segregation and composting, transplanting, irrigation, nutrition management, weeding, harvesting, drying, processing and preservation. Gardening also stimulates the spiritual and artistic minds to create best out of waste, for making colourful pots, planting arrangements, making planting material for social exchange, preparing gardens for competitions and flower shows, etc.

Disruptions to food supply chains caused by climatic aberrations can disproportionately affect women who are often responsible for food management at home. Having a kitchen garden at homes in cities offers alternate source of emergency food especially tuber vegetables which can be harvested as and when required. Women who prefer not to venture out alone for food supplies can also create and rely on the home garden supplies. It signifies that urban home gardens are an essential social empowerment tool since it allows women to govern the choice of vegetables grown and also contribute to household food requirements.

In spiritually dynamic states like Odisha, women of all age groups venture out in dark wee hours to collect flowers in cities for puja. Generally, they also tend to steal flowers from other homes risking their safety. Growing flowers for various purposes including for religious purposes, at own homes saves women such troubles and is ethically more acceptable.

Enhancing women's access to education, economic opportunities, and decision-making roles to improve their resilience. Many bright examples have come up recently where the women who opted not go for regular government or private jobs, have created many opportunities through home garden-based ventures. Ms Jayanti Sahoo has developed extraordinary home gardening skills enriched by many innovative garden structures and designs. She has earned huge social recognition and serves as resource person in many gardening events. She has created a profitable YouTube channel wherein she shares her expertise with the world. Similarly, Ms Kalpana Sahu who has a very productive rooftop garden shares her daily exploits with the world on her YouTube channel. Such opportunities created due to home gardens opens up the world to the home bound urban women while creating a source of income too. Ms Lipsa Behura, has created an interesting profession from making best out of waste and making beautiful artifacts, flower pots, and other items from waste material and repurposing them as corporate gifts. Engaging these successful women in local climate action initiatives and providing targeted support to address their specific needs to further enhance their skill sets is essential. Exposure to appropriate horticultural technologies empowers the women folk to explore more lucrative business ideas. Ms Pragyan Sahu has setup a hydroponic vegetable production and catering business in the peri-urban vicinity of Cuttack and Bhubaneswar. In Bhubaneswar the home garden -based organic farming initiatives have taken root, fostering sustainable horticulture practices. Ms Priyambada Patnaik has taken the license for commercial production of Arka Vertical Garden structures and plant nutrient mix Arka sasya poshak ras. Such initiatives will fuel expansion of home gardens in cities with space limitation. Ms Puspa Panda, who has a very productive rooftop garden trains other city farmers for organic sustainable horticulture practices on rooftop gardens. Ms Neelima Mishra, another bright entrepreneur who has taken up commercial waste disposal in urban areas, and promoting segregation of urban domestic waste and safe disposal, reducing environmental pollution, and generating additional income from sale of domestic waste. Waste segregation also opens up the possibility of composting organic waste like fruit and vegetable peels, egg shells, etc. at home and use the compost in home gardens, reducing the need of purchase of scarce and expensive garden soil.

It is evident that women's work in urban food and gardening systems can be made augmented by mainstreaming gender into urban agriculture systems and policy. It is possible to diversify employment and income alternatives even more, enhancing urban life during uncertain situations and boosting food security. These success stories exemplify the transformative potential of climate-resilient and sustainable development in horticulture. By adopting innovative approaches, fostering collaborations, and empowering farmers, these initiatives not only mitigate climate change impacts but also enhance biodiversity conservation, ensure food security, and promote equitable socio-economic development. These examples serve as beacons of hope, inspiring further action and providing a roadmap for a greener and more sustainable future in horticulture. They also demonstrate that urban farming increases women's contribution to family support, a sign of their increased social and economic empowerment. Climate-resilient and sustainable development in horticulture has gained traction worldwide, with numerous success stories and initiatives demonstrating the potential for positive change. Many State governments have supported the urban gardening initiatives across the country. In Odisha, the State government has funded an innovative project for promotion of rooftop and home gardening in selected cities of Odisha. Many educative campaigns and trainings are being conducted to increase the area under urban greenery.

Conclusion

Climate-resilience in horticulture is not only essential for the future of food production but also for environmental conservation and economic prosperity. By adopting innovative approaches and technologies, implementing sustainable practices, and fostering collaborations across sectors, the horticulture industry can mitigate the impacts of climate change while ensuring the long-term viability of its operations. The expansion of urban horticulture gives a much-needed fillip to the cause of food security and urban microclimate.

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Women Empowerment through Resource Conservation Technologies for Climate Change Adaptation & Mitigation

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Women play a pivotal role in agriculture, contributing nearly 50% of the global agricultural workforce. In India, they are extensively involved in crop cultivation, livestock management, seed preservation, and post-harvest activities such as cleaning, grading, and packaging. Their active participation in natural resource management—particularly water conservation, soil fertility enhancement, and afforestation—highlights their indispensable contribution to rural livelihoods. Despite their critical role, gender disparities persist, especially in land ownership, access to institutional credit, and adoption of modern agricultural technologies. According to the FAO (2023), women farmers in climate-vulnerable regions demonstrate faster adoption of sustainable practices compared to their male counterparts. However, limited access to education, training, and decision-making platforms constrains their potential. Addressing these challenges through gender-inclusive policies, capacity-building initiatives, and self-help groups (SHGs) can significantly boost productivity and resilience in agriculture. Community-based participatory approaches have proven effective in enhancing women's skills in climate-smart agriculture, thereby improving household food security and economic stability.

Resource Conservation Technologies for Climate Change Adaptation & Mitigation

Mitigation strategies for farm women

Agriculture is a major contributor to greenhouse gas emissions, but it also has the potential to mitigate climate change through sustainable practices. One effective approach is carbon sequestration, where trees are planted on farmlands to absorb atmospheric carbon, enhancing carbon storage in biomass and soil. Additionally, reducing chemical fertilizers by promoting biofertilizers, green manure, and precision nutrient management can significantly cut down nitrous oxide emissions while improving soil health.Conservation agriculture plays a vital role by incorporating minimum tillage, cover cropping, and crop residue retention, which not only enhance soil organic matter but also prevent carbon loss. Similarly, efficient livestock management can help reduce methane emissions through improved feeding practices and proper manure handling. Another crucial strategy is the integration of **renewable energy** into farming operations, such as adopting solar-powered irrigation pumps, biogas plants, and wind energy, reducing reliance on fossil fuels.

Mitigation Strategies	Description
Carbon Sequestration	Planting trees on farmlands to absorb atmospheric carbon.
Reduced Chemical Fertilizers	Promoting biofertilizers, green manure, and precision nutrient management.
Conservation Agriculture	Practicing minimum tillage, cover cropping, and crop residue retention to enhance soil carbon storage.
Efficient Livestock	Reducing methane emissions through improved feeding

Management	practices and manure management.
Renewable Energy	Adoption of solar pumps, biogas plants, and wind energy in farming operations.
Methane Reduction	Promoting Alternate Wetting and Drying (AWD) irrigation to reduce methane emissions.
Sustainable Land Management	Preventing deforestation, restoring degraded lands, and maintaining soil organic matter.
Waste-to-Energy Initiatives	Utilizing crop residues, animal waste, and food waste for biogas production.
Precision Agriculture Technologies	Using drones, IoT sensors, and AI for efficient resource use and reduced emissions.
Climate-Smart Policies and Incentives	Implementing carbon credits, sustainable farming subsidies, and policies that promote eco-friendly agricultural practices.

Methane reduction in paddy fields can be achieved through Alternate Wetting and Drying (AWD) irrigation, which minimizes the continuous flooding of fields, thereby lowering methane emissions. Moreover, sustainable land management strategies, such as preventing deforestation, restoring degraded lands, and maintaining soil organic matter, are crucial for climate resilience. Waste-to-energy initiatives, such as utilizing crop residues, animal waste, and food waste for biogas production, not only manage waste efficiently but also provide renewable energy sources.The use of precision agriculture technologies, including drones, IoT sensors, and AI, enhances resource efficiency and reduces emissions by optimizing inputs like water, fertilizers, and pesticides. Lastly, the adoption of climate-smart policies and incentives, such as carbon credits, sustainable farming subsidies, and eco-friendly agricultural policies, can encourage farmers to adopt environmentally responsible practices. These combined efforts contribute significantly to mitigating climate change while ensuring sustainable agricultural productivity.

Adaptation strategies for farm women

Agriculture is highly vulnerable to climate change, necessitating the adoption of adaptive strategies to ensure food security and sustainable livelihoods. One key approach is **climate-resilient crop varieties**, which include drought, flood, and salt-tolerant cultivars capable of withstanding extreme weather conditions. **Diversification** in agriculture through mixed cropping, intercropping, and agroforestry further reduces risks by enhancing ecosystem resilience and spreading economic risks across multiple crops and livestock enterprises.

Adaptation Strategies	Description
Climate-Resilient Varieties	Promoting drought, flood, and salt-tolerant crop varieties.
Diversification	Encouraging mixed cropping, intercropping, and agroforestry for risk reduction.
Water Management	Adoption of rainwater harvesting, micro-irrigation (drip/sprinkler), and soil moisture conservation.
Integrated Pest and Disease Management (IPDM)	Use of biopesticides and natural predators to manage climate-induced pest outbreaks.

Soil Health Management	Application of organic matter, mulching, and conservation tillage to improve soil fertility and water retention.
Agro-Meteorological Advisory Services	Providing real-time weather forecasts and climate advisories for farmers.
Livelihood Diversification	Integrating livestock, poultry, fisheries, and non-farm activities to reduce climate vulnerability.
Climate-Smart Livestock Management	Improved feeding strategies, better breed selection, and disease control to sustain productivity.
Resilient Infrastructure Development	Constructing elevated storage structures, flood-resistant farm buildings, and climate-resilient roads.
Community-Based Adaptation Approaches	Strengthening local institutions, SHGs, and cooperatives to support collective decision-making and climate resilience.

Water management plays a crucial role in adaptation, with techniques such as rainwater harvesting, micro-irrigation (drip and sprinkler systems), and soil moisture conservation helping to optimize water use and improve productivity under erratic rainfall conditions. Similarly, Integrated Pest and Disease Management (IPDM) is essential for mitigating climate-induced pest outbreaks. This approach promotes the use of biopesticides, natural predators, and resistant crop varieties to reduce the reliance on chemical pesticides and maintain ecological balance. Maintaining soil health is fundamental to climate adaptation. Practices such as applying organic matter, mulching, and conservation tillage improve soil fertility, enhance water retention, and prevent degradation. In addition, agro-meteorological advisory services provide real-time weather forecasts and climate advisories, enabling farmers to make informed decisions on planting, irrigation, and pest control.

To reduce climate vulnerability, livelihood diversification is crucial. Farmers are encouraged to integrate livestock, poultry, fisheries, and non-farm activities to ensure stable income sources despite climatic uncertainties. Likewise, climate-smart livestock management focuses on improved feeding strategies, better breed selection, and effective disease control to sustain productivity under changing climatic conditions. Developing resilient infrastructure is another critical aspect of adaptation. The construction of elevated storage structures, flood-resistant farm buildings, and climate-resilient roads helps safeguard agricultural produce and inputs from extreme weather events. Finally, community-based adaptation approaches empower local institutions, self-help groups (SHGs), and cooperatives to facilitate collective decision-making and resource-sharing, strengthening the overall resilience of farming communities.

Water Conservation: Rainwater Harvesting, Farm Ponds, Micro-Irrigation

Water conservation is critical to sustainable agriculture, particularly in climate-vulnerable regions. Women, as primary water managers at the household and farm levels, have been instrumental in adopting efficient water-saving techniques. Traditional methods like rainwater harvesting, combined with modern innovations such as farm ponds, drip irrigation, and sprinkler systems, have significantly improved water-use efficiency. For instance, the implementation of rainwater harvesting structures in Odisha, led by women-led watershed committees, has increased groundwater recharge and reduced dependence on erratic monsoon rainfall. These initiatives have enhanced crop productivity by ensuring water availability during dry spells. Micro-irrigation techniques, particularly drip and sprinkler systems, have improved water-use efficiency by 40% and reduced labor requirements, thereby easing the workload for women. Community-driven water management programs have fostered a sense of ownership and encouraged collective action in addressing water scarcity. Additionally, integrating water conservation practices with livelihood activities, such as kitchen gardening and aquaculture, has further strengthened household income. The table below illustrates the efficiency and adoption rates of various water conservation techniques across different regions:

Technique	Efficiency (%)	Adoption Rate (%)
Drip Irrigation	50-70	35
Farm Ponds	30-50	40
Rainwater Harvesting	60-80	25

Promoting these techniques through capacity-building programs, access to financial support and local institutional backing can ensure long-term water security and agricultural sustainability.

Soil Health Management

Soil health management plays a critical role in ensuring long-term agricultural productivity and environmental sustainability. Women farmers across India are actively engaging in organic farming, vermicomposting, and conservation tillage to enhance soil fertility and reduce dependency on chemical inputs. Organic farming practices, such as the use of farmyard manure, compost, and biofertilizers, improve soil structure, enhance microbial activity, and increase water retention capacity. Vermicomposting, a process involving earthworms to decompose organic waste, has gained popularity among women-led self-help groups (SHGs), providing both income and improved soil health. Conservation tillage, which minimizes soil disturbance, helps reduce soil erosion and maintain carbon stocks. Recent reports from NABARD (2023) indicate a 20% rise in organic farming in India, with women leading 60% of these initiatives. These practices not only support sustainable agriculture but also empower women through knowledge-sharing and participation in decision-making processes. The positive impacts, such as increased soil organic matter, improved water infiltration, and better nutrient cycling, are depicted in Figure 2. By promoting soil health through eco-friendly techniques, women farmers contribute significantly to climate change mitigation and sustainable food production.

Climate-Resilient Agriculture

Climate change poses significant challenges to agriculture, particularly in rainfed and flood-prone areas. To mitigate these impacts, women farmers are adopting climate-resilient practices like growing drought- and flood-tolerant crops, practicing crop diversification, and implementing agroforestry systems. Crops like millets, known for their drought resilience, and flood-tolerant rice varieties are being increasingly cultivated to cope with erratic weather patterns. Crop diversification, which involves growing multiple crops in a given area, helps reduce risks associated with climate variability while ensuring better soil health and stable yields. Agroforestry, the integration of trees and crops, contributes to carbon sequestration, reduces soil erosion, and provides additional income through fruit and timber production. According to ICRISAT (2024), the adoption of climate-smart crop varieties has increased yields by 30% in rainfed regions. Table 3 illustrates key climate-resilient crops and their yield benefits, with millets showing a 35% increase in yield, flood-tolerant rice with 28%, and agroforestry practices enhancing carbon sequestration by 40%. Women farmers, through their participation in community-based climate adaptation programs, are becoming catalysts for resilient and sustainable agricultural practices in vulnerable regions.

Integrated farming systems

Livestock and fisheries sectors play a vital role in enhancing rural livelihoods, particularly for women who are traditionally involved in these activities. Sustainable livestock management practices, such as integrated fodder production, improved cattle breeds, and animal health interventions, have contributed significantly to increased productivity and income. Women-led dairy cooperatives, supported by training and institutional frameworks, have reported a 25% increase in milk production in Odisha (NDDB, 2023). Climate-smart aquaculture is another emerging practice where women adopt techniques like pond management, water quality monitoring, and stocking of resilient fish species to combat climate-induced stresses. Fish species tolerant to temperature fluctuations and salinity changes have improved aquaculture yields, ensuring food security and income stability. Integrated farming systems, combining livestock, aquaculture, and crop cultivation, optimize resource use and minimize environmental impact. These practices not only enhance household nutrition but also create opportunities for women's entrepreneurship in dairy, poultry, and fisheries sectors. Capacity-building initiatives and access to markets have further empowered women to play a significant role in the livestock and fisheries value chains. Through these efforts, women farmers contribute to sustainable natural resource management while strengthening their socio-economic status in rural communities.

Women’s Involvement in Climate Mitigation

Women’s Involvement in Climate Mitigation Women's involvement in climate mitigation is vital, especially in sectors like agriculture and energy. In India, women-led initiatives have been at the forefront of promoting sustainable agricultural practices and renewable energy solutions. By integrating women into climate mitigation strategies, communities benefit from enhanced resilience and sustainable development. Renewable energy adoption significantly benefits women in agriculture and household management by reducing drudgery, enhancing productivity, and promoting environmental sustainability. In Maharashtra and Odisha, women-led Self-Help Groups (SHGs) have successfully implemented solar dryers, biogas plants, and improved cookstoves. Solar dryers help reduce post-harvest losses by 25%, enabling women to preserve fruits, vegetables, and spices for longer durations. Biogas plants provide clean cooking fuel, reducing the time spent collecting firewood by 60%, as reported by MNRE (2023). Additionally, improved cookstoves reduce indoor air pollution, lowering respiratory ailments among women and children. These interventions not only contribute to household well-being but also support climate change mitigation by reducing carbon emissions. Moreover, women are trained in maintaining these systems, ensuring long-term sustainability. Community awareness programs have encouraged more households to adopt these technologies, fostering a culture of energy efficiency. Table 4 illustrates the growing adoption of renewable energy solutions in these regions, highlighting the positive impact on women's time management, health, and economic activities. Thus, renewable energy initiatives play a critical role in empowering women while promoting sustainable agricultural practices in vulnerable regions.

Agroforestry and Carbon Sequestration

Women play a crucial role in agroforestry and carbon sequestration through afforestation initiatives and seed conservation practices. In tribal areas of India, particularly in Jharkhand, Odisha, and Madhya Pradesh, women-led community efforts have increased forest cover by 12% (Forest Survey of India, 2024). These women actively participate in planting native, climate-resilient tree species, contributing to carbon sequestration and mitigating climate change impacts. Women's participation in seed conservation ensures the preservation of indigenous crop varieties, which are often more resilient to extreme weather conditions. Community seed banks managed by women's groups store and distribute traditional seeds, promoting biodiversity and enhancing agricultural sustainability. Training programs have equipped women with knowledge of soil health, water conservation, and carbon sequestration techniques. These activities not only improve ecological balance but also offer women new income opportunities through the sale of tree saplings and non-timber forest products. Collaborative efforts with local forestry departments have further strengthened these initiatives. The success of these programs demonstrates the potential of women’s leadership in environmental conservation and climate-resilient farming practices.

Institutional Support & Capacity Building

Institutional Support & Capacity Building Institutional support and capacity building are crucial for effective climate action in India's agriculture sector. The National Innovations in Climate Resilient Agriculture (NICRA) project exemplifies this approach by focusing on strategic research, technology demonstrations, and capacity building to enhance resilience to climate variability. Such initiatives provide farmers with knowledge and tools to implement climate-smart practices, fostering sustainable agriculture. Additionally, capacity building empowers local institutions and communities to develop and apply adaptive strategies, ensuring long-term climate resilience.

Enhancing Adaptive Capacity

Adaptive capacity in agriculture refers to the community’s ability to respond, recover, and adapt to climate shocks through innovative practices and social cohesion. Women, as primary caregivers and food producers, play a crucial role in strengthening community resilience. Their indigenous knowledge of cropping patterns, water management, and soil conservation is invaluable in adapting to climate variability. Climate-smart practices such as the adoption of drought-tolerant crop varieties, integrated nutrient management, and participatory watershed development are increasingly being led by women farmers. Women’s involvement in collective action, such as self-help groups and farmers' cooperatives, has facilitated better access to climate information services, credit, and markets. Training programs focusing on climate-resilient agriculture, combined with community participation, have strengthened the social capital necessary for adaptive decision-making. For example, in Odisha, women farmers have spearheaded efforts to diversify cropping systems, reduce input dependency, and enhance soil organic matter through organic farming practices. Promoting gender-inclusive strategies in climate adaptation ensures sustainable agricultural development, enhances food security, and builds more resilient farming communities across diverse agro-ecological regions.

SHGs for Credit Linkages and Value-Added Enterprises

Self-Help Groups (SHGs) have emerged as transformative platforms for empowering women in sustainable farming, credit access, and value-added enterprises. In India, over 8 million women farmers are engaged in SHGs, with significant participation in states like Bihar, Odisha, and West Bengal (NABARD, 2024). SHGs provide women with access to institutional credit, enabling them to adopt improved agricultural practices and invest in small-scale food processing units. Training programs conducted by agricultural universities and NGOs have enhanced women's skills in organic farming, water-saving techniques, and value-added product development. Many women have successfully established enterprises in pickles, jams, and millet-based snacks, contributing to household income. Credit linkages with microfinance institutions have helped women access working capital, while cooperative marketing initiatives have expanded market reach. Figure 3 showcases the positive impact of SHG participation on women's income, with a reported increase of 35% over the last three years. SHGs also foster collective decision-making, enhancing women's social and economic status within their communities. The success of SHG-led farming enterprises underscores the importance of financial inclusion, capacity building, and community support in promoting sustainable agricultural practices.

Skill Development and Market Linkages

Training and skill development programs are crucial for enhancing women's participation in climate-resilient agriculture and agribusiness. Across various climate-vulnerable districts in India, women farmers have been trained in climate-smart technologies such as precision farming, integrated pest management, and the use of ICT tools. These programs, often organized by agricultural universities, KVKs, and NGOs, have significantly improved farm productivity and profitability. For instance, in climate-resilient villages, training initiatives have increased women's income by 30% (FAO, 2023). Workshops on market linkages have empowered women to engage directly with local and digital marketplaces, ensuring better prices for their produce. Skill development sessions also focus on post-harvest management, product packaging, and branding, particularly for women engaged in value-added enterprises. Additionally, exposure visits to model farms and agri-processing units provide practical insights and boost confidence. The adoption of mobile-based advisory services has further enhanced decision-making on crop selection and resource use. Community-based training models have proven effective in disseminating knowledge across SHG networks, resulting in widespread adoption of sustainable practices. These capacity-building efforts not only improve farm productivity but also position women as key stakeholders in climate-resilient agriculture.

Policy Interventions

Government policies play a critical role in ensuring gender equity in climate adaptation and resilience-building efforts. Women's participation in agriculture and natural resource management has been historically underrepresented, necessitating targeted interventions. Initiatives like the Mahila Kisan Sashaktikaran Pariyojana (MKSP) empower women farmers by enhancing their skills, improving access to credit, and promoting sustainable agricultural practices. Similarly, the National Adaptation Fund for Climate Change (NAFCC) has acknowledged the importance of women's contributions by funding gender-sensitive climate projects. Recent policy frameworks, including those by the Ministry of Agriculture and Farmers' Welfare (MoAFW, 2024), emphasize gender inclusion in climate negotiations, equal land rights, and access to technology. Recognizing women as key stakeholders in climate action leads to better resource management and increased adaptive capacity. Further, integrating gender-focused policies into national climate programs ensures that women have access to financial resources, extension services, and climate-resilient technologies. To achieve long-term sustainability, it is essential to institutionalize gender-sensitive policies at all levels—local, regional, and national. Strengthening legal frameworks for women's land ownership and decision-making rights will further enhance their role in climate-resilient agriculture. Governments must continue investing in policies that facilitate women's active participation in climate governance.

Economic & Social Benefits

Economic & Social Benefits implementing climate-resilient agricultural practices yield significant economic and social benefits. Adopting RCTs leads to increased crop productivity, reduced input costs, and enhanced profitability for farmers. Socially, these practices improve food security, promote sustainable livelihoods, and empower marginalized communities, including women.

Improved Income, Food Security, and Livelihoods

The adoption of climate-smart agricultural (CSA) practices by women has resulted in notable improvements in income, food security, and overall livelihoods. Techniques such as integrated farming systems, drought-resistant crops, agroforestry, and improved irrigation methods have enhanced agricultural productivity and reduced risks associated with climate variability. Research by the International Food Policy Research Institute (IFPRI, 2023) indicates that women-led climate interventions have led to a 30% increase in household income, primarily due to better crop yields, diversified farming, and value addition. Additionally, climate-smart strategies, such as organic farming and precision agriculture, have strengthened food security by ensuring sustainable crop production and enhanced nutrition. Women who engage in these practices not only improve their family's well-being but also contribute to community-level resilience against climate shocks. Table 5 in the report highlights how women's involvement in CSA has directly influenced income stability, dietary diversity, and household food sufficiency. Moreover, access to microfinance, cooperatives, and self-help groups (SHGs) has further facilitated income generation for women farmers. Strengthening climate-smart livelihood opportunities through policy support, extension services, and market linkages will be crucial in ensuring that women continue to thrive in the face of climate challenges.

Strengthened Community Leadership and Participation

Women's participation in community leadership and decision-making processes has significantly increased through self-help groups (SHGs), farmer producer organizations (FPOs), and community-based organizations (CBOs). These platforms have enabled women to take active roles in climate resilience planning, natural resource management, and sustainable farming practices. Reports by the World Bank (2024) indicate that more than 60% of women-led SHGs are now involved in climate-related decision-making at the village level. This shift marks a transformation in traditional leadership structures, where women are now playing a pivotal role in guiding climate adaptation strategies. By participating in local governance, women contribute to water conservation projects, disaster risk management, and sustainable land-use planning. Leadership training, digital literacy, and climate education programs have further empowered women to voice their concerns and advocate for gender-inclusive climate policies. Additionally, women’s involvement in climate cooperatives and producer collectives has strengthened their economic resilience and bargaining power in agricultural markets. Encouraging policy support, financial incentives, and leadership training for women in climate governance will ensure their continued involvement in shaping sustainable development pathways. Expanding gender-sensitive leadership programs will help build more inclusive and resilient communities capable of effectively addressing climate challenges.

Conclusion

Women play a pivotal role in climate change adaptation and mitigation, especially in agriculture and resource conservation. Addressing climate change from the right perspective requires gender sensitization among target groups to recognize women's contributions and challenges. Awareness generation and knowledge dissemination are crucial to equipping women with skills that enhance their adaptive capacity. Providing access to appropriate technologies through an amalgamation of traditional and modern practices ensures that women can effectively implement climate-smart solutions. Gender-based technology targets help measure adoption levels and ensure inclusive participation in sustainable practices. Capacity building through upscaling efforts, networking, and dissemination strengthens women's role in climate resilience. Regular follow-ups with stakeholders foster long-term engagement and impact. Additionally, involving local governing bodies enhances program effectiveness by integrating policies that support women-led climate adaptation strategies. By prioritizing these aspects, resource conservation technologies can empower women as change agents in mitigating climate risks and ensuring sustainable development.

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Understanding Livelihood Ecosystem Inter-dependencies for Reducing Climate Vulnerability of Tribal Women

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The concept of understanding livelihood ecosystem interdependencies for reducing climate vulnerability, particularly for tribal women, is a complex phenomena that connects several fields, including climate change adaptation, gender studies, tribal culture, and sustainable development. Hence, interdependence between livelihoods, ecosystems, and the climate can be leveraged to reduce the vulnerability of tribal women.

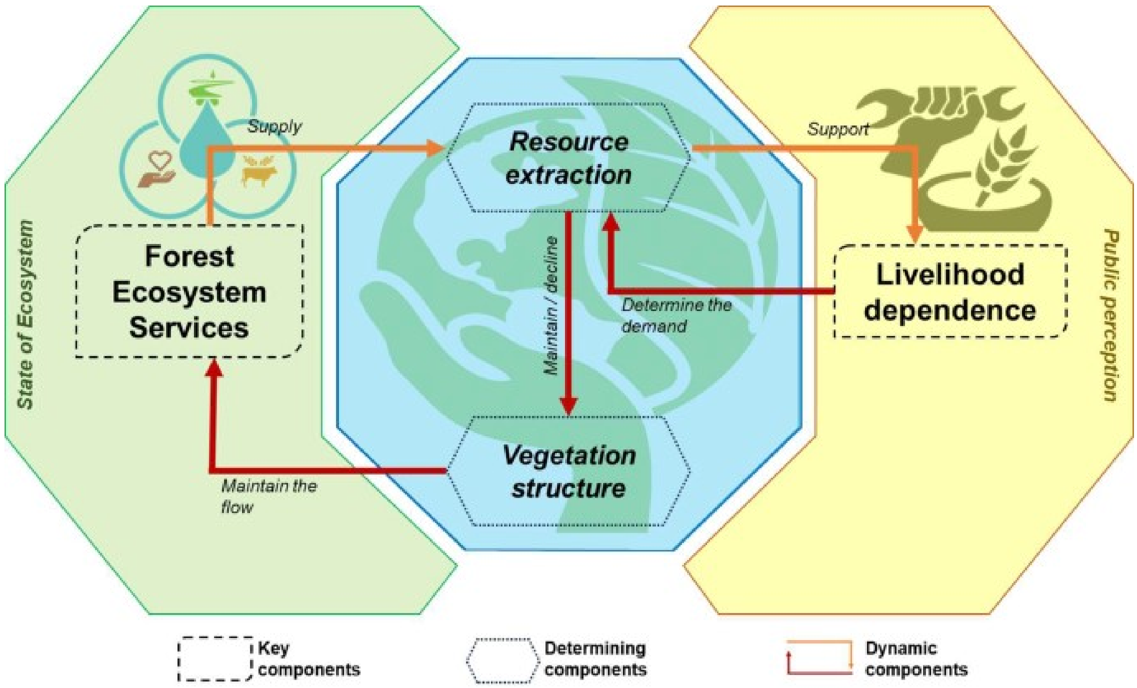

Fig 1: Livelihood Ecosystem Inter-dependencies <u>Source : Das, & Mallick (2024)</u>

Livelihood Ecosystem Interdependencies

Ecosystem-human interdependencies happen within complex socio-ecological systems, with highly interdependent governance arrangements, technology choice and economic considerations. This synergistic and inherently sustainable relationship between societal needs and the surrounding and supportive ecosystems is embedded in tribal culture, traditions and beliefs, and enabled by authoritative local governance arrangements enshrined in protected tribal rights. Human–ecosystem connections operate interactively, local people playing important roles in use and management of, as well as impacts on, the ecosystems that support their needs. Consequently, integrated socio-ecological systems can operate in a degenerative cycle when the vitality and supportive capacities of unsustainably used ecosystems decline, with inevitable adverse outcomes for socio-economic wellbeing. Alternatively, ecosystem protection or restoration can create regenerative socio-ecological cycles, in which maintenance or enhancement of ecosystem resilience and services offers improved human security and opportunity.

The livelihood of tribal communities, especially women, is often deeply rooted in their local ecosystem. These communities typically depend on a mix of natural resources like forests, water, soil, biodiversity, and agriculture for sustenance, income, and cultural practices.

- **Resource Access**

  Tribal women are often primary caretakers of natural resources and involved in activities like farming, gathering firewood, collecting medicinal plants, and fishing. These tasks are essential for food security, health, and income generation.

- **Ecosystem Services**

  Ecosystem services such as clean water, pollination, soil fertility, and climate regulation are vital to their livelihoods. Any disruption to these services due to climate change (e.g., deforestation, droughts, or soil erosion) directly impacts their ability to maintain these livelihoods.

- **Traditional Knowledge**

  Tribal women are often custodians of traditional ecological knowledge, including sustainable agricultural practices, natural resource management, and biodiversity conservation, which can help communities adapt to changing environmental conditions.

Climate Change and Vulnerability

The repercussions of climate change have a higher effect on marginalized populations, incorporating poor, young, old, sick, and tribal communities. Tribal communities, which mainly depend on regional natural resources like forests, are more exposed to the effects of climate change than urban people. Their close relationship with nature for livelihoods, culture, and health intensifies their susceptibility.

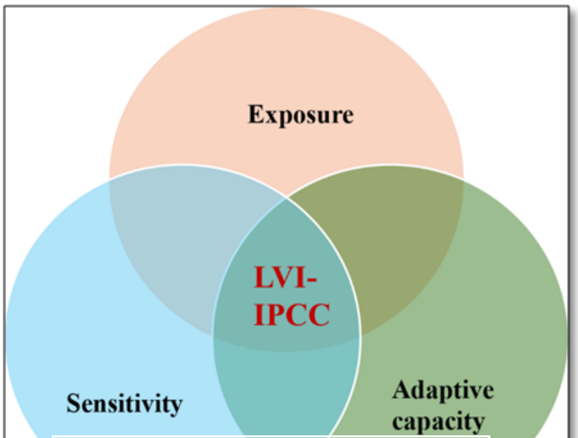

Figure 2: Contributing factors of Livelihood vulnerability index

Forest ecosystems provide diverse economic and social benefits, including job opportunities, forest resources, and cultural protection. Approximately 100 million people in India reside in forested areas, mostly tribal communities that sustain themselves by collecting and selling non-timber forest products (NTFPs). These items play a crucial part in their lives globally. Forest-dependent populations, such as nomadic tribes, are among the most vulnerable to the impacts of climate change on forests. India's tribal population constitutes 8.6%, while in Madhya Pradesh, 21.1% belongs to scheduled tribes, with 43 distinct tribal groups living there. These tribal communities are severely impacted by climate change, worsening their current social and economic issues.

It is important to comprehend the factors contributing to livelihood vulnerability to address the local climate-related concerns. A comprehensive and complex method is important to evaluate vulnerability, concentrating on three components: exposure, sensitivity, and adaptive capacity. Exposure consists of variations in climate and extreme natural events, and sensitivity encompasses land and infrastructure, food security, social security, water access, and health, and adaptive capacity includes awareness, socio-demographic profiles, financial stability, livelihood strategies, and social networks. Indicator-based methods integrate qualitative and quantitative methodologies, including data from censuses, surveys, and climatic records. Indexes like the Agricultural Vulnerability Index, Socioeconomic Vulnerability Index, Climate Change Vulnerability Index, Livelihood Vulnerability Index, Multidimensional Livelihood Vulnerability Index, and Human Development Index are essential tools in climate vulnerability analysis.

Climate change affects tribal communities in various ways, often exacerbating existing vulnerabilities. For tribal women, who may already face social, economic, and political marginalization, the impacts are even more severe.

- **Food Insecurity**

Changes in rainfall patterns, crop failures, and reduced access to resources can lead to food insecurity, disproportionately affecting women who are usually responsible for food production and preparation.

- **Health Risks**

Climate-related diseases (e.g., malaria, waterborne diseases) and environmental changes (e.g., air pollution, heat waves) can disproportionately affect women, particularly those in remote areas with limited access to healthcare.

- **Displacement**

Climate-induced displacement, especially from droughts, floods, or loss of arable land, can lead to loss of livelihood sources and exacerbate socio-economic inequalities.

- **Increased Workload**

As resources become scarcer, women may face increased burdens of collecting water, firewood, or finding alternative food sources, which further limits their time for education, economic activities, and self-care.

Reducing Vulnerability: Solutions through Interdependence

Reducing the climate vulnerability of tribal women requires a multi-faceted approach that takes into account the interdependence of livelihoods and ecosystems. Here are some strategies:

- **Promoting Sustainable Resource Management**

Empowering tribal women to continue or expand sustainable resource management practices, such as agroforestry, water conservation, and organic farming, can help build resilience to climate shocks while preserving ecosystem services.

- **Climate-Resilient Livelihoods**

Introducing diversified livelihood options that are less dependent on environmental degradation (e.g., eco-tourism, renewable energy, or market-based forest products) can reduce dependency on vulnerable ecosystems.

- **Strengthening Social Networks and Governance**

Strengthening community-based organizations or women's cooperatives can enhance collective action to address climate impacts. These groups can also advocate for policies that protect tribal rights to land and resources, which are often at risk due to climate impacts.

- **Capacity Building and Knowledge Sharing**

Women can be empowered through training programs that focus on climate adaptation techniques, disaster risk reduction, and sustainable agriculture. Combining traditional knowledge with modern technology can also enhance resilience.

- **Access to Resources**

Ensuring that tribal women have access to credit, insurance, and other financial services can help them recover from climate-induced losses and invest in climate-resilient livelihoods.

Policy and Advocacy

- **Inclusive Policy-making**

  Ensuring that the voices of tribal women are included in decision-making processes at the local, regional, and national levels is critical. Policies should recognize the distinct challenges tribal women face and aim to address them through specific interventions.

- **Land and Resource Rights**

  Protecting the land rights of tribal communities and women ensures that they retain access to resources that are essential for their livelihoods and resilience to climate change. Secure land tenure also incentivizes long-term investments in sustainable resource use.

- **Climate Finance**

  Allocating financial resources to support adaptation efforts in tribal areas is crucial. This includes funding for climate-resilient infrastructure, improved agricultural practices, and social protection mechanisms that target vulnerable women.

Conclusion

In summary, understanding the interdependencies between livelihoods, ecosystems, and climate change is crucial to reducing the vulnerability of tribal women. The focus should be on preserving ecosystems that sustain their livelihoods, providing climate-resilient livelihood alternatives, and empowering tribal women with the necessary resources and knowledge to adapt to changing environmental conditions. Additionally, it’s important to involve tribal women in decision-making and ensure that policies are inclusive and protect their rights. By leveraging their traditional knowledge and creating supportive policies, we can help tribal women better navigate the challenges posed by climate change and build a more resilient future for their communities.

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Empowering Farmwomen with Rain Water Harvesting: A Climate Change Adaptation Strategy

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In climate change scenario we experience more extreme events of cyclone, flood, drought, long dry spells etc. The intensity, amount and distribution of rainfall are also not as per the crop requirement. Secondly land and water are the two most vital natural resources of the world and these resources must be conserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite, non-renewable over the human time frame, and prone to degradation through misuse and mismanagement. Total global land degradation is estimated at 1964.4 M ha, of which 38% is classified as light, 46% as moderate, 15% as strong and the remaining 0.5% as extremely degraded, whereas present arable land is only 1463 M ha which is less than the land under degradation (Koohafkan 2000). The annual rate of loss of productive land in the whole world is 5 to 7 M ha, which is alarming. In India, out of 328 M ha of geographical area, 182.03 M ha is affected by various degradation problems out of which 68 M ha are critically degraded and 114.03 M ha are severely eroded whereas total arable land is only 156.15 M ha (Velayutham 2000). It was reported that in India 0.97% of total geographical area is under very severe erosion (> 80 t ha^{-1} yr^{-1}), 2.53% area under severe erosion (40-80 t ha^{-1} yr^{-1}), 4.86% area under very high erosion (20-40 t ha^{-1} yr^{-1}), 24.42% area under high erosion (10-20 t ha^{-1} yr^{-1}), 42.64% area under moderate erosion (5-10 t ha^{-1} yr^{-1}) and rest 24.58% area under slight erosion (0-5 t ha^{-1} yr^{-1}) (Singh et al. 1992). Therefore, the problem of land degradation due to soil erosion is very serious and with increasing population pressure, exploitation of natural resources, faulty land and water management practices, it will further aggravate. Land degradation also reduces the world's fresh water reserves. It has a direct impact on river flow rates and the level of groundwater tables. The reduction of river flow rates and the lowering of groundwater levels lead to the silting up of estuaries, the encroachment of salt water into groundwater, the pollution of water by suspended particles and salinization, which in turn reduces the biodiversity in fresh and brackish water and consequently fish catches. Lower river flows also interfere with the operation of reservoirs and irrigation channels, increasing coastal erosion and adversely affecting human and animal health.

Women farmers are greatly affected by the climate change as they take care of water requirement of both family (domestic use) and farm (irrigation water). There is a need for water harvesting, conservation and its efficient utilization as a climate change adaptation strategy. Water harvesting with a watershed concept is a major approach for water harvesting,conservation, and its efficient utilization. A watershed is an area from which runoff, resulting from precipitation, flows past a single point into a large stream, a river, lake or an ocean. Watershed management or protection implies the proper use of all land and water resource of a watershed for optimum production with minimum hazard to natural resources. Rainwater harvesting and its judicious use is the key for enhancing irrigated area, cropping intensity, land productivity and farm profitability in rainfed areas. Water conservation and harvesting measures which could be adopted are: In-situ water conservation by afforestation/ plantation/ vegetation; contour trenching on barren hill slopes; Bench terracing of steep slopes; Contour or graded bunding if agricultural lands; water harvesting though temporary and permanent gully control structures; and construction of water harvesting structures and ponds etc.

Contour trenching

Contour trenching implies excavating trenches along the contour or along a uniform level. Contour trenches are used both on hill slopes as well as on degraded and bare wastelands for soil and moisture conservation and afforestation purposes. These trenches break the slope lengths, reduce the velocity of surface runoff and consequently retard its scouring action and carrying capacity. The water retained in the trenches helps in conserving the moisture and provide advantageous sites for sowing and planting. Even though contour trenches have been used on all slopes, trenching on slopes exceeding 20% is not advisable either technically or economically. Contour trenches have been profitably used in both high rainfall and low rainfall conditions, varying soil types and depths, for soil and water and conservation and afforestation. The size of the trenches depends upon the soil depth available at the site. Normally sizes between 1000 cm^2 to 2500 cm^2 in cross-section are adopted.

Bench terracing

Bench terracing consists of construction of series of platforms along contours cut into hill slope in a step like formation. These platforms are separated at regular intervals by vertical drops or by steep sides and protected by vegetation and sometimes by packed stone retaining walls. In fact, bench terraces convert the long unintercepted slope into several small strips and make protected platforms available for farming. Depending upon the purpose for which they are used, bench terraces are also classified as follows: Hill-type bench terraces; used for hilly areas with a reverse grade towards the hill; Irrigated Bench terraces; level benches adopted under irrigated conditions; and Orchard /half moon bench terraces; narrow width terraces (about 1 m) for individual trees. The conversion of land into bench terraces over a period of time is referred to as gradual bench terracing. Bench terraces with slopes in side are to be adopted in heavy rainfall areas where a major portion of the rainfall is to be drained as surface runoff.

Stone terracing

Stone terracing, also known as stone wall terraces are small embankments constructed with stones across the hill slopes. These can be adopted on any slope where stones are available in plenty at the spot. By intercepting the surface runoff, these stone terraces help in retarding the soil loss and conserving soil and moisture. At the same time, the formation of the stone terraces help in removing the stones that lie scattered on the field and otherwise hinder agricultural operations like ploughing, inter culture etc. The spacing adopted for stone terraces need not be rigid and suitable spacing can be adopted depending upon local conditions. Spacing from 10 meter to 30 meters can be adopted depending upon the slope. Stone terraces should be as far as possible straight.

Temporary Structures

Temporary structures for gully control are designed to retard the flow of water and reduce the channel erosion. In addition, they retain some quantities of sediment and moisture, which helps in establishment of vegetation. These are temporary in nature and normally last for a very short period say up to 2 to 4 years i.e. till vegetation is established. The first order and/or second order streams where runoff contributing area is within 20 to 40 hectare, depth within 2 m and width within 5-6m, the temporary gully control measures are very useful. They are usually made of wooden poles, wire, sand filled plastic bag, wooden plank, loose boulder etc. These have to be repaired annually or after every heavy monsoon. Various types of temporary gully control structures are: (i) One row or single row wooden post check dam, (ii) Two row or double row wooden post check dam filled with brush wood, (iii) Two row or double row wooden post check dam filled with boulders, (iv) Woven wire-wooden post check dam, (v) Loose boulder check dam, (vi) Sand filled plastic bag check dam, (vii) Wooden plank -post check dam. Construction of temporary structures for gully control purposes are advantageous as i) They are cheap as compared to permanent structures, ii) Locally available material can be used, iii) No technical skill is needed for their construction.

Semi-permanent Gully Control Measures

These usually have a longer life, say of 10-15 years, and normally do not require regular maintenance. They do not require the assistance of vegetative growth for controlling the gully but helps the vegetation to come up on gully sides. They are constructed in places where materials are available in sufficient quantity. These are very effective in steep gullies traversing hilly and mountainous regions. They are also useful in ravines where passage for livestock has to be provided. These are very much suited in second and third order streams with a runoff contributing area of 40 to 100 ha. The depth of gully is usually less than 4 m. Various types of semi-permanent gully control structures are: 1. Loose boulder check dam, 2. Log check dam, 3. Gabion check dam

Permanent Structures for Gully Control

General requirement of the permanent structures for gully control are: 1) They should be constructed with permanent materials, 2) They should have adequate capacity to handle the runoff , 3) They should help in stabilizing the gully and store water whenever necessary. The different types of structures for water harvesting are: Drop spillway/ check dams, and Drop-inlet or pipe spillway .

The drop inlet spillways are used at appropriate locations in the gully for storage of water. The permanent structures for gully control consist of three main components. These are the inlet, conduit and the outlet. Water enters the structure through the inlet and is conveyed through the conduit. The water leaves the structure through the outlet. The outlet is mainly responsible for dissipating the energy of the water so that the water flowing through the structure does not cause any erosion downstream of the structure.

ICAR flexible check dam commonly known as **rubber dam** is an inflatable structure build across a stream used for water conservation, flood control and regulating flow of water in the stream. When it is inflated, it serves as a check dam/weir and when it is deflated it functions as a flood mitigation device and sediment flushing. The head or height of rubber dam is variable. This variable head also regulates the depth of flow in the irrigation diversion channel present in the upstream side of the check dam or in irrigation canals and distributaries. This can also be used in coastal creeks, estuaries, streams and channels to restrict the inflow of sea water into land mass. During high tide it can also prevent the high tides to enter into the fresh water system.

As an innovative hydraulic structure, the rubber dam mainly consists of the following parts: (i) a concrete foundation with head wall extension, side wall and wing wall of a normal check dam; (ii) the head wall replaced by rubberized fabric dam body; (iii) anchoring system (anchoring of rubber sheet with bottom and side of the check dam); (iv) Inflation deflation system (an inlet/ out let piping system for inflation and deflation by water); and (v) a pump for filling water for inflation.

The span or length of the rubber dam can vary from 1 m to 10 m (depending upon the width of the stream). For wider streams also, there can be several spans.

Advantages of Rubber Dam

- ✓ Traditional check dams get silted up due to continuous inflow of sediment from upstream side thus reducing the storage capacity. Rubber dam can be occasionally deflated during flood to flush out the deposited sediment in the upstream side.
- ✓ During dry period/ lean season, the head wall can be easily inflated to store more water.
- ✓ Due to flexibility of the head wall, during extreme events of high intensity rainfall and extreme flood situation, the structure can be easily deflated. This prevents damage to the structure, breaching of stream bank/ levees, and erosion of stream bed.
- ✓ Earth quake, land slide cannot damage the head wall as it is made of rubber and repair to the side and wing walls can be easily done without dismantling the structure.
- ✓ There will be no conflict of interest between the upstream and downstream farmers and other beneficiaries as desirable amount of water can be easily delivered to downstream side by storing the required quantity in the upstream side and thereby maintaining environmental flow.

Fig.1: Rubber dam in operation in Konakn region of Maharashtra installed by ICAR-IIWM

Important Links for VDO and Reading Materials on Rubber Dam

- ❖ https://youtu.be/Wr4WQsW5qts
- ❖ https://youtu.be/0_cPPqdQIuI
- ❖ https://youtu.be/Fr6zDoVe04Y
- ❖ https://youtu.be/bZ7tr2-s-Lg
- ❖ http://www.iiwm.res.in/pdf/rubber_dam_leaflet.pdf
- ❖ http://dadf.gov.in/sites/default/filess/ebooks4yrsmodi.pdf(E-book on "Modi Government; 4 years of development, commitments and trust, MoAFW, GOI. Multipurpose, inflatable flexi rubber dam for watersheds; page no. 93)
- ❖ www.theweekendleader.com/innovation/1952/Versatile-rubber.html **(Article in magazine "The Weekly Leader")**

- https://www.thehindu.com/sci-tech/science/rubber-dam-for-sustainable-production/article6218016.ece (Article under Science & Technology in "The Hindu")
- http://www.iiwm.res.in/pdf/RubberDam_FAQ_Booklet_English.pdf

Cost of the ICAR Flexi Check Dam Structure and Operational Cost

The cost of rubber dam along with its RCC base structure varies from Rupees one lakh to 10 lakh in small watershed streams for 3 m to 15 m width. Since the head wall is semicircular in shape and hydraulic jump occurs very close to the structure, a long apron is not required, thus reducing the cost of the base structure. The head wall is replaced by a composite rubber sheet. The cost of rubber composite sheet is around Rs. 3800/m^2 for 8 mm thick at present. However, the cost will reduce when produced on commercial scale in large quantity. The operating cost is variable and is required to deflate during high flood, inflate during dry period or any other emergency condition and then pumping cost for inflation. On an average 4 to 5 times inflation/ deflation is required which will cost around Rs.1000 per year.

Installation and Field Evaluation

The different steps followed in successful design and installation of rubber dam by Indian Institute of Water Management (IIWM), Bhubaneswar and its impact on agricultural productions are given below.

a) Selection of sites for check dam, impounding structure and loose boulder structure to install rubber dam.

b) Socio-economic survey of the location where rubber dams were to be installed.

c) Hydrological data collection and analysis

d) Design, estimation and execution of base structure

e) Fabrication, installation and testing of rubber dam

f) Development of inflation, deflation mechanism of the rubber dam.

g) Observation of crop yield data of the farmers who got benefit from rubber dam.

Two of the installed rubber dams at Chandeswar, Odisha are presented through plate 1.

Fig.2: Rubber dams installed in watersheds of Odisha by IIWM, Bhubaneswar

Location of Rubber Dams in India

Initially the rubber dams were installed at the following locations of our country by ICAR-Indian Institute of Water Management, Bhubaneswar and evaluated.

State	AER	District	No of rubber dams
Himachal Pradesh	14	Kangara	2
Uttarakhand	14	Dehradun	3
		Tehri-Garhwal	1
Meghalaya	17	Ri-Bhoi	1
Gujarat	5	Navsari	4
Maharashtra	19	Ratnagiri	3
	6	Pune	3
Odisha	18	Khordha	5
	12	Koraput	3
	12	Nabarangpur	1
	18	Baleswar	3
	12	Dhenkanal	1
Tamil Nadu	8	Nilgiri	1
West Bengal	15	East Medinipur	2

Following the success of the ICAR flexi rubber dam, Government of Kerala had installed four rubber dams in Kasargod district of Kerala with technical collaboration of ICAR-IIWM, Bhubaneswar. Government of Maharashtra, Government of Odisha had also installed and in the process of installing few more rubber dams.

Impact of Rubber Dam Technology on Water Harvesting and Crop Performance

The average positive impact of a rubber dam having width 5 to 7 m and height varying between 1 to 1.5 m resulted in water storage and crop performance as described in the below table.

Parameters	Amount	Remark
Additional storage	4000 -10000 m^3	At any point of time
Additional area irrigated	13-17 ha	During kharif
	2-5 ha	During rabi & summer
Average productivity enhancement	2.87 t/ha to 4.67 t/ha	For paddy in kharif
	0.63 t/ha to 0.92 t/ha	For green-gram in rabi
	22 to 34%	Rabi & summer vegetable
Increase in cropping intensity	31%	
Cultivated Land Utilization Index	0.43 to 0.60	
Enhancing net returns	Rs. 44000 per ha	Rice-greengram cropping system
Benefit: cost ratio	2.30	
Internal Rate of Return	14.3%	Payback period of 3 years

Conclusion

During climate change scenario, it is essential to adopt water harvesting, conservation, and its efficient utilizations though in-situ (where it falls: field) and ex-situ (where it flows: stream) water conservation techniques and its efficient utilization. Further, from the agricultural and hydrologic data observation it is apparent that, rubber check dams can be well utilized for achieving sustainable crop production and could be instrumental for enhancing crop and water productivity in watersheds. It does not have adverse impact on environment. It can be easily installed, operated by farmers of the watersheds. There is almost no maintenance except the running cost of filling (inflating) with water at the time of need.

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Climate-smart Pest Management to Build Resiliency of Farm Women for Sustainable Food Production

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Climate change now days are a scientifically established and over all accepted fact (IPCC, 2013). The global average surface temperature of earth's has increased by 0.78°C in the 20th century and it is expected to increase up to 1.8-4°C by the end of 2100, as predicted by different change projections. The Intergovernmental Panel on Climate Change (IPCC, 2014) has developed long-term emissions scenarios based on the carbon intensity of energy supply, the income gap between developed and developing countries, and sulphur emissions (IPCC, 2014). These climate change scenarios derived from the global circulation model (GCM) are widely used in the analysis of possible climate change and its impacts on inhabitant biota, and options for adaptation to climate change impacts on agriculturally important insect pests. These scenarios are generated based on hypotheses about drivers of future global emissions. While modelling the insect pests status one has to take into account, the selection of an appropriate model GCM (one or several), emission scenarios (i.e. RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5), time periods (near, distant, very distant future), GCM (one or numerous), environmental variables (e.g. temperature, humidity etc.), and downscaling methods to reduce the uncertainty. Changes in climatic factors may have consequences on distribution, population dynamics, invasion pattern, area and crop suitability, extinction, incidence etc. of insect in natural and agricultural systems (Berzitis et al., 2014; Ikeda et al., 2017). Temperature among climatic variables, is considered as the foremost environmental factor due to being insects as poikilotherms, which influencing their distribution, survival, behaviour, reproduction and further development (Bale et al., 2002). Insect pest infestation is one of the most limiting factors in agriculture production systems. Despite timely crop protection measures, insect pests contribute to an average of 16-18% yield losses in crops (Oerke et al., 1994). These problems are likely to be exasperated by the changing climate which may put forth a major challenge to attain a goal of food security. The efficacy of pest management tactics largely depends on the timing of management option application.

Likewise, temperature, carbon-di-oxide (CO_2) concentration also play a significant role in determining the characteristics of a food-generating ecosystem which ultimately influences the insect pest population. Increased concentration of CO_2 results in faster acquisition of carbon, which promotes rapid growth and development of plants conducive to insect pest population growth. Elevated CO_2 reduces leaf nitrogen in peanuts and parthenium, leading to increased food consumption and slower growth rate in insects such as tobacco cutworm, *Spodoptera litura* and *Zygogramma bicolorata* (Rao et al., 2022; Kumar et al., 2021). Climate change has impacts on insect pest distributions, overwintering survival, risk of invasive alien species, number of pest generation, effectiveness of natural enemies as biological control, and change in frequency of phytopathogen spread by insect carriers (Choudhary et al., 2019a).

The number of generations of insects in a year can be to the thermal development tolerance of an organism, which is measured by growing degree days (GDD) (Choudhary et al., 2019b).

GDD is calculated as the total heat accumulation over a year and is determined by summing the difference between the daily maximum and minimum temperatures. The impact of temperature rise on insect species will vary depending on whether increase or decrease of temperatures (Choudhary et al., 2019c). For example, multivoltine fruit flies (Diptera: Tephritidae) will experience faster development and an increased number of generations per year due to the temperature rise (Figure 1; Choudhary et al., 2019c).

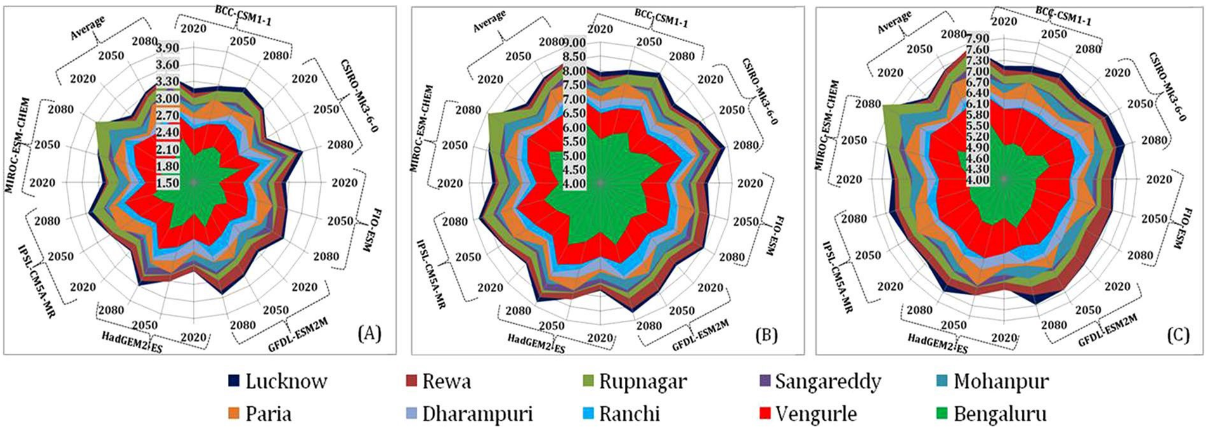

Figure 1. Increase number of generations with reduced generation time observed in fruit fly species (A = *Bactrocera correcta*; B = *Bactrocera dorsalis*; C= *Bactrocera zonata*) during future climate change periods across ten mango growing locations of India. (Source Choudhary et al., 2019c).

Invasive Alien Species (IAS) are creatures that have been introduced into an ecosystem, either deliberately or inadvertently, outside their indigenous range (Masters and Norgrove 2010). These species may include nuisance insects and disease-carrying insects. Due to increased travel, trade, and agriculture, many species have become much more widespread in recent years (P´erez et al., 2022). The impact of climate change on several variables, including species distribution, growth, and survival in new environments, is complicated and can have both good and negative effects. In the past, physical barriers might have prevented some species from spreading to inappropriate environments, but climate change may now allow them to do so. Since all biological systems have intrinsic thermal constraints, rising temperatures will have a substantial effect on the ecosystems and organisms that inhabit them. Climate change is disrupting insect overwintering strategies by altering photoperiod through changes in temperature and precipitation. This can lead to a skewed timing of diapause and a higher danger of extreme cold temperatures if insects enter diapause late in their life cycle.

Insect pests are known to be negatively impacted by climate change, with temperature changes expected to be especially severe. Insect life-table metrics like growth, reproduction, and survival may be directly impacted by these changes, or they may have an indirect effect on elements like host effects, competition, and pressure from natural enemies.

The amount, range, and timing of pests and natural enemies are predicted to be significantly impacted by climate change, endangering the efficacy of biocontrol initiatives (Nechols, 2021). Aphids are a type of insect pest kept in check by various natural enemies, such as parasitic wasps and ladybirds (Eigenbrode and Trumble, 1994). However, the effects of global warming could result in different responses from these species. A temperature rise has the potential to accelerate the development of natural enemies at a faster rate than their prey, leading to a possible extinction of the natural enemies if this repeatedly occurs over a prolonged period.

These problems are likely to be exasperated by changing climate which may put forth the major challenge to attain the goal of food security. The efficacy of pest management tactics largely depends on the timing of management option application. So the prediction of pest population dynamics, distribution and abundance through modelling has to be well in advance and it has to linked with more number of climate change projection that could facilitate better preparedness to combat outbreaks of serious insect pests through development of efficient pest management strategies to cope with the changing situations. Quantification of insect pest damage on crop production is one of the most important research questions for agricultural simulation modelling. Dealing with the impacts of climatic variability in time and space on biological systems is a really tedious task owing to its complexity, uncertainty, unpredictability, and differential impacts over time and place. The impacts of climate change on agricultural insect pests usually assessed through various tools and techniques *i.e.* growth chamber studies for pest phenological modelling, field manipulation studies and historical data of population dynamics. These information's can be linking with climate change projection models and pests future prediction can inform through process-based models or climate pattern matching models at regional or global level. Adaptation to the effects of climate change is a continual process that involves implementing strategies that manage and reduce the risks of climate change. Therefore, prospective measures for adjusting to new pests and diseases and alleviating the adverse effects of current ones have been recommended. These measures comprise adjusted IPM methodologies, monitoring of climate and insect pests, and utilization of prognostic modeling instruments.

Proposed women-centric interventions of climate resilient management practices

a. **Monitoring and surveillance for timely management**
   Surveillance and monitoring of the insect are prime necessities to carry out effective management operations. A robust and continuous surveillance system at ICAR RCER Farming System Research Centre for Hill and Plateau Region, Ranchi under National Innovations on Climate Resilient Agriculture (NICRA) on mango pests implemented from 2011 to 2019 in six mango centres in India measured insect pests of mango at the proper time and brought down the incidence rate of major pests like mango hoppers, thrips, mealy bugs and fruit flies etc. by application of protection measures at right time. It also indicated the increase of any pest within a particular period of the crop season so that a proper control strategy can be applied. This strategy can be replicated for other crops also.
b. **Weather-based forewarning models for insect pest management**
   Timely and accurate prediction of pests in cropping ecosystems would check pests' population outbreaks. Time series seasonal autoregressive integrated moving average (SARIMA) models were developed for forecasting the mango hoppers and thrips population in the mango agroecosystem (Bana et al., 2024). Forecasting models developed from ICAR RCER predict mango insect pests well in advance which can be used for timely better management of insect pests in mango agroecosystem. Forecasting models developed for mango pests are integrated into android based mobile apps and readily available for end users. The development of weather-based forewarning models will be a viable technological option for pest management strategies in the region.

c. **Resistant and tolerant sources**
Research on host plant resistance should be taken to the forefront to address the biotic stresses related problems in crops in changing climate scenarios. The development of pest-resistant varieties along with other desired traits should be the top priority for the region. Resistant/tolerant varieties like Udaya, Lalat, Saktiman, and Daya against rice hopper and Himayuddin, Lal Sinduria, Mulgoa Hill, and Hybrid- 11/4 against mango shoot gall psylla are available to combat changing pest status (Choudhary and Das, 2020).

d. **GIS-based modelled risk maps as a decision-making tool for pest management**
Early predictions on the future pest distribution and abundance through prediction models could facilitate better preparedness to combat outbreaks of serious insect pests by developing effective area-wide pest management strategies well in advance. In that way, models are considered important analytical tools that allow a better understanding and prediction of insect population dynamics and growth potential under an array of environmental conditions. The recent developments in GIS and geostatistics have made it easier to analyze complex spatial patterns of insect species and will landmark a breakthrough in insect pest management.

e. Crop and canopy management
The technologies like alley formation and alternate wetting & drying in rice, centre opening in mango, ecological engineering in vegetable crops etc are proven against pest management. These environmentally friendly and economically viable technologies should be promoted, and such types of technologies should be developed for the large area covering the region.

f. Modified Integrated pest management strategies
Climate-resilient and region-specific integrated pest management (IPM) packages are to be developed and demonstrated in farmers' fields for sustainable and environmentally friendly pest management strategies.

In conclusion, insect pests in agricultural ecosystems will pose a significant threat to food security in changing climate scenarios. To address this issue effective management strategies, especially to women-centric must be implemented. Understanding the biology and behavior of pests with the environment is crucial, as climate change will alter their distribution and behavior. Monitoring changes in pest populations through traditional methods, as well as advanced methods is essential for timely intervention. Modified Integrated Pest Management (IPM) strategies, combining cultural, biological, and chemical methods, should be employed to minimize reliance on pesticides and reduce environmental impact.

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Predictive technologies for climate resilient agriculture

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The United Nations apex organization, International Panel on Climate Change (IPCC) declared that climate change is real. Theleaders of countries has understood this vital issue and started to take corrective steps to curtail the impacts on the various eco systems. IPCC also signified clearly that human activities like industrialization, increased greenhouse gas emission, urbanization forest clearing are the key factors for this faster change in climate and the pace of the change is significantly higher in the last half-century.Owing to this, the world's temperature has increased by 1˚C since the 1950s and it is predicted that global air temperature may rise by 1.5˚C during 2030–2052 (IPCC 6thAssessment ReportWG1, 2021; Zong et al., 2022).This certainly pose severe risks to global agricultural productivity as well as food and nutritional security. Agriculture supports around 58%of the population and 70% of ruralhouseholds (82% of small and marginal farmers)(Borkar, 2019) in India, while estimated food grains production for the year 2023-24 was 332.3 million tons regardless ofweather related stresses(DA&FW, 2024).Though, diverse climate of our country allows cultivation of wide range of crops it also amplifiesthe threat to production of essential staples like wheat and rice. It is projected that during 2050s' the temperature of our country may increase by 2.8˚C and hence climate resilient technologies are essential to manage any unforeseen changes (Birthalet al., 2021).

Climate Resilient Agriculture (CRA) is an approach that includes sustainably using existing natural resources through crop and livestock production systems to achieve long-term higher productivity and farm incomes under climate change and variability. CRA is a risk management strategy and is a way to transform the agricultural and livestock system to be more sustainable and environmentally friendly. CRA strategies can help farmers mitigate the effects of drought, floods, and other extreme weather events which in turn alter the current situation and sustain agricultural production from the local to the global level, especially in a sustainable manner.This lecture aims to unfold the predictive techniques available for practicing the climate resilient agriculture like weather and climate forecasts to monitor the crop growth and development, pest & disease forecast, water management, climate resilient crops and varieties and challenges and opportunities in implementing the these techniques.

2. Climate projections and weather forecast at different time scales

In the sixth Assessment Report unveiled by the IPCC projected the future climate using Shared Socio-economic Pathways (SSPs). These pathways describe possible socio-economic conditions, land-use changes, and other human-caused climate drivers that influence greenhouse gas emissions, thus affecting radiativeforcing (Table 1). Radiative forcing describes the amount of excess energy trapped within the Earth's climate system due to the variation of a climate change factor such as greenhouse gases concentrations.

Projection of mean rainfall, daily rainfall extremes (number of rainy days and simple daily intensity), maximum, minimum and mean temperature changes during the southwest (SW) and northeast (NE) monsoon seasons in the near (2021–2050) and far future (2071–2100) under the SSP2-4.5 & SSP5-8.5 scenarios relative to the baseline period (1985–2014) was made by Lakshmi Kumar et al., (2023) using bias-corrected models from CMIP6 (Coupled Model Intercomparison Project Phase 6) for Indian region. The output of the study indicated that the rainfall is increased significantly over many regions of India in the SW and peninsular Indian regions in the NE monsoon season by the end of the 21st century. Number of rainy days during SW monsoon season is reduced by 10% per year in the northeastern parts and Himalayan region of India, while it is around 5% during NE monsoon by 2100 under the SSP5.8.5 scenario. Rise in maximum and minimum temperature by 4.5° C during summer and 5°C during winter season is expected over northern parts of India.Under the SSP2-4.5 and SSP5-8.5 scenarios, average temperatures and precipitation are expected to increase rapidly from mid-century onwards, with continued significant, rapid increase throughout the century.

Table1. Different Shared Socio-economic Pathways of IPCC and projected temperature change during 2021-2040

Scenario	Characteristics	Very likely change in global average temperature (ºC)* during 2021-2040
SSP1 (Sustainability)	Low challenges to both mitigation and adaptation. Policies focus on human well-being, clean energy technologies, and the preservation of the natural environment.	1.2 to 1.7
SSP2 (Middle of the Road)	Moderate challenges to both mitigation and adaptation	1.2 to 1.8
SSP3 (Regional Rivalry)	High challenges to both mitigation and adaptation. Nationalism drives policy and focus is placed on regional and local issues than global issues.	1.2 to 1.8
SSP4 (Inequality)	High challenges to adaptation and low challenges to mitigation	1.2 to 1.8
SSP5 (Fossil-fuelled Development)	Characterized by high challenges to mitigation and low challenges to adaptation	1.3 to 1.9
*Temperature differences relative to the average global surface temperature of the period 1850-1900 (Source: https://environment.govt.nz)		

Information on how would be the climate in the ensuing future are important to take proactive measures. Stakeholders like policy makers and government officials can take effective actions/policiesbased on the future rainfall and temperature projections provided at global and regional scales. Though this information would help researchers, educators and non-governmental organizations to understand and prepare for reducing the ill effect of climate change, forecasts at seasonal, extended range and medium scale range are practically assists the farming community in crop planning before, during and after crop season. India Meteorological Department (IMD) generates weather forecasts at different temporal scale i.e. short range, medium range, extended range and seasonal scales and these forecasts are used for tactical and strategic decisions in agriculture. For instance, seasonal forecast provided at different times (Fig.1) i.e. before and during the monsoon season helps in taking up strategic decision in agriculture for the farming communities particularly in the states where prolonged dry spells and floods are expected during the monsoon season. Through these general outlook on seasonal rainfall appropriate strategies can be taken for input management like arrangement for seeds for short and medium duration alternate crops, fertilizers, pesticides, water harvesting etc.

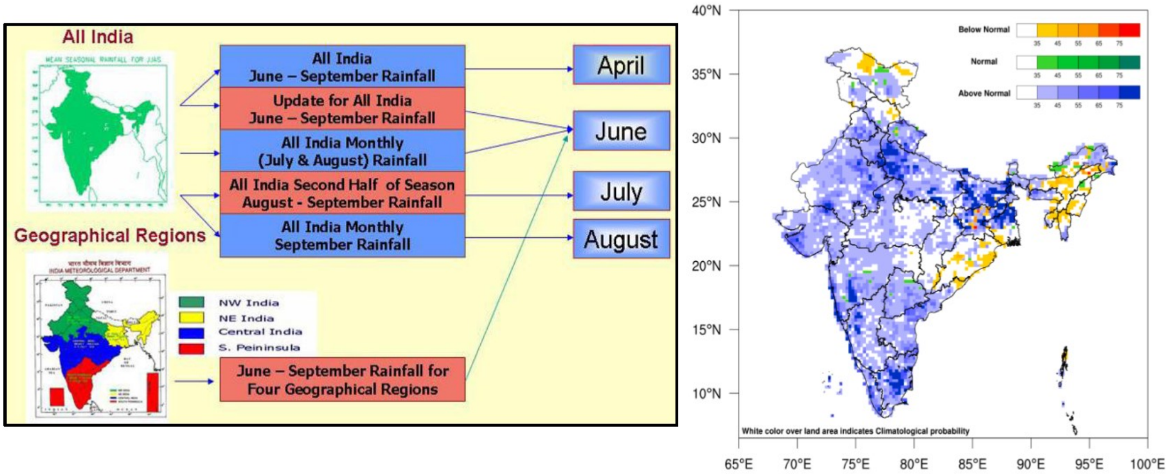

Fig. 1. Different time schedule for IMD long range forecast for southwest monsoon rainfall (left) and probabilistic forecast for 2024 southwest monsoon season (right)

Like seasonal rainfall forecast, extended range weather forecast(15 days) enables farmers to organize and carry out appropriate climate resilient agricultural operations to cope with weather vagaries. Medium range weather forecast (5 days) issued by National Center for Medium Range Weather Forecast are being used to prepare block level agromet advisories on a real time basis at Agro-Met Field Units on every Tuesday and Friday. It has been proved to be useful in the decision making process in every farm operation, rain water harvesting, crop planning, control of pest& diseases, irrigation scheduling etc. Socio-economic benefits of agro-met advisory services was assessed out by reputed National Council of Applied Economic Research, Delhi (NCAER, 2015) and the council highlighted the following points.

(i) Management of sowing in case of delayed onset of rains;
(ii) Shifting to short-duration crop varieties in case of a long-term delay in rainfall;
(iii) Deferring of spraying of pesticides for disease control on forecast of occurrence of rainfall in near future;
(iv)Postponement/ skipping artificial irrigation in case of heavy rainfall forecast.

For the benefit of farmers, IMD has developed many mobile applications so as to know the weather condition at present and forecast for the coming days which helps to take appropriate steps.

Mausam : provides weather conditions and different types of weather information through many weather maps of India.
Meghdoot Agro:delivers critical information to farmers through weather based agrometadvisories
Damini Lightning: gives alert on lightning by GPS notification.

3. Crop health monitoring

Crop condition monitoring at continued intervals and assessing the condition at the earliest is essential for achieving better crop yield. In general, general crop condition in terms of nutrient status can be seen through leaf colour change. However, it is not easy for all the farmers to identify the deficit symptoms and which nutrient responsible for the same and how much amount of fertiliser should be applied to manage the deficiency. In this context, early in 1996, international Rice Research Institute introduced a cheap (around 100 rupees for 4 panel card), easy to interpret Leaf Colour Chart (LCC) for nitrogen management in rice (Fig.2). Later, PAU (for rice, basmati rice, wheat, maize, baby corn, and BT cotton), ICAR-NRRI (rice), UAS-Dharwad(sugarcane) and ICAR-IIMR (sorghum, pearl millet, finger millet) have modified this chart by introducing various green shades for different crops. PAU and ICAR-NRRI has developed decision support system called "PAU Urea Guide" and "riceXpert", respectively through which farmers can get information on quantity of nitrogen fertiliser to be applied.

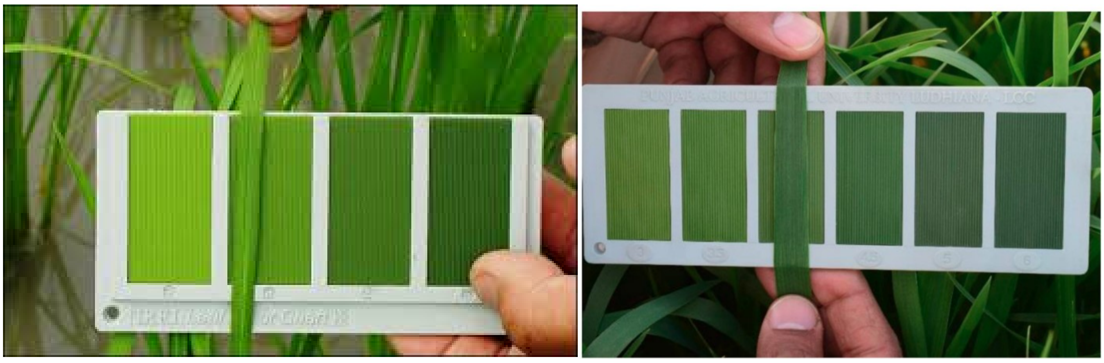

Fig.2. Leaf Colour Chart developed by IRRI (left) and PAU (right) for nitrogen management in rice

With the help of NGO called AtamPargas Social Welfare Council who actively involved in sensitising the importance of leaf colour chart and how to read the LCC in the role model village Bassian in Ludhiana district of Punjab. By adopting the LCC based nitrogen application, the farmers of this village reaped almost same yield obtained by conventional farmers' practice and they could also save 75 kg N/ha for rice in 2017 season and 50 kg N/ha for wheat in 2017-18 season (Moring et al., 2021).

e-Crop is an electronic crop simulator that simulates crop growth in real-time based on weather, soil moisture and nutrient status; calculates nutrient and water requirements and generates agro-advisory for the crop at a daily time scale (Fig.3.). This crop simulation model-based device gives periodical advices as SMS to the growers about water and nutrient (nitrogen, phosphorus and potassium) requirements. This IoT based device developed by ICAR-CTCRI, Thiruvananthapuram was demonstrated in the cassava, sweet potato, elephant foot yam and banana fields. It is reported that by following the advisories received from the e-crop device higher yield was obtained and around 50% of nutrients and water could be saved owing to more knowledge-intensive management of spatial and temporal variability of soil and plant properties. This device is generic nature and can be modified for any field crop and efforts are being in progress in collaboration with Kerala state department of agriculture and farmers welfare and ICAR institutes.

Fig. 3. E-Crop device

In recent years, several countries and organizations currently employ crop monitoring systems to know regional and global crop condition. The NDVI, an indicator of the level of photosynthetic activity, reflecting whether the vegetation is stressed or not, is one of the most commonly used indices.Space Applications Centre (SAC) of ISRO has developed a web based analysis tool platform called Visualisation of Earth Observation Data and Archival System (VEDAS) (https://vedas.sac.gov.in)(Fig.4) for vegetation monitoring. Users can access this platform to visualise and understand condition of crop at village level based on NDVI images and also soil moisture status, temperature and rainfall.

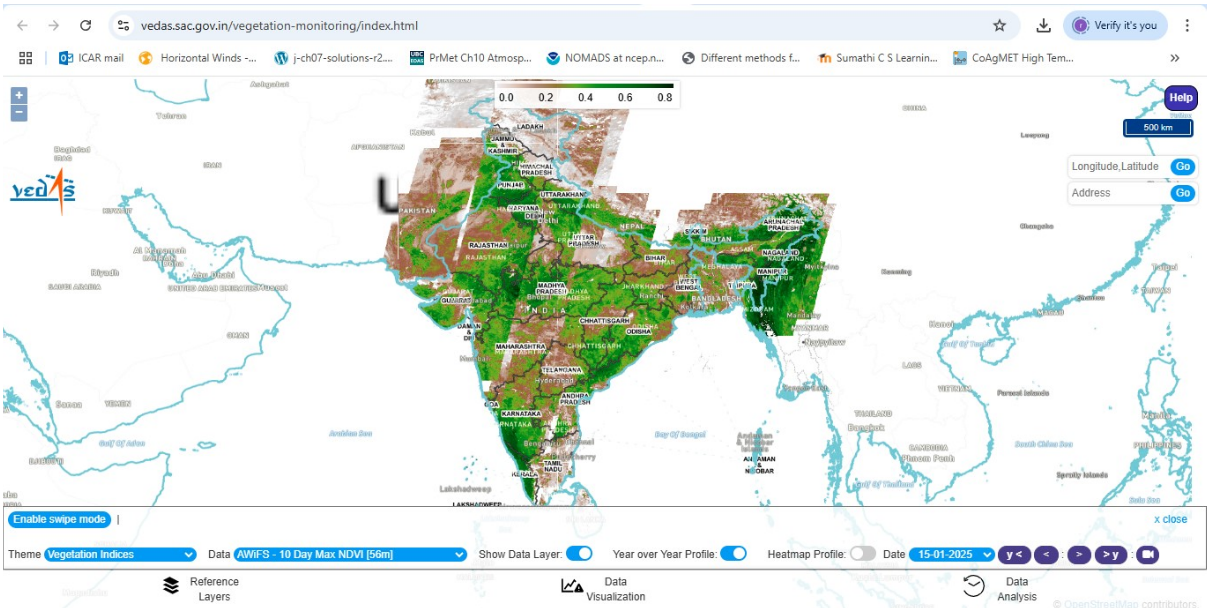

Fig.4. Crop health monitoring through web based platform VEDAS

Analysing satellite imageries using AI based tools can provide a more comprehensive information on crop dynamics even at farm level is possible for timely decision-making, optimizing resource allocation and to enhance the crop yieldsat weekly/fortnightly interval to increase/minimise the biotic and abiotic stress. Singh et al., (2023) analysed multispectral satellite images at fortnightly interval to monitor wheat crop at the farm level in Bathinda district of Punjab. They revealed that satellite images provided valuable insights into the importance of timely sowing, crop health monitoring, irrigation management, and soil suitability in optimizing wheat crop production. In recent days, many start-ups/companies using AI based gadgets/systems (https://farmonaut.com) to monitor the crop condition at field leveland are available in the market.Though, these latest techniques seems good, cost and how far a farmer can interpret the outputs are deciding factors.

4. Pest and disease forewarning

It is estimated that about 20-40 per cent of the global food grains supply is lost owing topests attack (Savary et al., 2019) and it is vital to lessen the impact of pests for ensuring world's food and nutritional security as well as to cut down the input requirement. Climate resilient approaches are multi-disciplinary one looking for time bound insect and disease monitoring and management which helps in resilient agricultural production systems. Many weather based statistical insect/disease forecasting models have been developed and forewarning was disseminated through agromet advisory services in different parts of country.

Nonetheless, forecasting insect/disease incidence using district/block level weather forecast data may not holds good at different locations. Hence, decision support system/sensors fixed at particular field would help the farming community in managing the damages inflicted by crop pests.Two decades before, an instrument called leaf wetness recorder (Fig.5) was developed at ICRISAT, Hyderabad to forecast the incidence of early and late leaf spot disease in peanut crop. Leaf wetness recorder gives indication for fungicide spray to control disease whenever diseased leaves proportion exceeds 10 per cent and the total wetness index was higher than the threshold value (Butler et al., 2000).

Fig.5. View of leaf wetness sensor

Over the years, development in information and communication tools paved way for smart techniques to detect and manage the crop pests as manual method is cumbersome and less effective. Artificial Intelligence (AI) techniques in insect and disease identification and management is a good substitute for sustainable agricultural practices. Moreover, this enables the farmers for early detection, decision-making for pest control that lead to efficient and resilient pest management systems.For instance, ICAR-Central Institute for Cotton Research, Nagpur developed an AI-based smart pheromone trap to monitor pink bollworms in cotton.

While sex pheromone traps are used to monitor pink bollworms adult populations for insecticide spray decisions, conventional trap methods have limitations. Collecting trap data is labour-intensive, costly and prone to errors. Manual data only provides information between surveys, typically 7-14 days apart, making timely insecticide application difficult. This smart trap sends live data—including images, insect counts, and weather information—directly to the cloud and registered users (e.g., farmers, and extension officials) every hour. Alerts are being also issued to individual farmers when trap catches exceeded the economic threshold level(Fig.6).

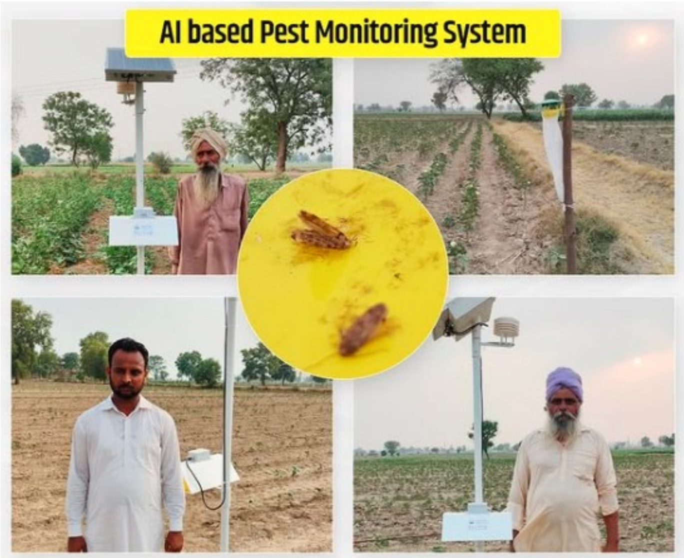

Fig.6. Farmers in Punjab with AI based pheromone trap to monitor cotton pink boll worm

5. Climate resilient irrigation water management

Agriculture is a major consumer of global freshwater resources. Around 72% of the world's freshwater withdrawals are used for irrigating agricultural crops(FAO, 2021).The per capita availability of surface water in our country reduced to 1453 m^3in 2015 from 5247 m^3in 1951and it is expected that it would further come down to 1170m^3 during 2050 (CWC, 2015).The declining trend of groundwater level in all parts of the country also indicates that the assured supply of good quality water will become a concern for country's development. It is estimated that overall efficiency of the flood irrigation system ranged from 25 to 40% (Amarasinghe, 2007). But, when compared to traditional irrigation methods, micro irrigation methods are highly water efficient and also have additional advantages likelabour and energy saving, yield increase and net return per unit volume of groundwater (Kumar and Palanisami, 2010). Hence, scientific irrigation scheduling assists the farmers for effective utilization of the water resources as well as for enhanced farm production and income. Central and state governments have sensitised the farmers to use sprinkler and drip irrigationthrough subsidy. Practicing micro irrigation for perennial crops comparatively easier than field crops due to practical difficulties.

Technologies developed should be easy to use and no complication in interpretation that leads to higher adoption rate by women farmers and technology plays pivotal role to empower the women farmers. It is also informed by FAO (2016) that farm yield could increase by 20-30 percent if women farmers in rural areas have access to technology, land and financial services. Researchers have developed low cost, easy to use small size can evaporimeter which can be used at individual farm for irrigation scheduling in rice, wheat and sugarcane or any other crops (Fig.7). But, this requires manual intervention for water refilling and maintenance. Decision support system based on MS-Excel called Water Impact Calculator (WIC) was developed at ICRISAT, Hyderabad (Garg et al., 2016) and results indicated that as much as 30–40% saving in irrigation water was achieved using WIC than the calendar-based method without compensating crop yields.

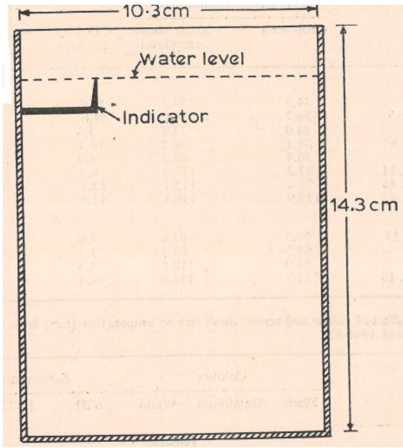

Fig.7. Can evaporimeter and mini pan evaporimeter

Laser Land Leveling (LLL) is a laser-guided technology used to level fields by removing soil from high points of the field and depositing it in low points of the field. It levels the land at the accuracy of ±2 cm from its mean elevation and also creates a constant slope of 0-0.2% slope across the field (Fig.8). It is estimated that almost 20-25% irrigation water saving can be achieved through LLL and also reduces the GHG emissions (Nayak et al., 2021).

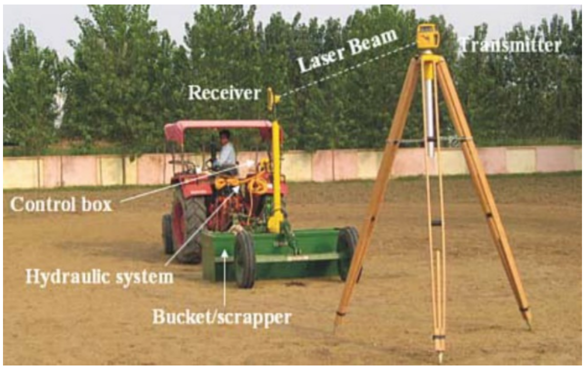

Fig.8. Laser Land Leveller in field

Economic evaluation of LLL in Punjab indicated that the cost for LLL operation was around Rs.1025 per acre. The farmers who adopted LLL in paddy field informed that time for irrigation and yield increment were the factors influenced to adopt. Though, yield increase, reduced water and fertiliser requirement and less weed occurrence are the benefits of LLL opinion survey among the farmers revealed that non-availability of the laser land leveller in the peak season (65%), high cost of levelling (45%), small size of holding (60%) and lack of awareness (55%) were the major constraints in adopting the LLL(Sandhu et al., 2019).

Alternate Wetting and Drying (AWD) is a water-saving technology that farmers can apply to reduce their irrigation water consumption in rice fields (15-30%) with no or very low yield penalty (5%) (Nayak et al., 2021). In AWD, irrigation water is applied a few days after the disappearance of the ponded water. Irrigation water is to be applied from 10 DAT or 20 DAS after disappearance of ponded water in the field. Field water pipe or 'pani pipe' (30 cm length and 7-10 cm diameter) (Fig.9) is useful to practice AWD which helps in water depth monitoring. Whenever water level in pani pipe goes below 15 cm from soil surface, field should be irrigated. At the same time, it is advised to keep 5 cm water in the paddy field. It is reported that practicing AWD improve the water use efficiency as well as it lessens the greenhouse gas emissions by 30-50% (APR, 2019).

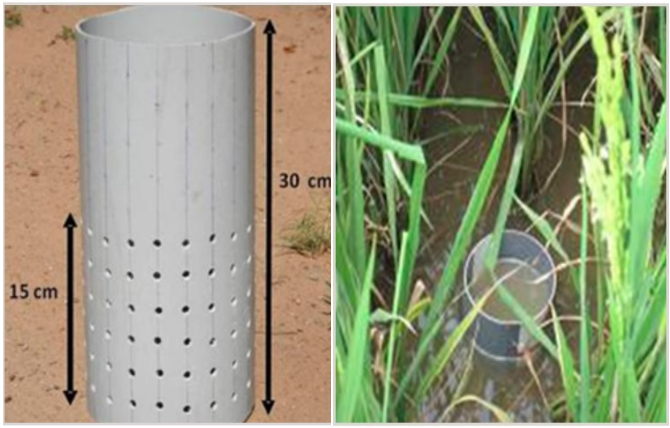

Fig.9. View of field water tube and inside the paddy field

Researchers in ICAR-NRRI have improved this AWD through field water pipe by attaching a sensor at a desired depth inside the perforated tube (40cm length and 15cm diameter)to automatically identify the water level in the pipe and also give alarm and send message to registered farmer mobile. This device known as Eco-friendly Irrigation Alert System (e-IAS) as the battery is charged by the solar panel (Fig.10).

Fig.10. Eco-friendly Irrigation Alert System (e-IAS) in the paddy field

In this system the sensor is connected to a microcontroller and relay module. Whenever the water level in the rice field is below the desired level the sensor communicates the signalto the microcontroller, which switches on the red bulb and alarm system.This system alerts the enduser through SMS, light, and sound alarms and thus it facilitates effective monitoring ofreal-time water levels in the field. Almost 30% save in irrigationwater without yield penalty was observed also increases net return for farmers by reducing pumping costsand fuel consumption. It also curtails the methane emission from rice fields by around37% (Kumar and Nayak,2022).

Tensiometer based irrigation scheduling is another simple and effective technique in saving irrigation water in conventional paddy cultivation. Though, tensiometer is being used at research station level for irrigation scheduling, usage of tensiometer at farm level is very low. In 2009, CIPT (The Centers for International Projects Trust, India; the Punjab Agricultural University and the Columbia Water Center of Columbia University, USA started to promote improved tensiometer to reduce the usage of groundwater in Punjab state for paddy crop (Vatta et al., 2018). The instrument is installed in the field around a week after paddy transplantation. It is saturated with water before its installation in the field.

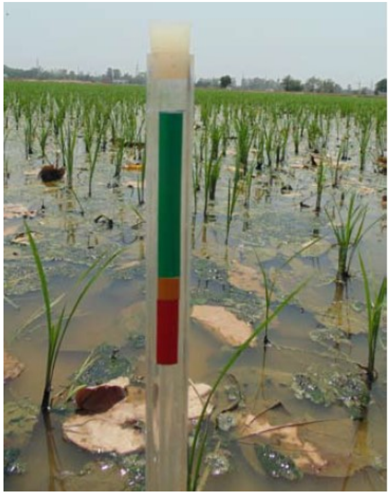

Fig.11. Simple tensiometer in paddy field

The need for irrigation can be known by the water level in the tensiometerwhich is indicated by the three colour bands i.e. green, yellow and red (Fig.11). The green band indicates no irrigation requirement and yellow band indicates that the crop needs irrigation while water in the red band indicates irrigation at the earliest as the crop is water-stressed that lead to reduction in yield. Vatta et al., (2018) studies clearly showed that usage of tensiometer helped

i. Reduced number of irrigation in paddy led to 13% water savings
ii. Reduction in pumping hours led to 13% save in electric power consumption
iii. Cut in labour use by 3% led to lower cost of cultivation by 7% without yield reduction

They also specifiedsensitizing the non-adopted farmers and other stakeholders through training by the already adopted young and more educated farmers (male and female)may help in increase the adoption rate of this water conservation technology not only in state of Punjab and also in other paddy growing states.

ICAR-NRRI also developed a simplified, farmer-friendly version of the tensiometer tube (customised colour coded tensiometer) for real-timeirrigation scheduling based on soil water potential. This tube consists of the four colored stripes viz., light blue, deep blue, orange, and brown. According to water level in tensiometer tube farmers can easily understand when to irrigate their field. For instance, irrigation is not needed if the water level in tensiometer in light blue stripe while water level in deep blue indicates requirement of irrigation. However, water level in orange and brown stripes shows immediate irrigation and without irrigation crop yield at risk. Around 29% save in irrigation water was reported than the conventional flooded paddy cultivation (Table 2) (Kumar et al., 2021).

Table 2. Comparison of water used, water productivity of paddy crop under different irrigation methods

Treatments	**Grain yield (t/ha)**	**Water used (mm)**	**Water productivity (kg/m^3)**	**% of water saved over flooding**
Flood	4.14	1610	0.25	-
AWD	4.63	1099	0.42	31.73

Tensiometer	4.14	1140	0.36	29.19
SRI	5.35	1119	0.47	30.49
Source: Nayak et al., 2021				

With the advent of computation technology, numerous products for automatic pump operating are available in the markets / e-markets. AI based electronic gadgets are really handy especially for women farmers to irrigate the field through their smart phones.

6. Selection of climate-resilient crops and varieties

Across the world, abiotic stresses like heat, cold, drought, flood and high soil salinity is the common adverse environmental conditions that impact the crop development and yield. Due to global warming particularly human made actions like industrialisation and urbanization the situation is aggravated. However, it is also crucial to increase the food production to feed the increasing population in future. One of the finest approaches to avoid or cut down the impact of abiotic stresses is cultivation of climate-resilient varieties. Constructive efforts are being undertaken by Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) to develop varieties resistant/tolerant to different abiotic stresses.In different parts of the country farmers are cultivating some of these climate-resilient crop varieties in the event of extreme weather situations to mitigate the adverse impact of abiotic stresses on crop production. To some extend farming communities cultivating varieties tolerant to abiotic stresses across the world including India. Nonetheless, lack of awareness about varieties developed for different various abiotic stresses is the important limiting factors for cultivation of such varieties at large scale (Chattopadhyay et al., 2016). In addition, availability of seed material among the farmers in need also another factor in adopting simple technology to be followed by vulnerable groups.

Boraiah et al., (2023) found that almost 750 varieties of different crop groups have been developed and released by different ICAR institutes and SAUs in India. Among these varieties, 65% of them are developed against drought, 17% for high temperature, 8% for salinity/acidity, 5% each for flood/waterlogging and low temperature. Some of varieties developed for various abiotic stresses are furnished in table 3.

Table 3. Crop varieties tolerant to different abiotic stresses

Abiotic stress	Crop	Name of the variety
Drought	Rice	Kalinga 1& 2, CR Dhan 40, CAUR-1, MTU-1010, Pant Dhan 16, DRR Dhan 42, 44, 47,50, Sabour Shree, BirsaVikasDhan 111, Tripura Khara 1
	Wheat	HD 2160, HD1467, Ratan, Netravati, SabourNirjal, HUW 669, HD3411
	Maize	MahiDhawal, JM-216, NAH-1147, PEHM-1
	Pigeon pea	Palnadu, Co 5, ICPL-87, BDN-708, BRG 5, PRG 176
	Chickpea	JG-315, Phule G-81-1-1 (Vijay), Pant G 186, Indira Chana,

		Nandyal Gram 49
Water logging	Rice	Swarna Sub1, CSR43, Reeta, CR Dhan 500, Jalamani, Sabour Shree, BahadurSub-1, Tripura Jala
	Wheat	KRL 19, KRL 210 & KRL 283
	Maize	Jawahar Maize 218, PusaJawahar Hybrid Maize-1, Pragati
	Soybean	NRC-37, JS 97-52
High temperature	Rice	DRR Dhan 47 & 52
	Wheat	WH 1124, DBW 107, DBW 173, HI 1634 (PusaAhilya)
	Chickpea	Indira Chana, JG-11, Pant G 186
Low temperature	Rice	Kalinga 1, VarunDhan, Gizza-14, K-39, 343 & 448
	Wheat	RSP 561, Shalimar wheat-1
Salt tolerant	Rice	CSR56, CSR60 and CSR76, Luna Suvarna, Panvel 3, CARI Dhan 5
	Chickpea	Karnal chana-1

7. Conclusion

India accounts for only 2.4% of the global land yet 17.7% of the world's population is living in our country.The Ministry of Agriculture and Farmers Welfare reported that India witnessed a record food grain prediction of 329.7 million tons in 2022-23. Even though, in the face of climate change, increased occurrence of extreme weather events would impact the food grain production and managing or reducing the impact of ill effects of abnormal weather situation is a Himalayan challenge and requires a multi-pronged strategies for overall sustainable agriculture and food systems in the country. Sustainable productivity, adaptation to climate change and mitigation of greenhouse gas emissions are the three pillars of climate resilient agriculture to address the climate change mitigation. In the wake of fast development of information and communication tools, development of climate resilient technologies which are low cost and farmers friendly particularly women farmers are the key factors to improve the status of farming communities.

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Enhancing adaptation strategy of farmwomen to climate variability through vegetable grafting technology

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Agriculture occupies a key position in Indian economy providing a source of livelihood for a majority of the population. Women play an important role in the entire agricultural sectors by participating and contributing in almost all the important activities and services related to the sector. In fact, women contribute 53.2% of labour in the agricultural household in rural areas as compared to 46.8% by men. Realising gender equality (SDG 5) and women's empowerment in agriculture is essential to economic development. But in the era of climate change raising the income of farmwomen is a challenging task. The average change in various climatic parameters such as temperature, rainfall, relative humidity and gaseous composition etc. over a period of time in a geographical area is referred to as climate change. Due to climate change, there has been increased in the frequency of events such as drought and flood, high-temperature, low temperature and salinity, as well as changes in atmospheric CO_2 or ozone level which considerably affect the yield and quality of vegetable crops. Vegetables are an important component of human nutrition that are a rich source of fibre, protein, vitamins, antioxidants, carbohydrates and minerals. Apart from the source of nutritional security, vegetable crops cultivation provides a constant source of income to the farmers.Vegetable crops are more prone to climatic changes compared with other horticultural crops.Although vegetable breeders are making tremendous efforts to develop crop varieties that are more tolerant to such abiotic stresses; however, due to a lack of practical selection tools like genetic markers, it is a slow and inefficient process so far. An effective method of adapting plants to counteract environmental stresses is by grafting elite, commercial cultivars onto the selected vigorous/tolerant rootstocks (Fig. 1). Grafting is nowadays regarded as a rapid alternative tool to the relatively slow breeding methodology aimed at increasing environmental-stress tolerance of fruit vegetables.As most of the grafted vegetable seedlings have been prepared by the farmwomen in many states such as, Chhattisgarh, Andra Pradesh, Telangana, Maharashtra, U.P., etc. Therefore, the farmwomen can easily develop entrepreneurship/ start up in grafting technology to generate sustainable income.

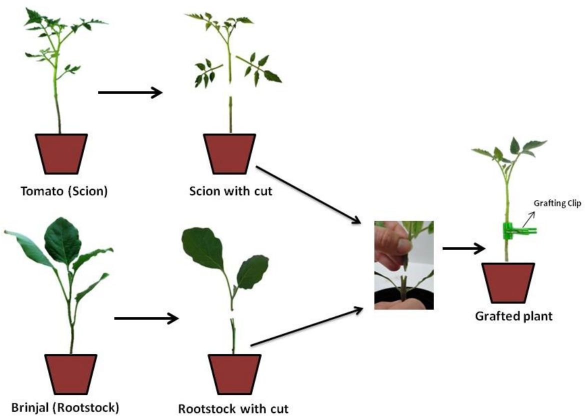

Fig. 1: Illustration of grafting process

Grafting for alleviating abiotic stresses

Temperature tolerance

Temperature is one of the most important environmental factors which cause heavy yieldlosses by reducing plant growth and fruit set, causing wilt and necrosis.

Chilling and sub-optimal temperature

The production of vegetables in winter or cold climate has to face chilling and suboptimaltemperature conditions. Depending on the vegetables, the threshold temperatures for growthof most of the chilling-sensitive fruit vegetables, such as bell pepper, brinjal, cucumber,tomato and melon is about 8-12℃ (Hansen et al., 1994). Above to this range (approx. up to25-30℃), metabolic activities increase exponentially with increasing temperatures, and belowthis threshold, many vegetable crops suffer from physiological disorders which, depending onthe intensity and length of exposure, subsequently lead to cell death and finally plant death.Low (root-zone) temperatures both affect root growth, size, and architecture, as well as itsfunctioning. The root function at decreased (root-zone) temperatures is attributed to theviscosity of water, root pressure and hydraulic conductance, metabolic activity, productionand upward transport of phytohormones, as well as the ability of the root to absorb nutrients.Cold-tolerant rootstocks may overcome restrictions to water absorption at chillingtemperaturesby an increase of the root hydraulic conductance, decreased induction of cellwall suberin layers, lipid peroxidation, and closure of the stomata.

During the vegetative growth phase suboptimal temperatures mainly result in slower leafexpansion and initiation rate of new leaves. Low temperature (below 10℃) to adversely affect the vegetative growth of tomato by shortening internodes, reduced leaf expansion, leafnumber, and total leaf fresh biomass (Venema et al., 1999). At generative growth phase oftomatoes suboptimal temperature (i) reduces fruit set as a result of poorer pollen quality, (ii)increases the period between anthesis and maturity of the fruit, (iii) increases fruit size, and(iv) decreases truss appearance rate (Van der Ploeg and Heuvelink, 2007). In tomato,rootstocks accession LA 1777 of *S. habrochaites*(earlier *L. hirsutum* Dunal, Venema et al.,2008), KNVF(the interspecific hybrid of *S. lycopersicum*× *S. habrochaites*, Okimura et al.,1986), and chill-tolerant lines from backcrossed progeny of *S. habrochaites*LA 1778 × *S.lycopersicum*cv. T5 (Bloom et al., 2004) were able to alleviate low root-temperature stressfor different tomato scions. Figleaf gourd (*Cucurbita ficifolia*) has ability to tolerate low roottemperature of about 15°C, which is about 6°C lower than that of cucumber roots (Ahn et al.,1999; Rivero et al., 2003c). For watermelon, grafting onto Shin-tosa-type (an interspecificsquash hybrid, *Cucurbita maxima* × *C. moschata*) rootstocks is used to advance the plantingdate during cool periods (Davis et al., 2008).

High temperature

Vegetable production can also be constrained by high temperature under hot arid and semiaridconditions in the lowland tropics. High temperature affects vegetable crops in severalways. Increase in temperatures can reduce crop duration, increase plant respiration, alterphotosynthesis process, affect the survival and distribution of pest population, hasten nutrientmineralization in soil, increase evapo-transpiration, etc. High temperature causes reduction inpollen formation or viability in tomato at temperature above 37°C. Fruit set in tomato occursonly when night temperatures ranging between 12.8-24°C. The typical red colour of mosttomato cultivars does not develop when temperatures go above 30°C, but yellow pigmentcontinues to develop. In sweet pepper, when temperature falls below 15°C or exceeds 32°C,growth is usually retarded and yield decreases. When temperature falls below

15°C orexceeds 32°C, growth is usually retarded and yield decreases. Hot chilli does not set fruitwell when night temperatures are greater than 24°C. Among the many deleterious effectsdescribed are growth reduction, decrease in the photosynthetic rate and increase inrespiration, assimilate partitioning towards the fruits, osmotic and oxidative damage, reducedwater and ion uptake/movement, cellular dehydration. On the other hand, plants activatestress-responsive mechanisms, such as shifts in protein synthesis (e.g. heat shock proteins),detoxification, osmoprotection, and stabilization of enzymes and membranes.Use of brinjal as rootstock for grafted tomato may confer a certain degree of resistanceagainst thermal stress (Rivero et al., 2003b). Since brinjal is better adapted to hot arid climateand have a better tolerance against supra-optimal soil temperature, its use as rootstocks fortomato at higher temperature seemed to be more promising. Abdelmageed and Gruda (2009)reported improved vegetative growth (higher biomass), higher chlorophyll fluorescence,greater leaf area and dry biomass, higher pollen grains per flower, and lower electrolyteleakage ingrafted tomato plants over brinjal or Summerset (tomato) than non-grafted plants. Comparingdifferent lines of chilli pepper rootstocks (*C. chacoense*, *C. baccatum*, *C. frutescens*, *C.annuum*) confirmed highest yields under high-temperature conditions for rootstocksrecommended by the AVRDC (*C. annuum* cv. Toom-1 and 9852-54; Palada and Wu, 2008).

Drought

Water is quickly becoming an economically scarce resource in many areas of the world, especially in arid and semiarid regions. One way to reduce losses in production and to improve water use efficiency under drought conditions in high-yielding genotypes would be grafting them onto rootstocks capable of reducing the effect of water stress on the shoot. A promising strategy to enhance yield stability under water stress conditions should be the selection of rootstock with constitutive potential to increase yield rather than plant survival (Kumar et al. 2017). Altunlu and Gul (2012) demonstrated that grafting tomato onto a vigorous rootstock Beaufort provides resistance to drought stress without having a negative effect on yield. Grafted mini watermelons onto a commercial rootstock (PS 1313: *Cucurbita maximaDuchesne* × *Cucurbita* moschata Duchesne) revealed a more than 60% higher marketable yield when grown under conditions of deficit irrigation compared with un-grafted melons (Rouphael et al., 2008). The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake, indicated by a higher N, K and Mg concentration in the leaves, and higher CO_2 assimilation.

Waterlogging / Flooding

Most of the vegetables are sensitive to waterlogging or flooding. Tomato plant cannotsurvive, if exposed to waterlogging for more than 48 h during early growth stage (Bahadur etal 2015). Flooding and submergence are serious abiotic threat for many flood sensitivevegetables during rainy season. Flooding conditions cause oxygen starvation, this arises fromthe slow diffusion of gases in water and from oxygen consumption by microorganisms andplant roots. Problems caused by flooding may be solved by growing flood-tolerant crops orgrafting intolerant plants onto tolerant ones. Grafting with promising rootstocks is consideredan effective measure for mitigating deleterious effects of flooding in many vegetable crops. Itwas observed that grafting improved flooding tolerance of bitter gourd when grafted ontosponge gourd (Liao and Lin, 1996). The reduction of the chlorophyll content in cucumberleaves induced by waterlogging was enhanced by grafting onto squash rootstocks (Kato et al.2001). It was observed that grafting watermelon onto bottle gourd, the decrease inchlorophyll content was less pronounced compared with non-grafted watermelons (Yetisir etal., 2006; Liao and Lin, 1996). Waterlogging study conducted at ICAR-IIVR, Varanasi(Bahadur et al., 2015, 2016) revealed that when tomatoes grafted on brinjal rootstocks (IC111056 and IC 354557) and exposed to 48-120 h waterlogging stress, they recoveredwaterlogging shocks 3-4 days after removal from water, while non-grafted tomatoes couldnot tolerate to more than 48 h stress and died after yellowing and wilting. Similarly, Bhatt etal (2015) reported that when Arka Rakshak tomato was grafted over Arka Neelkanth brinjal,the grafted plants have better in gas exchange and other physiological traits, and they wereable to survive 6 days of waterlogging stress. The World Vegetable Centre, Taiwanrecommends growing tomatoes on eggplant rootstocks EG195 or EG203 and pepper on chiliaccessions PP0237-7502, PP0242-62 and Lee B under for flooding situation during heatperiod of lowland tropics (AVRDC, 2003, 2009).

Nutrient deficiency

Many wild, relatives, or hybrids rootstocks used for vegetable grafting have more vigorousroot systems than those of highly productive cultivated varieties (Davis et al., 2008). Öztekinet al. (2009) have reported significant increase in the root density (25.3% more) in tomatoplants grafted onto He-Man and Beaufort, in comparison with self-grafted plants. Due tomore vigorous root system nutrient and water uptake increased, and this may enhance thegrowth rate and yield performance of the plant. Ruiz et al. (1997) reported that melon cv.Yuma and Gallicum grafted on three *C. maxima* × *C. moschata* rootstocks (Shintoza, RS-841and Kamel) were more efficient in N uptake. The foliar N concentrations positivelycorrelated with the fruit yield. In other study, Pulgar et al. (2000) demonstrated thatwatermelon (cv. Early Star) grafted onto the rootstocks Brava, Shintoza and Kamel (*C.maxima* × *C. moschata*) exhibited significantly lower NO_3^- concentrations, accompanied by higher nitrate reductase activity and higher concentrations of total-N, free amino acids andsoluble proteins in comparison with non-grafted plants. Higher leaf N concentration was alsoreported in mini-watermelon plants (cv. Ingrid) grafted onto the commercial rootstock PS1313 (*C. maxima* × *C. moschata*) in comparison with non-grafted plants (Rouphael et al.,2008b). Colla et al. (2010a) found that N use efficiency and N uptake efficiency increased by11.8% and 16.3%, respectively, when Proteo melon plants were grafted onto P360, incomparison with un-grafted Proteo plants.

Phosphorus uptake also seems to be increased or decreased by grafting onto some rootstocksdepending mainly on the genotype of the rootstock (Kawaguchi et al., 2008). Kawaguchi etal. (2008) observed low concentration of P in the scions of tomato/pepper and pepper/tomatografts that were ascribed to the smaller root system and restricted xylem hydraulicconductivity from the rootstock to the scion owing to low compatibility. In contrast, higher Pconcentrations in the leaves of grafted plants, or higher translocation rates from root to shoot,in comparison with non-grafted plants have been reported by Leonardi and Giuffrida (2006)for eggplant grafted onto Beaufort, Rouphael et al. (2008a) for cucumber grafted ontoShintoza, Colla et al. (2010b) for watermelon grafted onto P360 and PS 1313 (*C. maxima*×*C. moschata*), and Salehi et al. (2010) for melon grafted onto the Cucurbita rootstock‗ShintoHongto'. Due to the low mobility of P, a more vigorous root system characterized bya higher density of root hairs is expected to increase active P uptake by the plants.Enhancement of K uptake in grafting scion have been also reported by Leonardi andGiuffrida (2006) for eggplant grafted onto Beaufort and two *S. lycopersicum* rootstocks (PG3and Energy), Qi et al. (2006) for melon grafted onto No. 1 Shengzhen (*C. moschata*),Rouphael et al. (2008b) for mini watermelon grafted onto pumpkin (PS 1313), Zhu et al.(2008) for cucumber seedlings grafted onto Chaojiquanwang (*C. moschata*) and Albacete etal. (2009) for tomato grafted onto three high-vigour rootstocks derived from a cross between*S. lycopersicum* L. var. cerasiforme x S. cheesmaniae. The K mobility in the soil is basedpredominantly on diffusion, a more vigorous root system is expected to improve the total Kavailability in the rhizosphere and concomitantly its uptake rate by the plants.Enhanced Ca uptake due to grafting and higher Ca translocation rates to the fruit areimportant in fruiting Solanaceous vegetables as they are highly susceptible to the calciumrelateddisorder -blossom-end rot (BER). Fernández-García et al. (2004) found a significantincrease in leaf Ca concentrations when the tomato cultivars Fanny and Goldmar weregrafted onto the hybrid tomato rootstock AR-9704. Similarly, Leonardi and Giuffrida (2006)found significant increases in the leaf Ca concentrations in tomato plants grafted onto theinter-specific rootstock Beaufort. The fruit vegetables of Cucurbitaceae do not exhibit anyincrease in their ability to take up Ca when grafted onto some commonly used rootstocks asindicated by results reported by Rouphael et al. (2008a) for cucumber grafted ontoShintoza, Huang et al. (2010) for cucumber grafted onto Black Seeded and ChaofengKangshengwang, Edelstein et al. (2005) for melon grafted onto TZ-148 and Rouphael et al.(2008b) for mini-watermelon grafted onto PS 1313.

Salinity and alkalinity

Salinity affects almost every aspect of the physiology and biochemistry of plants and significantly reduces yield. Conventional breeding programs to improve the salt tolerance of elite genotypes using wild species as donors are inefficient. One possibility of avoiding or reducing yield losses caused by salinity would be to graft cultivars on to rootstocks able to reduce the effect of external salt on the shoot. This strategy could also provide the opportunity to growers of combining good shoot characters with good root characters. The salt tolerant rootstocks have ability to exclude chloride transport to the scion. Huang et al. (2010) showed that the crop performance of three grafting combinations of cucumber (*Cucumis staivus* L. cv. Jinchun No. 2), self-grafted, grafted onto the fig-leaf gourd (*Cucurbita ficifolia* Bouché) and *Lagenaria siceraria*Standl. responded differently as to EC increases from 1.9 to 5.7 and 9.8 dSm−1. Compared with the self-grafted plants, cucumber plants grafted onto fig-leaf gourd had higher scion dry weight at 5.7 and 9.8 dSm^{-1}. These plants could significantly alleviate scion growth reduction, maintain higher soluble sugar and manganese (Mn) contents, higher superoxide dismutase (SOD) and peroxidase (POD) activities, but lower electrolyte leakage and malondialdehyde (MDA) at 5.7 dSm^{-1}.

Alkalinity in irrigation water and soils restricts the cultivation of plants. Alkaline water and soils are generally characterized by low bioavailability of plant nutrients, and high levels of insoluble $CaCO_3$ in the soil and HCO_3 in the soil solution. The concentration of HCO_3 interacts strongly with the availability of several micronutrient ions, especially $Fe2^{+}$, and it is often considered to be the primary factor causing chlorosis in cultivated plants, which may lead to serious yield losses. In a study, Colla et al (2010b) found substantial differences in the agronomical, physiological and biochemical responses between grafting combinations of watermelon plants. The watermelon plants were either un-grafted or grafted onto two pumpkin rootstocks P360 and PS1313 (*C. maxima* × *C. moschata*) and two bottle gourd rootstocks (Macis and Argentario) and exposed to two levels of solution pH, 6.0 or 8.1 dSm^{-1}. The leaf chlorosis symptoms in the plants grafted onto bottle gourd rootstocks, and the un-grafted plants were, in general more pronounced than those in plants grafted onto pumpkin rootstocks. Plants grafted onto pumpkin rootstocks and exposed to an excessively high external pH level were capable of maintaining higher net assimilation rates, and exhibited a greater strong capacity to accumulate Fe in the aerial part, and a better plant nutritional status (higher P and Mg) in the shoot tissue in comparison with those grafted onto bottle gourd rootstocks and the un-grafted plants.

Specialized grafted plants: Pomato and Brimato

At ICAR-IIVR, Varanasi dual grafting of brinjal and tomato (termed as 'Brimato') was successfully demonstrated in field during 2017-21. For preparation of Brimato, brinjal hybrid-Kashi Sandesh and improved cultivar of tomato- Kashi Aman were successfully grafted onto brinjal rootstock- IC 111056. Grafting operation was performed when brinjal seedlings were about 30 days and tomato 22-25 days old. Grafting is done after 15^{th} September and prepared grafted plants are transplanted upto 20^{th} October. During early growth stage, precaution was taken for maintaining balance growth both in brinjal and tomato scions. Also shoots, if any arises below grafting union, removed immediately. Fertilizers were applied at 150:60:100 kg NPK/ha, apart from 25 tons of FYM. Both brinjal and tomato starts fruiting 60-70 days after planting. Experimental findings revealed that about 30-35 fruits with 3.5 kg yields were harvested in tomato, while in brinjal 2.75 kg yields were obtained from single Brimato plant. Dual grafted brimato technology would be very useful for the urban and sub-urban areas, where limited spaces are available for accommodating vegetables in vertical garden or pot culture over terrace and compound. Brimato can easily be prepared by the farmwomen, and they can generate good income by selling of plants @ Rs 15-20/plant.

Experiments on Pomato (Potato+ Tomato) have been conducted at ICAR-IIVR since 2016 and technology was optimised in 2022. Pomato is an innovative and novel plant developed by inter-specific grafting of two solanaceous vegetables *i.e.* potato as rootstock and tomato as scion, and harvesting both potato and tomato from the same plant. It can have significant impacts in urban and peri-urban areas, where grower can save space, time and labor without affecting the quality of their produce by growing pomato. Similar to other solanaceous vegetables, pomato seedlings can be prepared by apical wedge (cleft) or side grafting. Pomato grafting is performed in the month of October by inserting two tomato scions on white potato cultivars. After harvesting tomato 5-6 times, potato is harvested at the end of March.About 3.5 kg of tomatoes and 0.8-1.0 kg of potatoes can be harvested from single pomato plant grown at 75x 50 cm spacing. Pomato can easily prepared by the farmwomen after obtaining 3-5 days training program at ICAR-IIVR, Varanasi.

Conclusion

Vegetable grafting is an efficient and rapid alternative for enhancing tolerance to several biotic (bacterial wilt, Fusarium wilt, verticillium wilt, collar rot, gummy stem blight and root-knot nematodes) environmental-stresses (drought, flooding, salinity, heavy metal and herbicide) in vegetable crops. The use of appropriate tolerant rootstocks improves crop growth, yield and quality, beside to resistance against biotic and abiotic stresses.Transferring knowledge of grafting to the farmwomen has immense potential to reduce their crop losses and for ensuring the nutritional security.Production of Pomato and Brimato are another new avenue in grafting technology, and identified by ICAR as an innovative technology. Farmers from different states have now developed expertise in successful production of these specialized plants. Grafting enterprises in India is developing very fast, particularly in Chhattisgarh, Andra Pradesh, Telangana, Maharashtra, U.P., etc, and farmwomen have very good opportunity to adopt this venture to earn income.

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Vertical Farming under Changing Climate: a Case Study of Integrated Vertical Nutri-Farming System (IVNFS)

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United Nations Food and Agriculture Organization (FAO) statistics hypothesized that by 2050, the amount of arable land per person will be less than 0.20 hectares, which is less than a third of what it was in 1970 (FAO, 2016). The consequences of climate change, the expanding geographic area of arid regions, the depletion of freshwater supplies and population expansion this loss is expected to continue (Fedoroff, 2015). By 2050, the population is expected to reach 9.7 billion and world has to produce 50% more food, thereby requiring an additional arable land that is simply not available (Zhu, 2023). Thus, novel and sustainable agricultural production strategies for year-round production of huge quantities of nutritious food from within a small space are the necessity of the hour. In this context, vertical farming contributes to food security and resilience with year-round crop production, through ensuring a constant supply of fresh produce, regardless of seasonal limitations.

Vertical farming is a system of cultivation of plants in vertically stacked structures, above each other under controlled indoor environments, allows year round crop production without risk for crop failure due to weather or climate change (Pinstrup-Andersen, 2018) offers more crop yield per unit area of land while mitigating the environmental impact of traditional farming practices (Oh and Lu, 2023). The term 'vertical farming' was created in 1915 by American geologist Gilbert Ellis Bailey architects. Even though the concept of vertical farming focuses on farming in urban and peri-urban areas, it can be successfully done in rural areas having small farms and marginal lands (Nitisapto, 1993). Vertical production of vegetables, fruits, flowers and foliage plants, hydroponic green fodder, mushrooms and poultry birds are now gaining popularity all over the world. In addition, indoor growth systems shield plants from outside weather and climate change. Vertical Farming systems can be broadly divided into two categories – those comprising multiple levels of traditional horizontal growing platforms, and those where the crop is grown on a vertical surface.

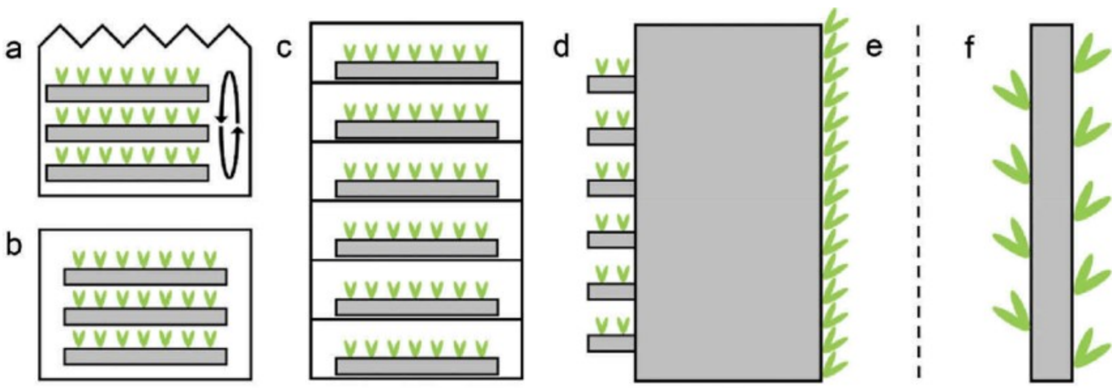

Fig. 1: Exemplification of vertical farming (VF) types. (a & b) Stacked horizontal VF systems, (c) Multi-floor towers, (d) Balconies, (e) Green walls, (f) Cylindrical growth units (adopted from Beacham *et al*., 2019)

Advantages and Challenges of Vertical Farming

Advantages	Challenges
:rease in production and availability in crops	Expensive Startup Costs-initial investment is costly
) weather related crop failures as crops are grown indoors	High operational cost-energy consumption for artificial lighting and climate control in a vertical farm can add significantly to operations costs
oduction of organic crops can be done as the system excludes usage of chemicals and pesticides	Lack of expertise-skilled manpower is required to manage and run vertical farms
nservation and recycling of natural resources	Semi/fully controlled environment- and with sophisticated technologies
vironment friendly-reduces the use of fossil fuel needed for running the mechanical equipments	Limited number of crop species can be grown in vertical farming as the system focuses on high value, rapid growing crops with a quick turnover such as lettuce, basil and other salad crops
stainable farming-profitable agribusiness venture for urban entrepreneurs	There are crops which require insect pollination and since insects are usually excluded from the growing environment therefore, pollination has to be done by hand requiring staff time and labour.

Climate Change Mitigation through Vertical Farming

Climate change is one of the most pressing challenges of the 21st century, driven by rising greenhouse gas (GHG) emissions, deforestation, and unsustainable agricultural practices. One promising solution to mitigate climate change is vertical farming. Vertical farming has the potential to sequester carbon through the cultivation of certain crop varieties. This method offers numerous environmental benefits, including reduced carbon emissions, water conservation, and decreased land use.

- **Reducing carbon emissions:** Traditional agriculture contributes significantly to climate change due to emissions from machinery, transportation, and deforestation. Vertical farming mitigates these impacts in several ways:

    1. **Reduced transportation needs:** By reducing the need for transportation of produce over long distances, it minimizes carbon emissions associated with food transportation.
    2. **Energy efficiency improvements:** While vertical farms require artificial lighting and climate control, advancements in renewable energy sources such as solar and wind can reduce their carbon footprint.
    3. **Minimal use of fossil fuels:** Traditional farming relies on fossil fuel-powered equipment; vertical farming, however, often utilizes automated and electric-powered systems that are more sustainable.

- **Water conservation:** Agriculture is a major consumer of freshwater resources, with traditional farming methods often leading to excessive water use and pollution. Vertical farming addresses this issue through:

    1. **Hydroponic and aeroponics systems:** These methods use up to 95% less water than soil-based agriculture.
    2. **Recycling and water efficiency:** Closed-loop water recycling systems ensure minimal waste, further preserving precious freshwater resources.
    3. **Reduced contamination:** With controlled nutrient distribution, there is minimal runoff of fertilizers and pesticides into nearby water bodies.

- **Decreased land use and deforestation prevention:** Deforestation for agricultural expansion is a major driver of climate change, as it releases stored carbon and reduces natural carbon sinks. Vertical farming mitigates this by:

    1. **Maximizing space utilization:** By growing crops vertically, it produces more food per square meter compared to conventional farming. Vertical farms often use controlled environments, reducing the need for pesticides and fertilizers, which can negatively impact surrounding ecosystems when they run off into natural water sources.
    2. **Reducing the need for deforestation:** Since vertical farms can be built in urban areas and repurposed buildings, there is less pressure to clear forests for farmland.
    3. **Biodiversity preservation:** Vertical farming plays a crucial role in biodiversity preservation by reducing the need for extensive agricultural land, which in turn helps protect natural habitats and ecosystems.

Types of Vertical Farming

Vertical farming involves three main soilless farming techniques such as hydroponics, aquaponics and aeroponics. Vertical farming provides entrepreneurial opportunities in urban areas to grow high value exotic vegetables and can grab the niche market.

a) **Hydroponics**- The term hydrponics is derived from the Greek word ‘hydro’ and ‘ponos’, which translates to ‘water doing labour’ or ‘water works’. William Frederick Gericke invented hydroponics at the University of California at Berkeley in the early 1930s. The primary advantage of this method is that it could eliminate or at least reduce the soil related problems i.e., the insects, fungus and bacteria that grow in soil. Hydroponics is the predominant growing system used in vertical farms which involves growing plants in nutrient solutions that are free of soil. The plant roots are submerged in the nutrient solution, which is frequently monitored and circulated to ensure that the correct chemical composition is maintained. It requires relatively low maintenance and also provides less labour intensive way to manage larger areas of production. The hydroponic method results in more uniform produce giving better yields, as the optimum combination of nutrients can be provided to all plants.

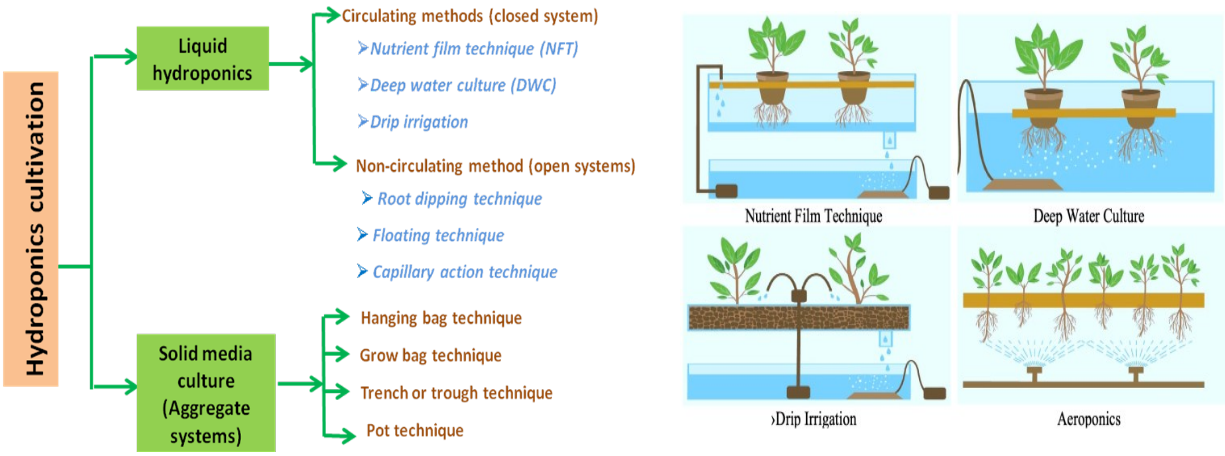

Fig. 2: Categorization of hydroponic farming

b) **Aeroponics**– The term aeroponics was coined by the National Aeronautical and Space Administration (NASA) in the 1990's. NASA was interested in finding efficient ways of growing plants in space and came up with the term aeroponics which can be defined as 'growing plants in an air or mist environment with no soil and very little water'. The major difference between hydroponics and aeroponics system is that the former uses water as the growing medium and the latter uses mist or nutrient solutions instead of water, so it does not require any container or trays to hold water. It is an effective and efficient way of growing plants for it requires 95% less water than traditional farming method and needs minimal space. Here, in aeroponics the plant boxes are stacked in such a manner that the top and bottom of the plants are suspended in air allowing the crown to grow upward and the roots downward freely. The plants are fed through a fine mist containing nutrient rich and water mix solution which can be fully recycled as the system is an enclosed one. High density planting can be carried out in aeroponics making harvesting easier and providing higher yield. Aero Farms, the leading aeroponics vertical farming company in the United States, is currently building the largest vertical farm in the nation in New Jersey.

c) **Aquaponics**–It is a bio system which integrates recirculated aquaculture or fish farming with hydroponic vegetable, flower and herb production to create symbiotic relationship between the plants and the fish. Fish are grown in indoor ponds, producing nutrient-rich waste that is used as a feed source for the plants in the vertical farm. Whereas, the hydroponic bed function as bio-filters that remove gases, acids and chemicals such as ammonia, nitrates, and phosphates from the water. Simultaneously, the gravel beds provide habitats for nitrifying bacteria, which augment the nutrient cycling and filter water. Consequently, the freshly cleansed water can be recirculated into the fish tanks. Aquaponics is used in small scale vertical farming systems which focus on producing only a few fast growing vegetable crops and don't include an aquaponics component. This simplifies the economics and production issues and maximizes efficiency.

Table 1. Comparison of advanced vertical farming techniques

Vertical Farming Technique	Advantages	Disadvantages
Hydroponics	• Efficient water and nutrient use • High crop yields • Precise control over nutrient delivery • Suitable for a wide range of crops	• Requires specialized knowledge and equipment • Dependence on electricity and pumps • Risk of waterborne diseases • Limited root space
Aeroponics	• Minimal water and nutrient use • Excellent aeration for roots • Reduced risk of plant diseases • Faster growth rates	• High initial setup costs • Requires precise control and monitoring • Vulnerable to power outages • Limited to certain crop types
Aquaponics	• Sustainable and eco-friendly • Nutrient-rich water from fish waste • Reduced need for fertilizers • Dual production of fish and crops	• Complex system design and management • Balancing nutrient levels for fish and plants • Higher initial costs and maintenance • Limited fish species suitable for the system

Tech-CIWA Women Friendly Multipurpose Integrated Vertical Nutri-Farming System for Vegetable Production with Mushroom and Poultry

ICAR-Central Institute for Women in Agriculture, Bhubaneswar, India developed women friendly multipurpose Integrated Vertical Nutri-Farming System (IVNFS) for vegetable production with mushroom and poultry is a resource efficient and climate resilient approach for ensuring dietary diversity and household nutritional security to the landless farm families.

- **Design and use of IVNFS**

  The multipurpose IVNFS is a low cost durable structure of iron that can easily be established in the limited area of homestead backyard and diverse produces could be harvested from small area. The system provides year round regular availability of nutri-dense diverse vegetables, mushrooms, eggs and meat to the farm families. The height of the troughs was designed to minimize drudgery during intercultural & harvesting operations. The women farmer could do the cultivation of vegetables and mushroom and rear poultry birds together with domestic chores and efficiently utilize time, water, energy, space and labour without involving hired labour. There was also minimum chance of soil erosion as the soil remained in the troughs. Additionally, there won't be any soil percolation during irrigation. The women friendly IVNFS model increases farmwomen’s resilience to climate vulnerability and offer subsidiary source of income (Seth *et al.*, 2023).

Fig. 3: Tech-CIWA Women Friendly Multipurpose Integrated Vertical Nutri-Farming System

- **Components of IVNFS**

  The system enables round the year vegetable cultivation in the vertical space along with mushroom cultivation and poultry farming in the intermediate space.

Vegetables	Mushroom	Poultry
Leafy vegetables	Paddy straw mushrooms	Vanraja
Root and tubers	Oyster mushroom	Gramapriya
Other fruit vegetables		

- **Yield**

  The IVNFS produces about 75-80 kg vegetables (inclusive of leafy, roots & tubers and other vegetables), 46-50 kg mushroom (paddy straw and oyster), 1900-2000 nos. eggs, 30-35 kg poultry meat and 125 kg manure in one year.

- **Impact of IVNFS**

  Women friendly multipurpose IVNFS was demonstrated in three districts (Puri, Khordha and Jagatsinghpur) of Odisha. On an average, each system increased the annual availability of vegetables (72 kg), mushroom (30 kg), poultry meat (33 kg) and eggs (1677 numbers) to each household. An annual savings of Rs. 12,000/- for the household can be achieved from a single unit.

Conclusions

Vertical farming is a sustainable and efficient technological intervention to meet out the increasing global food demand. It lowers carbon emissions, offers year-round access to fresh, chemical-free vegetables, are resource-efficient and climate adaptable. Vertical farming is a profitable business opportunity for entrepreneurs. Developments in artificial intelligence for resource management, renewable energy integration, and energy-efficient LED lighting are important research fields. Under the strains of climate change, vertical farming may be essential to creating a sustainable food system with ongoing innovation. To improve the scalability and affordability of vertical farming for global food security, governments and the business sector must work together. Priority must be given towards subsidiary and policy support on vertical farming to the farmers for better adoption among the farming community.

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Bio-based Nano-particle for Sustainable Agriculture

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Nowadays, agriculture is the most important and stable sector which produces and provides rawmaterials for food and feed industries. Recently, agriculture is facing new challenges due to the limited natural resources (production land, water, soil, etc.), climatechange, and the growth of population in the world. Therefore, the agricultural development should be economic, viable, environment friendly and efficient.

1.1. What do you mean by sustainable agriculture?

Sustainable agriculture is a farming method that aims to protect the environment, increase the availability of natural resources, and make the best use of non-renewable resources. It also seeks to improve the quality of life for farmers and communities (Fig. 1).

Fig. 1. Various Dimensions of Sustainable Agriculture (Aslam et al. 2022)

1.2. Sustainable Agriculture – Principles

- **Environmental Sustainability:** Sustainable environmental practices include safeguarding, recycling, replacing, and sustaining the natural resource base, which includes the land (soil), water, and animals.
- **Economic Sustainability:** Economic sustainability is achieved through enhancing crop rotation and soil management, which increases yields.
- **Social Sustainability:** Maintaining social justice and cultural unity is essential for achieving social sustainability.

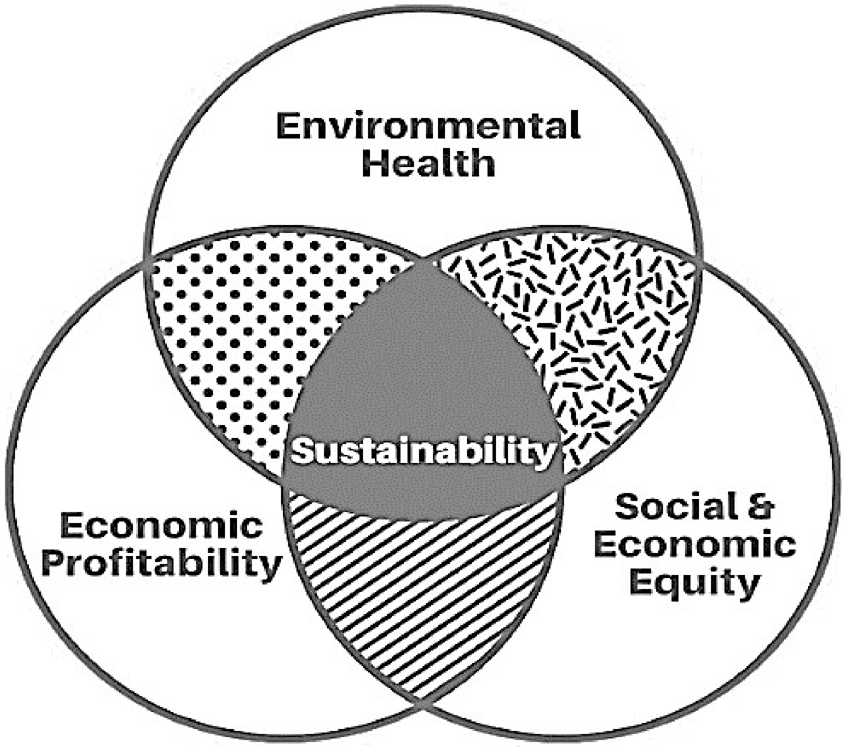

Fig. 2.Principles of Sustainable agriculture (Edukemy team, 2024)

1.3. Sustainable growth of agriculture and nanotechnology

Sustainability has become the core interest in the medical, industrial, and agriculture sectors. the sustainable growth of agriculture totally depends on the new and innovative techniques like nanotechnology. Additionally, the number of publications related to the term of “nano” was also grown exponentially(Fig. 3). In 2016, about 14,000 documents with nanotechnology in food or agriculture were listed meaning high activities of this field (Prasad et al. 2017). In agriculture, nanoparticles can also be used as nanofertilizers and nanopesticides. To achieve sustainable agriculture scientists have developed various nanoparticles (NP) such as silver (AgNPs), gold (AuNPs), copper (CuNPs), zinc oxide (ZnONPs), and iron oxide (Fe_3O_4NPs) nanoparticles. Richard Zsigmondy, Nobel Laureate in Chemistry, pioneer of the theory of a nanometer in 1925. He coined the word “nanometer” in the process. Richard Feynman, the father of modern nanotechnology, awarded the Nobel Prize in Physics in 1965. “There is plenty of room at the bottom” i.e. an atomic-level paradigm, alters matter. A Japanese physicist, Norio Taniguchi, coined the word “nanotechnology”.

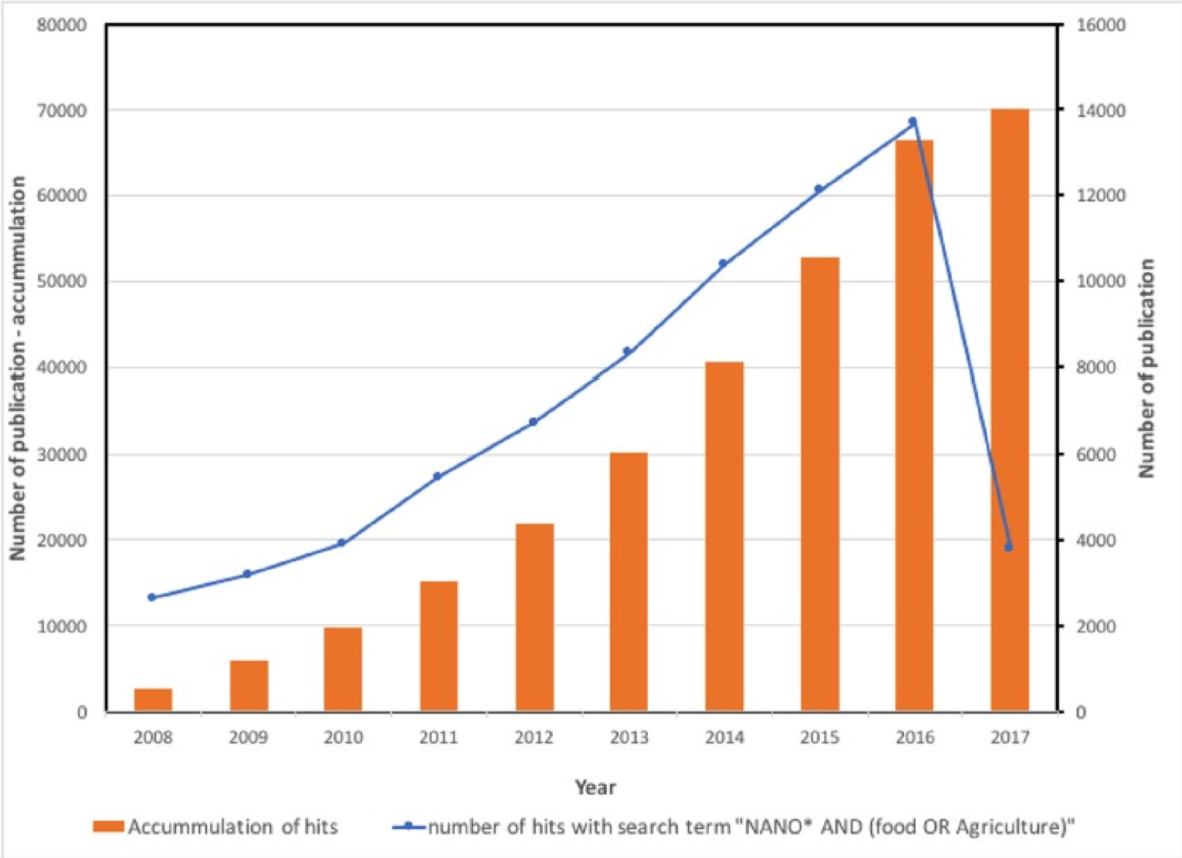

Fig.3.Number of documents on scopus.com with the search term “Nano and (food or agriculture). The hits were grouped annually. (Accessed date: March 15, 2017)

Nanotechnology is the science of manipulation, control, precision placement, modelling and integration of nanoscale (1–100 nm) substances to form structures, components, devices and systems having new problem-solving properties and functions. The distinctive characteristics of nanoparticles viz., small size(1–100 nm), greater surface area to volume ratio, quantum size effects, reactivity, physical strength, electrical, magnetic and optical properties are responsible for its wide variety of applications in the field of agriculture

2. Application of nanomaterials in agriculture]

Their application can lead to improved plant germination, enhanced growth, and increased toleranceto biotic and abiotic stresses, ensuring healthier cropsand higher yields (Fig.4). Additionally, these nanoparticles contributeto improved soil health, fostering a sustainableand balanced ecosystem. Furthermore, their use offersincreased safety for human consumption by reducing thepresence of harmful chemicals, paving the way for a moreenvironmentally friendly and sustainable agricultural system(Balusamy et al. 2023).

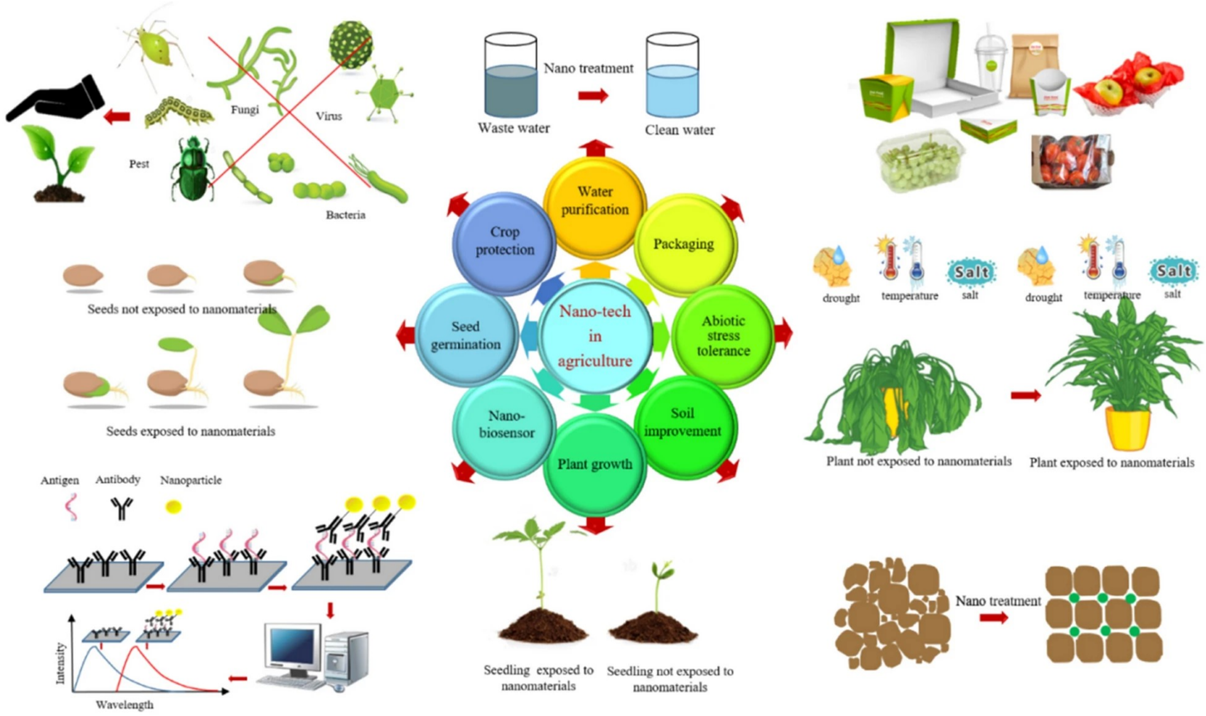

Fig.4. Application of nanomaterials in agriculture

3. Synthesis of nanomaterials

Generally, the synthesis of nanoparticles is done by either a top-down or bottom-up approach. In top-down method, there is breaking down of bulk material through milling, grinding and machining while in the bottom-up method, the small building blocks are assembled to form a large-size structure (nanoparticle growth). Nanoparticles synthesized from physical and chemical methods often use reducing agents to react with precursor material (Fig.5). However, these methods led to generate by-products which can be harmful to the environment as well as hazardous to people with excessive degree of toxicity. So, it is of great interest to synthesize such NMs that produce less toxic by-products or waste during their manufacturing. There is a need to find reducing agents which have a biological origin (Bio-based NMs) that can get rid of toxicity from the environment and such NMs can be obtained from algae, fungi, plants, bacteria and viruses. They are regarded as "Bio-nano factories". They show high efficiency as they are macroscopic and best in heavy metal remediation applications. Bio-based NMs can be synthesized by using different microorganisms like flora and their extracts, agro-industrial waste and agricultural waste, using biomolecules and enzymes, algae like micro-seaweeds, micro alga, phytoplankton, zooplankton and diatom. Bio-based NMs are materials derived from biological origin. Living organisms can endogenously synthesize both organic and inorganic NMs. Therefore, the cause behind moving on to the greener reducing agents in the remediation process is obvious as they are non-poisonous and reduce health risks like pulmonary toxicity, genotoxicity and carcinogenicity. The lower toxicity and high stability is due to the presence of bioactive components that are found in the biological substances (Saraswat et al. 2023).

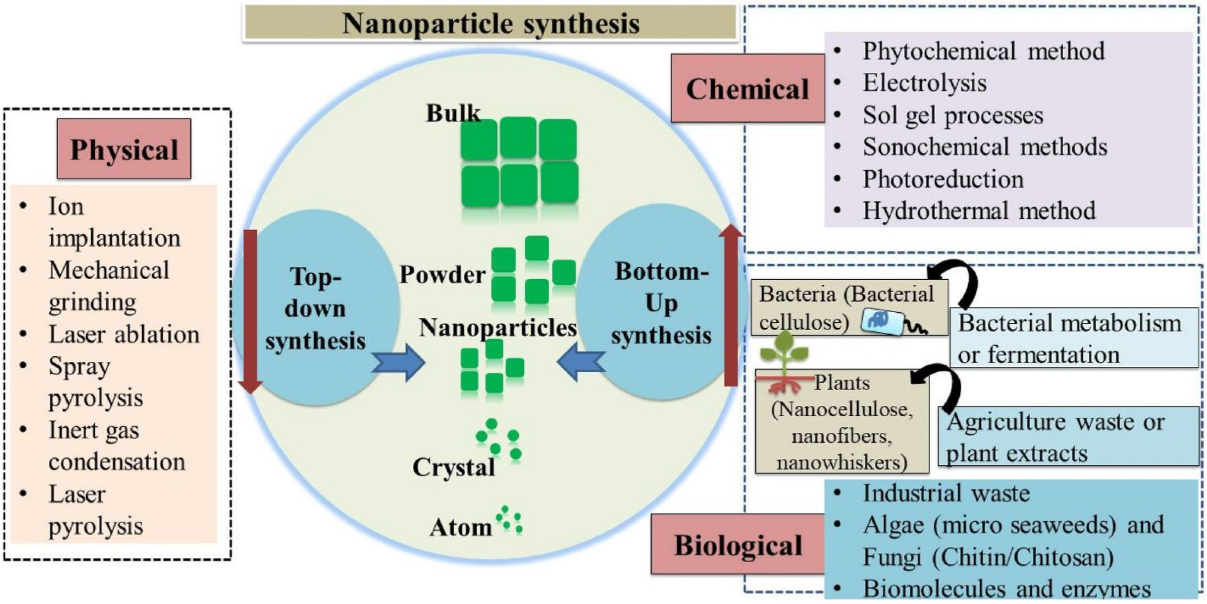

Fig. 5. Methods for the synthesis of nanomaterials (Saraswat et al. 2023).

4. Bio-based nano-particle

It emerged as a promising tool due to their unique properties and potential applications. It derived from natural sources such as plants, bacteria, or fungi. Possess a high surface area-to-volume ratio, excellent stability, and biocompatibility. Appropriate for various plant-related applications and it Includes cellulose, chitosan, and lignin NP. These nanoparticles possess unique properties that enable them to interact with plants at the cellular and molecular levels, influencing various physiological processes and improving overall plant performance. Bio' term used here is to introduce life in polymers by adding living organisms and naturally degradable material, which is manufactured from natural organic resources like microbes, and plants.

4.1. Bio-based nano-particle: Sources and types

Bio-based nanoparticles, also known as green nanoparticles, are a class of nanoparticles that are derived from natural sources such as plants, animals, and microorganisms. These nanoparticles have gained significant attention as a result of being environmentally friendly in nature and potential applications in various fields, including medicine, agriculture, and environmental remediation. These nanoparticles could be synthesized with the help of different methods i.e., chemical reduction, green synthesis using plant extracts or microorganisms, or physical methods like sonication or ball milling. There are several types of bio-based nanoparticles(Verma et al. 2024) that can be synthesized from different natural sources. Some of the commonly studied types include

- ❖ Cellulose nanoparticles,
- ❖ Chitosan nanoparticles,
- ❖ Protein-based nanoparticles,
- ❖ Lipid-based nanoparticles

Cellulose nanoparticles

One of the utmost extensively studied bio-based nanoparticles. Extracted from various plant sources, i.e., wood pulp, cotton fibers, microorganisms and agricultural waste.Synthesis of cellulose nanoparticles involves the breakdown of cellulose fibers into smaller particles using mechanical or chemical methods. These particles possess distinctive characteristics such as high aspect ratio, excellent mechanical strength, and biodegradability, which make them suitable for applications in packaging materials, reinforcement agents in composites, and drug delivery systems.There are nine types of cellulose-based particles, namely MFC, plant fibers (PF), microcrystalline cellulose (MCC), tunicate cellulose nanoparticles (*t*-CNCs), bacterial cellulose particles (BC), algae cellulose nanocrystals (AC) and wood fiber (WF).

Chitosan nanoparticles

It is derivative of chitin, a natural polymer found in button mushroom and exoskeletons of crustaceans such as shrimp and crabs. The chitosan nanoparticle synthesis involves the conversion of chitosan into smaller particles using techniques like ionic gelation or emulsion cross-linking. Chitosan has excellent biocompatibility and biodegradability properties

Lignin nanoparticles

Improve soil quality by enhancing soil structure, increasing water retention capacity, and promoting microbial activity. Facilitate nutrient uptake by increasing the surface area for nutrient adsorption and enhancing nutrient availability to plants. Stimulate root development and promote plant growth by influencing hormone production and regulating gene expression

5. Green synthesis of nano particle

The synthesis of diverse metal nanoparticles utilizing bioactive agents, including plant materials, microbes, and various bio-wastes like vegetable waste, fruit peel waste, eggshell, agricultural waste, algae, and so on, is known as "green" or "biological" nanoparticle synthesis. Synthesis of nanoparticles can be achieved by following chemical, physical, and biological methodologies.The main purpose of green approaches is to enhance the NPs activity and reduce their impact on health and the environment.Researchers mostly focus on the biological resources or green methodologies for the production of NPs.Green synthesis includes the synthesis of NPs using plants or their parts as well as using different microorganisms, including bacteria, fungi, yeast, and virusesGreen synthesis has been appreciated as a quick facile and produces stable and biocompatible nanoparticles. Especially, medicinal plants (e.g. *Panax ginseng, Rhodiolarosea, Cannabis sativa, Rowan berries, Siberian ginseng*,) are extensively reported for the rapid synthesis of nanoparticles.

5.1. Method of green synthesis of nanoparticle

Plant-mediated synthesis has been a promising way for nanoparticle mass production. It is eco-friendly, cost-effective, easily scaled up, and does not require high temperature or special energy resources (e.g., ultrasound waves). The components responsible for metal reductions in microorganisms are enzymes, proteins, and secondary metabolites, whereas in plants, those include flavonoids, terpenoids, phenols, carbohydrates, saponins, steroids, etc. The biological components mentioned above help in reduction and form a surrounding layer around the individual nanoparticles called the "capping layer" or "biological corona". The biological corona formed around the nanoparticles contains biological components released from the plant or microorganism in an extract or a culture medium used for synthesis. This capping layer offer the long-term stability of nanoparticles in aqueous solutions, protecting the nanoparticles from agglomeration, and most importantly, playing a major role in the interaction of green nanoparticles with cells. This helps nanoparticles to permeate easily into the plant or bacterial or fungal cells and cell organelles. Thus, the biological corona plays key beneficial role for nanoparticle production and its applications in different fields.

Fig.6 Green synthesis of nanoparticles, method parameters and applications in sustainable agriculture (Balusamy et al. 2023)

5.2. Green synthesis of metal nano particle (MtNP)by different microorganisms

Microorganisms, such as bacteria, fungi, yeasts and microalgae produce MtNPs either intra- or extracellularly (Fig.7.). Extracellular synthesis of MtNPs are of great interest because it eliminates the need for costly and complex downstream processing steps to recover intracellular MtNPs. Microorganisms are important nanofactories that are able to accumulate and detoxify heavy metals due to the presence of various reductase enzymes that are able to reduce metal salts to MtNP.Bacteria such as P*seudomonas deptenis, Bacillus* methylotrophicus, *Visella oriza*, Bhargavaeaindica and *Brevibacterium frigoritolerans*have been shown to be able to synthesize silver (Ag) and gold (Au) nanoparticles. Nanoparticles produced by actinomycetes have very good dispersion and stability and have significant lethal activity against various pathogens (Bahrulolum et al. 2021).

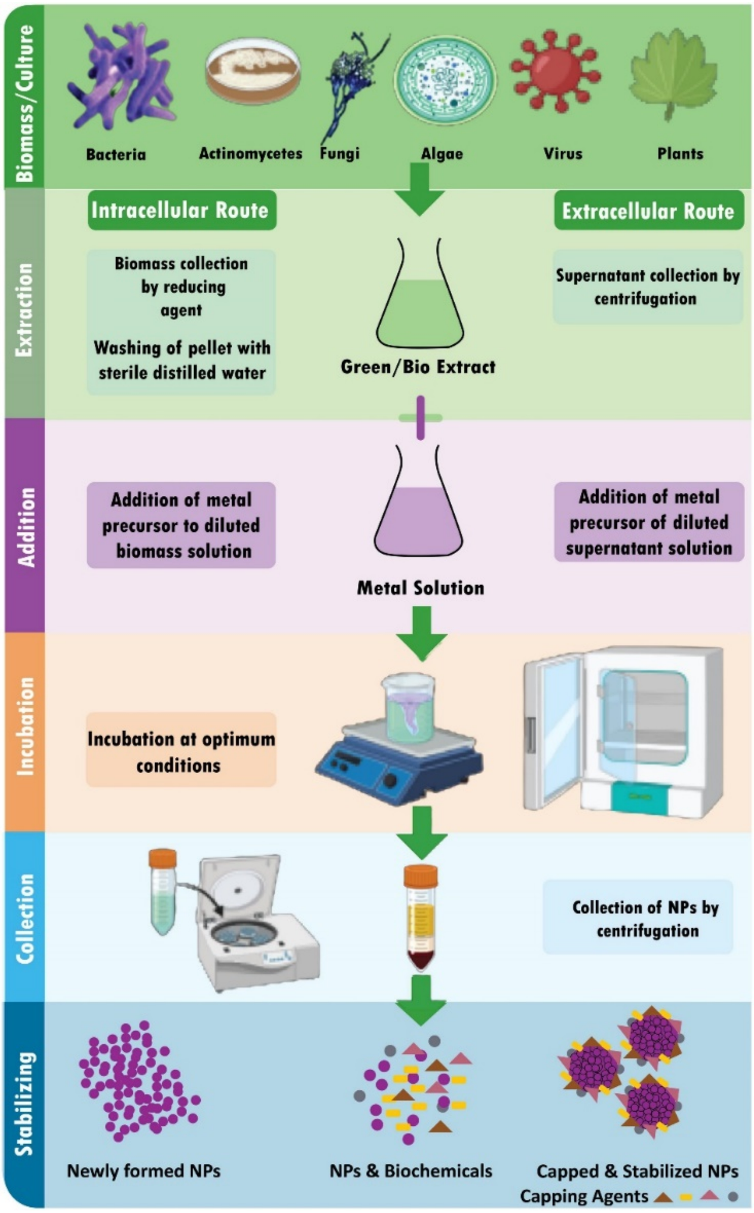

Fig.7. Schematic diagram for biosynthesis of NPs (Altammar 2023).

Extracellular biosynthesis of MtNPs

Reductase enzymes (e.g. nitrate reductase) which are either located in the cell wall or secreted from the cell to the growth medium.

Intracellular synthetic approaches

For microorganisms are cultured in a suitable growth medium with favorable pH and temperature conditions. The biomass is harvested after an optimal incubation period and washed thoroughly with sterile water to minimize potentially undesirable effects of the culture medium. The resulting biomass is then incubated with metal salt solution. In addition to the use of whole microorganisms for intracellular synthesis of MtNPs an alternative is the use of cell-free (CF) approaches using either culture supernatant or cell-free extracts (CFE). Intracellular biosynthesis involves unique transport systems in microorganisms in which the cell wall plays an important role due to its negative charge: positively charged metal ions are deposited in negatively charged cell walls through electrostatic interactions. After transport into the cells of the microorganism, ions are reduced using metabolic reactions mediated by enzymes such as nitrate reductase to forms MtNPs. The MtNPs accumulated in the periplasmic space can then be passed through the cell wall. Magnetotactic bacteria are used for the synthesis of various magnetic NMs by utilizing the mineralization proteins.

5.3. Characterization of MtNPs

It can be characterised using following instruments:

- ❑ UV–visible spectroscopy: Confirm the synthesis and stability of MtNPs.
- ❑ Fouriertransform infrared (FTIR) spectroscopy: Measure the properties of MtNPs such as chemical concentration, surface chemistry, surface functional groups and atomic arrangement
- ❑ Transmission electron microscopy (TEM), scanning electron microscopy (SEM)
- ❑ and atomic force microscopy (AFM): Visualize the position, size and morphology of MtNPs.
- ❑ X-ray powder diffraction (XRD): Determine the crystallographic structure. energy Dispersive x-ray spectroscopy (EDS): The elemental composition of MtNPs is usually examined.
- ❑ Dynamic light scattering (DLS): to evaluate the size as well as surface charge of MtNPs.

5.4. Factors influence the green synthesis of NPs

- ❖ Time used for synthesis: Reaction time is crucial for nanoparticle synthesis, which decides nanoparticles' shape, size, and stability. Higher the reaction time higher agglomeration of NP at higher temperatures.
- ❖ Temperature: At high temperature, 70–90 °C, green synthesis occur very quickly
- ❖ pH: Plays a major role in deciding nanoparticles' size and shape. Big nanoparticles form fewer functional groups attached to the corona layer at acidic pH [21].
- ❖ Temperature: Affect the morphology of NPs. The literature has evidenced that higher temperature helps in quick reduction and, if treated for a longer period, could cause agglomerations. However, many biological components also become inactive at higher temperatures, causes the instability of NPs. Increase in temperature allowed the change in the shape of nanoparticles and resulted in rod and plate-shaped nanoparticles.
- ❖ Reacting substances: Affect nanoparticle formation, i.e., the biomolecules available for reduction. Huang et al. showed the change in the shape of gold and silver nanoparticles from triangular to spherical with an increasing concentration of sun-dried *Cinnamomumcamphora*leaf extract.

6. Use of Bio-based NPs in agriculture

Bio-based NP can be used to improve nutrient uptake by plant as well as to improve soil environment for better crop growth and productivity (Fig.8).

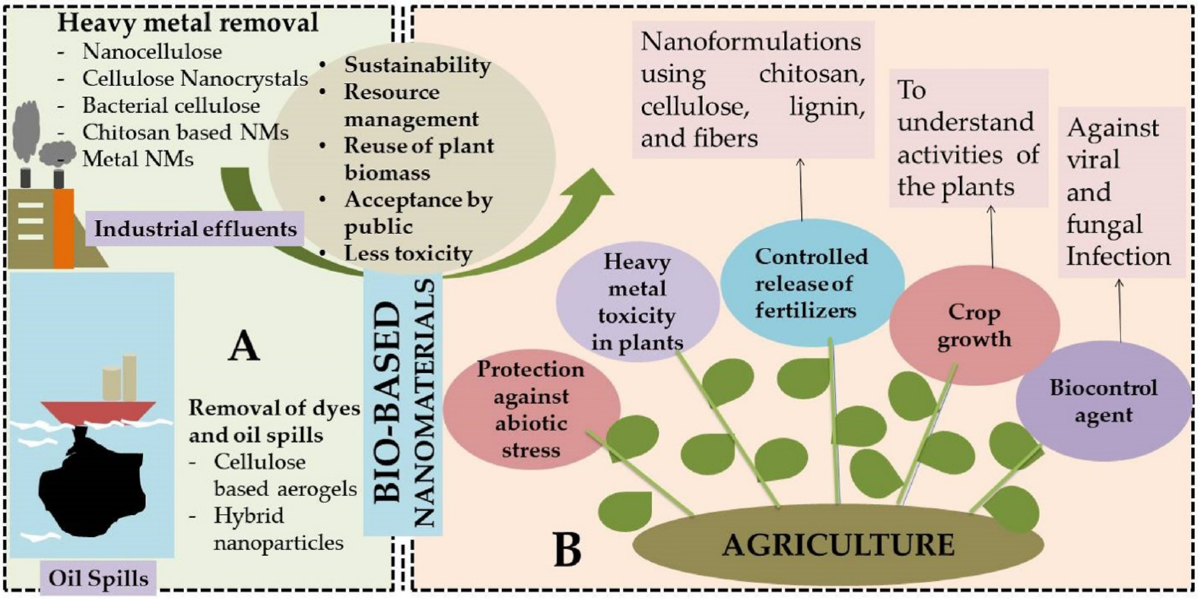

Fig.8.Use of Bio-based NPs in agriculture (Saraswat et al. 2023)

6.1. Increased nutrient uptake

Bio-based NP have a high surface area and can interact with a large number of nutrient molecules, forming strong bonds. This increased adsorption capacity allows the nanoparticles to capture and retain nutrients from the surrounding environment, preventing their loss through leaching or volatilization. It enhances nutrient solubility by forming complexes with them, increasing their dispersion in the soil solution and making them more accessible to plant root. It promotes the growth and development of new roots, increasing the root surface area and enhancing the plant's ability to absorb nutrients from the soil. It stimulates root elongation and branching, along with root hair formation, that increase the nutrient absorption capacity of the roots. It facilitates the transport of nutrients within the plant, ensuring that they reach the tissues where they are needed most.

6.2. Stress tolerant

It helps in stress conditions, such as drought, salinity, or nutrient deficiency, plants often experience reduced nutrient uptake and utilization. It alleviate these effects by improving nutrient absorption and transport, helping plants maintain their growth and productivity even under adverse conditions. It enhances nutrient adsorption, solubility, root development, nutrient transport, and nutrient use efficiency, bio-based nanoparticles can significantly increase nutrient uptake by plants, leading to improved growth, productivity, and overall plant health. It enhances the drought tolerance of plants by enhancing their ability to cope with water deficit stress.

6.3. Enhanced water retention in soil

Bio-based NM increases the water holding capacity of soil, allowing it to store more water for plant use by forming a protective layer on the soil surface and reduce water evaporation. It helps to reduce water evaporation from the soil. This layer acts as a physical barrier, preventing water molecules from escaping into the atmosphere. It also helps in maintaining optimal soil moisture levels for plant growth, especially in arid or drought-prone regions.

Hence, improved water retention also reduces the frequency of irrigation required for crop cultivation.

6.4. Improve soil structure

It helps to improve soil structure by promoting aggregation and reducing compaction. Bio-based nanoparticles can enhance microbial activity in the rhizosphere or soil, leading to increased nutrient mineralization and availability. The microbes' growth and metabolic activity can be stimulated by the nanoparticles by providing them with a supply of carbon and energy

6.5. Crop productivity

Bio-based nanoparticles play a substantial role in increasing crop productivity through various mechanisms;

- ❖ *Enhance photosynthesis:* The nanoparticles enhance the light absorption efficiency and utilization by chloroplasts. This increased photosynthetic activity leads to increased biomass production and crop yield.
- ❖ *Enhance disease resistance*: Bio-based nanoparticles have antimicrobial and antifungal properties, which can help to defend plants from diseases and pests. The nanoparticles can inhibit the growth and spread of pathogens, reducing crop losses and improving overall plant health.
- ❖ *Stress tolerance of plant:* Protect the seeds from pathogens and environmental stresses, increasing the chances of successful germination coupled with seedling establishment.
- ❖ *Improve seed germination and vigor* by enhancing water uptake as well as nutrient absorption by the seeds.
- ❖ Crop quality: Increasing the nutritional content and reducing the presence of Contaminants. Nanoparticles can help increase the levels of vitamins, minerals, and antioxidants in crops, creating more nutrition and benefits for human health

6.6. Biocontrol

The major limiting factors for the crop production are the various diseases caused by microbes results lower productivity. Agrochemicals has resulted in higher production but comes with disadvantages to the environment in terms of pollution, increased resistance to pesticides/herbicides and risk for the consumers. Nanoformulations are prepared using natural materials (chitosan, lignin, cellulose, fibers, etc.) that can be an alternate option to prevent risks associated with conventional techniques. The herbal formulations of essential oils coated on bio-based NMs like chitosan, PEG (poly ethylene glycol) and PCL (poly ε-caprolactone), have been effectively studied for developing pest resistance in a sustainable way. Chitosan-based NMs have been used as a delivery vehicle for bioactive compounds due to their less toxicity, biocompatibility and biodegradable nature. Lignin-based nano- and microcarriers prepared by encapsulating fungicides like pyraclostrobin, azoxystrobin, boscalid and tebuconazole are effective delivery methods inside the plant, resulting in high efficiency. Silver nanoparticles (AgNPs) synthesized from *B. licheniformis*, against *Bean Yellow Mosaic Virus* showed effective antiviral activity in laboratory research. Fava bean crop is largely affected by the *Bean Yellow Mosaic Virus* which can be protected by using biologically synthesized NMs. A study showed the utilization of the fungus *Curvulariapallescens*(causes tomato leaf mold) for the synthesis of Ag NMs. The presence of alkaloids and proteins in the fungus was found mainly responsible for nanoparticle synthesis. The results effectively showed the antifungal activity of AgNPs against *Cladosporiumfulvum*. Biologically synthesized selenium (Se) nanoparticles are utilized in agriculture as some microbes (bacteria, fungi and yeast) convert the toxic selenium forms such as selenium oxyanions and selenium dioxides into lesser toxic forms (elemental Se nanoparticles). Zinc oxide particles (ZnO NPs) were biologically synthesized using Tridaxprocumbens to examine its metabolic effects on *Vignaradiata*in the presence of PbCl2. The study proved the effectiveness of ZnO NPs against Pb toxicity in *Vignaradiata*

6.7. Nanofertilizers, Nanopesticides and Nanoherbicides

The modified biobased polyurethane is a hydrophobic coating which can be used for agricultural practices for the controlled release of fertilizers explained. Chitosan-based nanoformulation has shown promising effect on control release of bioactive compounds by encapsulating them. These are helpful in the improvement of plant growth with lesser toxicity and mitigation of various biotic and abiotic stresses. Chitosan encapsulated nanoparticles have long stability and controlled release which have prospered future for sustainable agriculture. Lignin is a highly abundant and inexpensive material to synthesise NMs. Lignin based NMs have shown remarkable potential in controlled release of pesticides, fungicides and fertilizers.The lignin based nanocarriers, along with fungicides, are one of the most promising drug delivery systems in plants. Lignin nanocarrier (NC) encapsulated with different types fungicides resulted in successful growth inhibition of fungus like *Phaeoacremonium minimum* after trunk injection in *Vitis vinifera.*

6.8. Impact of bio-based nanoparticles on plant differentiation

Bio-based NP influences cell differentiation processes such as trichome formation or xylem vessel differentiation.Bio-based NPs can interact with plant cells and modulate gene expression patterns, influencing various developmental processes, including differentiation. NPs can deliver genetic material (e.g., DNA or RNA) into plant cells, leading to the up-or-down-regulation of specific genes involved in differentiation pathways. It acts an important role in regulating cell division, organ formation, and tissue differentiation. NPs have the ability to modify reactive oxygen species (ROS) levels, which in turn affects signaling pathways related to differentiation and the redox status of cells. Bio-based NPs can act as nutrient carriers, facilitating their delivery to specific tissues or organs where differentiation occurs. Bio-based NPs have the ability to mimic or block these hormones (Auxin, cytokinin, gibberellin, and Abscisic acid) effects, changing the pathways leading to differentiation. NPs have the ability to alter cell fate and differentiation patterns by activating or inhibiting particular signaling pathwaysNPs can modulate the composition and activity of the plant microbiota, indirectly influencing differentiation processes.

6.9. Environmental Remediation by bio-based nanomaterials

Heavy metal absorption:

NMs have been used in environmental remediation (heavy metals, dyes). NMs based on cellulose are frequently used, such as nanocellulose (good adsorbent of metal ions). Kardam et al. [129] synthesized cellulose nanocrystals (CNCs) by using rice straw by performing acid hydrolysis to adsorb heavy metals (Ni2+, Pb2+, and Cd2+). Bacterial cellulose (BC) has also been used for the adsorption of metal ions after some modifications. Carboxymethylated bacterial cellulose (CM-BC) has been synthesized from *Acetobacterxylinum*

Oil spill cleanup:

The newly developed cellulose-based aerogels have emerged as an effective method for wastewater treatment. Aerogel microspheres isolated from cellulose nanofibril (CNF) and polyvinyl alcohol (PVA) were found capable in adsorption of floating oil.

7. Conclusions:

Bio-based nanoparticles (NPs) have developed as a promising tool in agriculture and provide an eco-friendly and sustainable approach to enhance plant development, growth, and differentiation. It enhances nutrient uptake and transport, supplying essential elements for plant growth. It improves plant tolerance to abiotic stresses and nutrient deficiency by mitigating the negative effects on differentiation and other physiological processes. The controlled release of pesticides, fertilizers and nutrients could be done more precisely with development of better nanoformulation approaches. Compared to synthetic NPs, bio-based NPs offer advantages such as decreased environmental accumulation, reduced toxicity, and better compatibility with plant cells, minimizing adverse effects on plant growth. Bio-based NPs offer a sustainable and promising approach to enhance plant development, growth, and differentiation, contributing to the advancement of agriculture and food security in a changing global environment. In-depth scientific knowledge is necessary to develop efficient bio-based NMs for sustainable use and overcome the upcoming challenges with the new innovations.

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Climate-resilient Horticulture: Innovations and Strategies

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Climate change, a global phenomenon, poses a significant challenge to food and nutritional security for the growing global population. Its impacts are far-reaching, influencing agricultural systems through extreme events such as droughts and floods, erratic rainfall patterns, and sudden temperature fluctuations. These changes directly affect plant growth, flowering, fruiting, and yield, while also increasing vulnerabilities to pests and diseases. Addressing these challenges requires concerted efforts in adaptation and mitigation strategies, which remain central to the global agenda of governments and research organizations.

In horticulture, the effects of climate change are multifaceted. The response of horticultural crops varies across species and regions; for instance, some crops may benefit from higher carbon dioxide levels, while others may experience disrupted flowering and fruiting cycles. Shifts in cropping zones, such as the movement of apple-growing areas to higher altitudes, are becoming evident. Additionally, altered phenological stages, shortened growth durations, and reduced yields have been observed. These challenges necessitate localized analysis, planning, and management based on agro-climatic conditions, cropping patterns, and socio-economic contexts.

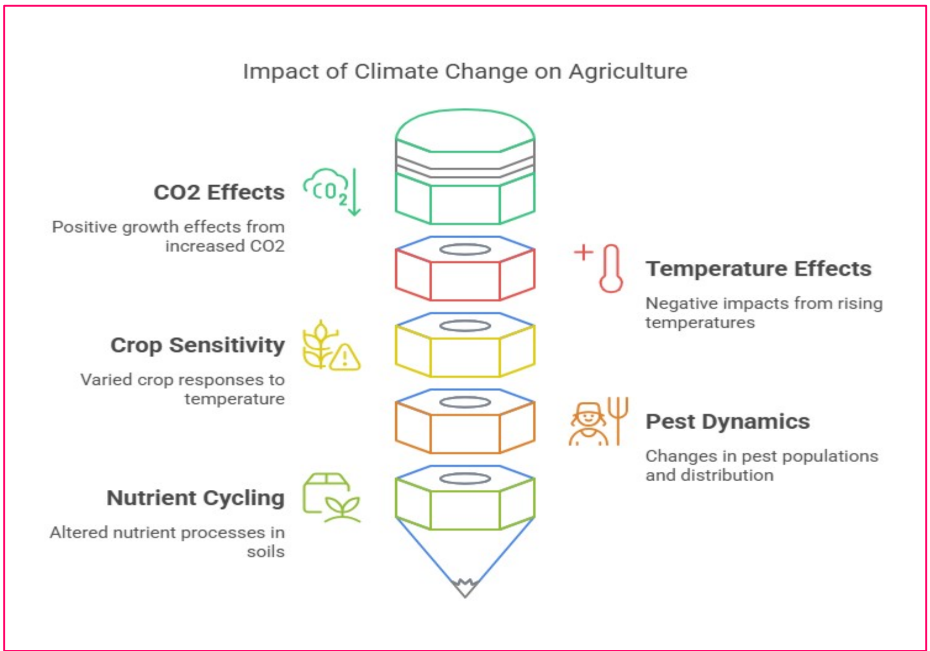
Innovative solutions, including the development of climate-resilient cultivars, advanced production systems, and cutting-edge technologies, are crucial for adaptation. Tools such as mathematical models now enable researchers to predict climate change impacts, assess crop responses, and devise region-specific strategies. Moreover, perennial horticultural crops offer opportunities for carbon sequestration, serving as sinks for increased carbon dioxide while contributing to soil carbon storage.

Understanding the regional impacts of climate change on horticultural crops, both annual and perennial, is imperative. Strategic innovations and technology refinement are essential to developing effective adaptive mechanisms. By utilizing the existing sustainable crop management practices and generating new insights into the effects of climate variables, the horticulture sector can build resilience and ensure sustainability in the face of climate change.

Climate change and Indian agriculture

- India is identified as one of the highly vulnerable countries to climate change (INCCA, 2010).
- A weakening of the Indian summer monsoon from the latter half of the 20th century has also been reported by Saha *et al*. (2014)

- Significant increase in temperature, frequent heat waves, droughts, extreme precipitation events, and intense cyclonic activities (Ray *et al*., 2021; Datta *et al*., 2022)
- Guiteras (2009) found that in the short-run (2010–2039), climate change would lower the yields between 4.5 to 9%, whereas, in the long-run (2070–2099), it will drastically reduce the yields at least by 25% in the absence of adaptation.
- Poor households globally lose 5% of their total income in an average year due to heat stress and 4.4% due to floods (FAO of the United Nations, October 16, 2024)



Impact of climate change on horticultural crops

Crops	Impact of climate change
Cauliflower	Increase in temperature is resulting in delayed curd initiation
Chilli	Drought stress can lead up to 50–60% yield loss
Cucumber	Sex expression is affected by temperature fluctuation. high temperatures lead to profuse production of more male flowers and reduces the potential yield
Tomato.	Water stress accompanied by temperatures above 28°C induced about 30–45% flower drop in different cultivars (Srinivasa Rao 1995). Under flooding conditions endogenous ethylene accumulate in plant, leading to rapid epinastic leaf response
Onion	Soil water stress at early stages of onion crop growth can cause 26% yield loss (Srinivasa Rao 1995). Flooding during bulbing leads to yield loss up to 30–40%. Duration of onion gets shortened due to high temperature, leading to reduced yields.
Cassava	Drought during first 3 months delays tuber initiation and bulking
Sweet Potato	Yield decreases when the available soil moisture decreases below 20% during the tuber initiation period. Water stress during tuber initiation period induces lignification of tubers and hampers tuber growth
Mango	Temperature fluctuation results in early or delayed flowering, multiple

	reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative ones
Banana	Higher temperature (31–32°C), increases the rate of plant maturity, thus shortening the bunch development period. Waters stress during flowering causes poor filling of fingers, reduces the bunch weight and other growth parameters.
Apple	Warmer winters reduce the chilling hours, leading to poor bud break, flowering, and fruit set.Higher temperatures can cause early flowering, exposing blossoms to late frosts and reducing yields.Prolonged high temperatures during the growing season affect fruit development, size, color, and quality.
Grapes	Higher temperature advances the ripening of berries and alters the berry composition in both table and wine grapes. Serious downy mildew disease developes by the unseasonal rains during the critical growth period

Adaptation and Mitigation Strategies for Climate-Resilient Horticulture

The increasing impact of climate change necessitates the adoption of effective adaptation and mitigation strategies to ensure the sustainability of horticulture. These strategies aim to address the challenges posed by changing climatic conditions, such as rising temperatures, erratic rainfall, and extreme weather events, which affect crop growth, flowering, fruiting, yield, and quality, while also increasing the risks of pest and disease outbreaks.

Adaptation strategies involve proactive measures to minimize the adverse effects of climate change on horticultural crops. Key approaches include:

- Developing climate-resilient cultivars with enhanced tolerance to high temperatures, drought, and salinity.
- Shifting cropping patterns and zones based on changing climatic suitability, such as cultivating apples in higher altitudes or introducing frost-sensitive crops in warmer regions.
- Modifying production practices, including micro-irrigation, mulching, and the adoption of protected cultivation techniques like greenhouses and shade nets.
- Diversifying crops to reduce risks associated with mono-cropping under unpredictable weather conditions.

On the other hand, **mitigation strategies** focus on reducing the contribution of horticulture to climate change while enhancing its role in carbon sequestration. These include:

- Promoting agroforestry systems and perennial fruit crops for their potential to act as carbon sinks.
- Enhancing soil carbon sequestration through organic farming practices, biochar application, and efficient nutrient management.
- Adopting renewable energy sources, such as solar-powered irrigation, and reducing dependency on fossil fuels in horticultural operations.
- Implementing integrated pest and disease management practices to minimize chemical use and reduce greenhouse gas emissions.

Strategies for Climate Resilience

1. **Crop Diversification:** Crop diversification in horticulture is an effective climate-resilient strategy that enhances sustainability, reduces risk, and improves productivity under changing climatic conditions. Crop diversification as a climate resilient approach includes:
   - **Intercropping:** Growing two or more crops simultaneously on the same piece of land. It involves integrating short duration fruit crops, seasonal vegetables, in interspaces of fruit orchards, plantation crops like coconut, arecanut etc. In intercropping mostly the shallow rooted crops are integrated with deep rooted crops, nutrient exhaustive crops are intercropped with leguminous vegetable crops.
   - **Multistorey cropping:** Multistorey cropping is an advanced form of intercropping where crops of different heights are grown together on the same field to maximize space utilization, improve microclimatic conditions, and enhance resilience against climate change. Some examples of multistory cropping include: Coconut + Banana + Pineapple, Mango + Papaya + Turmeric, Arecanut + Black Pepper + Ginger etc.
   - **Agroforestry:** Agroforestry systems in India include trees in farms,community forestry and a variety of local forest management and ethnoforestry practices. Agroforestry encompasses a variety of practices, includingtrees on farm boundaries, trees grown in close associationwith village rainwater collection ponds, crop-fallow rotations,and a variety of agroforests, silvopastoral systems, and treeswithin settlements. In NEH region, among horticultural crops ginger,turmeric, cardamom, large cardamom, black pepper, betel vines, pineapple, coffee, tea, and many vegetables are grown with forest and trees like *Pinus kesiya, Alnus nepalensis, Schima wallichii, Pyrus communis, Prunus domestica, Areca catechu*, and others. The vegetables include okra, cole crops, solanaceous vegetables, leafy vegetables, legumes, root crops, and cucurbit.

2. **Improved Crop Varieties**

A. Crop Varieties Suitable for Cultivation under Drought Stress

S. No.	Crop	Variety	State	Source of planting material availability
1	Apple	York Imperial	Jammu & Kashmir	SKUA&T-Jammu
2	Apricot	Badami, Inzhirnyl, Rannil	Jammu & Kashmir	SKUA&T-Jammu
3	Banana	Karpuravalli (ABB)	Southern A.P., NorthernKarnataka	NRC Banana, Trichy,Kerala
4	Ber	Sev, Gola, Umran	Rajasthan	CIAH-Bikaner
		Seb, Mudia, Jogia, Gola	Jammu & Kashmir	SKUA&T-Jammu
		Sev, Gola	Rajasthan	CAZRI, Jodhpur; CIAH,

				Bikaner
5	Citrus	Mosambi	Maharashtra	NRC on Citrus, Nagpur
6	Guava	Allahabad Safeda, Lucknow-49	Uttar Pradesh	CISH, Lucknow
7	Mango	Arka, Neelachal, Kesari	Orissa and A.P.	CHES, IIHR, Bhubaneswar
		Sinduri	Rajasthan	Anand, Gujrat
		Jalore seedless / Sindhuri	Rajasthan	CIAH, Bikaner; Anand, Gujrat

B. Crop Varieties Suitable for Cultivation under Heat Stress

S. No.	Crop	Variety	State	Source of planting material availability
1	Apricot	Badami, Inzhirnyl, Rannil	Jammu & Kashmir	SKUA&T-Jammu
2	Banana	Shrimanti and Grand Naine	South A.P. and Karnataka	NRC Banana, Trichy
		Poovan, Karpura valli	TN, Kerala, A.P., Karnataka, Bihar, W.B.	
3	Peach	Flordasun and Sunlet	Jammu & Kashmir	SKUA&T-Jammu
4	Sweet orange	Mosambi	Jammu & Kashmir	SKUA&T-Jammu

C. Crop Varieties Suitable for Cultivation under Cold Stress

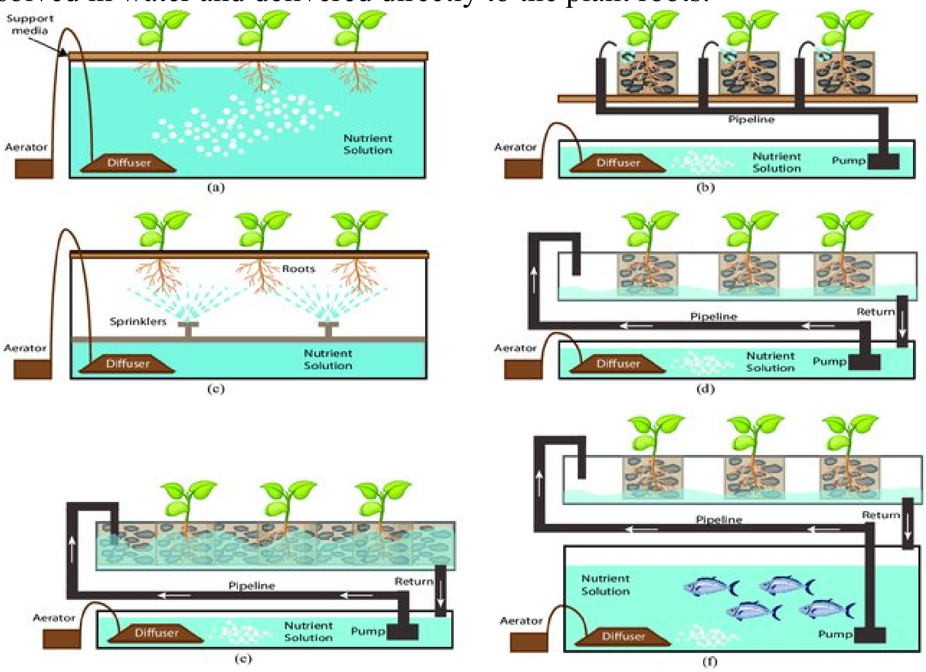
S. No.	Crop	Variety	State	Source of planting material availability
1	Banana	Poovan, Karpura valli	Tamil Nadu, Kerala, A.P., Karnataka, Bihar, W.B	NRC Banana, Trichy
2	Cashew	Indira Cashew	Chhattisgarh	IGKV Jabalpur
	Sweet orange	Indira navin	Chhattisgarh	IGKV Jabalpur

3. **Protected Cultivation**

Protected cultivation of horticultural crops is an effective climate-resilient strategy that enhances productivity, quality, and sustainability in the face of climate variability. By utilizing structures such as greenhouses, polyhouses, shade nets, and low tunnels, this approach shields crops from extreme temperatures, erratic rainfall, frost, and pest infestations, ensuring stable yields throughout the year. It enables efficient water and nutrient management, supports precision farming techniques, and reduces dependence on chemical inputs, promoting eco-friendly and resource-efficient agriculture. Additionally, protected cultivation facilitates the year-round production of high-value crops like vegetables, fruits, and flowers, improving farmers' income and market opportunities. As climate change intensifies, adopting protected cultivation can play a crucial role in enhancing food security, reducing risks associated with climate uncertainties, and promoting sustainable horticultural practices.

4. **Hydroponic Farming**

Hydroponic farming is a method of growing plants without soil by using nutrient-rich water solutions. Instead of soil, plant roots are supported by inert mediums such as coco peat, perlite, vermiculite, or clay pellets, and nutrients essential for growth are dissolved in water and delivered directly to the plant roots.



Different types of Hydroponic system: Deep Water Culture, (b) Drip System, (c) Aeroponics, (d) Nutrient Film Technique (NFT), (e) Ebb and flow, (f) Aquaponics (Source: Velazquez-Gonzalez*et al.,* 2022)

5. **Smart-irrigation and Rain Water Harvesting Structures**

Smart irrigation and rainwater harvesting structures ensures water efficiency and sustainability amid changing climate conditions. Smart irrigation technologies, such as drip irrigation, soil moisture sensors, and automated scheduling, optimize water use by delivering the right amount of water at the right time, minimizing wastage and enhancing crop productivity. Rainwater harvesting structures, including farm ponds, check dams, percolation tanks, and rooftop harvesting systems, help capture and store rainwater for supplemental irrigation during dry spells. These approaches not only conserve water but also improve groundwater recharge, reduce dependency on erratic rainfall, and mitigate the impacts of droughts. By integrating smart irrigation and rainwater harvesting, farmers can build a resilient farming system that sustains agricultural production, enhances water security, and supports climate adaptation in vulnerable regions.

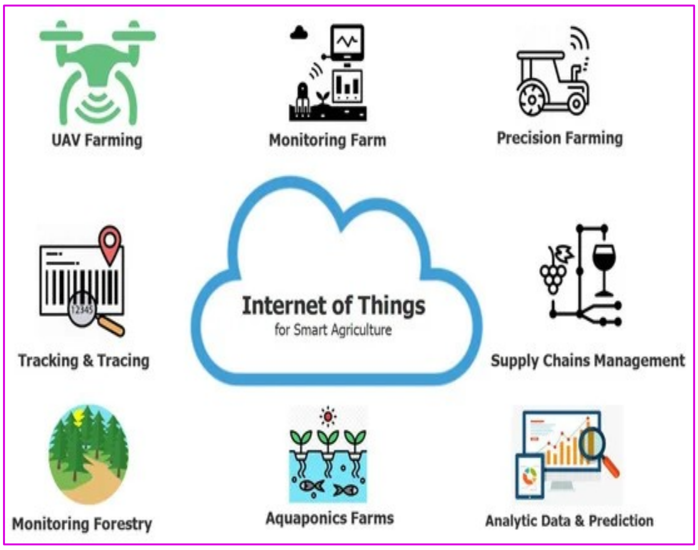
6. Precision Farming

Precision Agriculture (PA), also known as smart farming or site-specific crop management, refers to the use of advanced technologies, data analysis, and equipment to monitor, manage, and optimize agricultural practices at a much finer scale. It aims to ensure that crops receive exactly what they need for optimal growth. It includes the following technologies:

- Geospatial Technology: GPS (precise location), GIS (map out fields, crop variations), Remote Sensing (Satellite and drone imagery based real time data)
- Sensors and IoT (Internet of Things): Soil Sensors, Crop Sensors
- Variable Rate Technology (VRT):Allows for the application of inputs at different rates across a field based on specific needs identified through data analysis.
- Data Analytics and Decision Support Systems: Big Data, Farm Management Software
- Automation and Robotics: Drones, Autonomous Tractors and Harvesters

7. IoT (Internet of Things) in Agriculture

IoT technologies are integrated in farming and agricultural practices to optimize production, increase efficiency, and make more data-driven decisions. IoT in agriculture involves using interconnected sensors, devices, and systems to collect and analyze real-time data about various aspects of farming, such as soil moisture, weather conditions, crop health and irrigation management



IoT-Enabled Smart Agriculture: Architecture, Applications, and Challenges (Source: Quy et al., 2022)

8. Soil Management

Effective soil management is crucial for climate-smart agriculture, ensuring sustainable productivity while mitigating climate change impacts. Mulching, through organic (crop residues, straw, leaves) or synthetic materials, helps conserve soil moisture, regulate temperature, suppress weeds, and reduce soil erosion, making it an essential practice in water-limited environments. The use of organic amendments, such as compost, farmyard manure, and green manure, enhances soil fertility, improves microbial activity, and increases carbon sequestration, contributing to long-term soil health and resilience. Biochar, a stable carbon-rich material derived from biomass pyrolysis, further enhances soil properties by improving water-holding capacity, nutrient retention, and microbial diversity while also acting as a carbon sink to mitigate greenhouse gas emissions. Integrating these practices into soil management strategies not only improves soil structure and fertility but also enhances the adaptive capacity of agroecosystems, ensuring sustainable agricultural production under changing climatic conditions.

9. Manipulation of the Plant Canopy

Canopy management and innovative training systems are also key factors that contribute to maximizing yield efficiency and improving fruit quality, which are essential for the competitiveness of orchards. In grapes shoot trimming or apical leaf removal, post-verasion improves TSS and total anthocyanin accumulation. These approaches are based on exploitation of carbon and nutritional competition between the developing organs. Secondly a new irrigation tool and foliar application of particle materials, such as kaolin and zeolite, to reduce canopy and berry temperature enhance yield attributes and grape colour (Valentini et al., 2023).

10. Encouraging & supporting pollinators

Creation of habitats that support pollinators is a critical aspect of sustainable agriculture, as they play a significant role in the production of many crops, including fruits. It can be encouraged through:

- Plantingpollinator-friendly vegetation
- Providingnesting habitats
- Limitingpesticide use
- Providingfresh water sources
- Encouragingorganic and sustainable practices
- Protectingnatural habitats:

11. Climate-crop-hydrological-socioeconomic Models

These models study the interactions between climate, crop production, water resources, and socioeconomic factors. These models are particularly useful for assessing the sustainability of agricultural systems and can guide policy decisions, adaptive strategies, and future planning. It can also assist in crop management, environmental characterization and agroecological zoning. It will be useful in estimating potential production and yield gap analysis. Strategic and anticipatory decision making including developing breeding strategies, identifying crop potential zones for land use planning are some other beneficial aspects of such models. It also has application in: Indoor crop management, hi-tech horticulture; Crop insurance; Weather-based horti-advisory; Research priority setting; Local and regional planning and policy implications.

12. Community-Based Approaches

Community-Based Approaches for Climate-Smart Agriculture (CSA) refer to strategies that involve local communities in planning, decision-making, and implementation of agricultural practices that enhance resilience to climate change while improving productivity, reducing emissions, and supporting sustainable development. It includes:

- Afforestation initiatives
- Agroforestry systems
- Mass adoption of Natural farming, Organic practices
- Using indigenous varieties, local land races
- Diversified Farming Practices
- Local Resource Management
- Climate-Smart Technologies: Community based CSA

13. Govt. Programmes & Schemes

Government of India has formulated schemes/plans to make agriculture more resilient to climate change. The National Mission for Sustainable Agriculture (NMSA) is one of the Missions within the National Action Plan on Climate Change (NAPCC). The mission aims at evolving and implementing strategies to make Indian agriculture more resilient to the changing climate.

Indian Council of Agricultural Research (ICAR), Ministry of Agriculture and Farmers Welfare, Government of India launched a flagship network research project 'National Innovations in Climate Resilient Agriculture' (NICRA) in 2011. The project aims to develop and promote climate resilient technologies in agriculture, which addresses vulnerable areas of the country and the outputs of the project help the districts and regions prone to extreme weather conditions like droughts, floods, frost, heat waves, etc. to cope with such extreme events

Conclusion

Climate-resilient horticulture is essential for ensuring sustainable food production in the face of changing climatic conditions. Innovations such as climate-smart varieties, precision farming, protected cultivation, and integrated resource management play a crucial role in enhancing crop resilience. Strategies like efficient water use, soil health improvement, and digital tools for climate monitoring further strengthen adaptive capacity. By integrating scientific advancements with traditional knowledge, horticultural systems can be made more robust and productive. A collaborative approach involving researchers, policymakers, and farmers is key to successfully implementing climate-resilient practices, ensuring food security, economic stability, and environmental sustainability.

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Empowering Women through Climate Smart Animal Husbandry Practices

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Women play a vital role in livestock farming, particularly in rural communities across the world. In many regions, they are the primary caretakers of animals, contributing significantly to food production, income generation, and the sustainability of their households. Despite this, women's contributions in livestock farming are often undervalued and remain unrecognised. Women engage in livestock farming, face multiple challenges. Empowering women in this area is crucial for improving food security, livelihoods, and promoting gender equality in agriculture. Before understanding the strategies to empower women it is a prerequisite to understand what roles women in animal husbandry and what challenges they face.

Roles of Women in Livestock Farming

Women's roles in livestock farming vary by region and culture but typically involve a range of activities:

Care giving activity: Women are often the primary caregivers for animals, managing feeding, milking, and breeding. They are the ones who ensure that animals are healthy and productive, especially in smallholder and subsistence farming systems. Women typically gather or grow feed for animals, manage grazing areas, and ensure that the animals have a steady supply of food, which directly impacts livestock productivity. They also manage animal health, administering medicines, monitoring for signs of disease, and seeking veterinary care when necessary. They are integral in maintaining the health and well-being of livestock (Usman et al., 2022).

Milk Production, Processing and Marketing: In many parts of the world, women are responsible for the production of dairy products, including milking cows, goats, and sheep, processing milk into cheese, yogurt, or butter, and marketing these products. women play a key role in the marketing of livestock products (milk, eggs, meat, wool, etc.). They provide a crucial income stream for their households. They may also sell live animals for income.

Challenges Faced by Women in Livestock Farming

Despite their central role, women face several challenges in livestock farming.

Limited Access to Input: In many regions, women have limited access to land ownership, which can restrict their ability to raise livestock effectively. Even where they are the primary caretakers, they may not have legal rights to the land on which they farm. They often have less access to credit, loans, and financial services, which limits their ability to invest in livestock, equipment, and improvements in farming practices. Access to modern farming tools, veterinary care, quality animal feed and improved breeds of livestock is limited for women. This restricts their ability to increase productivity and improve livestock health.

Gender Norms and Social Barriers: Women often have to juggle livestock farming with other household responsibilities, including childcare, cooking, fetching water, and collecting firewood. This "double burden" of domestic and economic tasks can limit the time and energy they can devote to livestock management. In many societies, women's roles in livestock farming are undervalued, and they may have little decision-making power in matters such as livestock sales, pricing, and resource allocation. In some cultures, livestock ownership and management may be viewed as a male-dominated responsibility, leaving women excluded from certain aspects of the farming process, such as inheritance or ownership of livestock.

Lack of Training and Information: Women often have less access to agricultural extension services, training, and information about new livestock management techniques, climate-resilient practices, or market opportunities. This knowledge gap can hinder their productivity and income potential.

Because of all these challenges the animal husbandry practiced by women farmers are not environmentally sustainable and economically viable.

Sustainable Livestock Farming

Sustainable livestock farming focuses on raising animals for food production while prioritizing environmental sustainability, social responsibility, and economic viability. It seeks to meet current demands for animal-derived products while ensuring long-term ecosystem health, community well-being, and animal welfare. Sustainable practices minimize environmental impacts, promote ethical treatment of animals, and support local economies, ensuring profitability for farmers (Cheng et al., 2022). When selecting livestock breeds, considerations include the local climate, intended use (meat, milk, or labor), available resources, and market needs. Breeds should be chosen for traits like disease resistance, high productivity, and efficient resource use. It's essential to select breeds adapted to regional conditions, as this improves animal health, enhances productivity, and strengthens the resilience of agricultural systems. Sustainable breed selection supports both food security and the long-term viability of farming, ensuring that livestock farming can thrive while preserving resources for future generations. For sustainable farming and livestock welfare, proper animal nutrition and effective forage management are crucial. Providing a balanced diet that meets an animal's specific nutritional needs, based on factors like age, breed, and purpose, is essential. Forage management involves cultivating, harvesting, and storing high-quality feed, improving animal welfare, enhancing productivity, reducing costs, and minimizing environmental impacts (Spiller et al., 2023).

Efficient waste management and resource utilization also play a key role in sustainable livestock farming. By minimizing waste, reusing resources, and recycling the byproducts, environmental pollution is reduced, and valuable resources such as water and nutrients are conserved. Practices like composting soil health can be improved, and ecological footprint of animal husbandry can be reduced. Ethical animal welfare involves treating animals with respect and care, ensuring appropriate housing, nutrition, and medical care while minimizing stress and pain. To address antibiotic resistance and environmental harm, reducing the use of antibiotics is necessary.

Women farmer as a primary care taker of livestock devoid of these scientific animal husbandry practices which reduces profit and results loss to people and planet.

Interrelationship between Climate Change and Livestock Farming

Livestock's Contribution to Climate Change

Livestock and climate change are deeply interconnected, as the livestock sector both contributes to and is impacted by climate change. Understanding this relationship is crucial for addressing environmental challenges and promoting sustainable agricultural practices. The livestock sector is a significant source of greenhouse gas (GHG) emissions, contributing to global warming and climate change.

Methane Emissions (CH_4): Ruminants like cows, sheep, and goats produce methane, a potent greenhouse gas, during digestion through a process called enteric fermentation. Methane has a much higher global warming potential than carbon dioxide over a short period (25-28 times more powerful over 100 years). The growing demand for animal-based products has led to an increase in livestock numbers, which consequently raises methane emissions.

Land Use Change: Large-scale industrial animal farming can lead to the conversion of land for feed crops, further contributing to deforestation and land degradation. Clearing forests for grazing land or growing animal feed (e.g., soybeans) leads to deforestation. This destroys carbon sinks and releases carbon dioxide stored in trees into the atmosphere.

Nitrous Oxide (N_2O): Manure management and fertilizer use in pasture and feed crop production result in the release of nitrous oxide, another potent greenhouse gas. Manure decomposition can produce nitrous oxide, especially in intensive livestock systems that store manure in pits.

Energy Use and Feed Production: Farming practices and infrastructure in livestock production often require significant energy for machinery, transport, and processing. The cultivation of feed crops (like corn, soy, and alfalfa) can involve high energy inputs and fertilizer usage, which indirectly contribute to GHG emissions.

Climate Change Affects Livestock

Livestock farming is highly vulnerable to the impacts of climate change, and these challenges are expected to grow over time. Increased temperatures and more frequent heatwaves can lead to heat stress in animals, reducing their productivity (e.g., lower milk yield, slower growth, and reduced reproduction rates). Animals are more vulnerable in areas where climate change causes extreme temperatures that are beyond their tolerance (Rojas-Downing et al., 2017). Droughts and changing rainfall patterns can reduce access to water for both livestock and crops used for their feed (Godde et al., 2021). Water scarcity can lead to poor health and productivity in animals, as well as competition for water resources between livestock, agriculture, and humans. Droughts, floods, and extreme weather also reduce the availability and quality of pastures and animal feed crops. Reduced productivity of feed crops like corn, barley, and alfalfa can increase feed costs and decrease animal health due to nutrient deficiencies. Rising temperatures and altered precipitation patterns can expand the range of many livestock diseases and parasites (such as ticks, flies, and foot-and-mouth disease). New climate conditions may lead to the emergence of diseases previously confined to certain regions, putting livestock at greater risk. Extreme weather, water shortages, and disease outbreaks can increase the costs of raising livestock, making it harder for farmers to maintain profitability.

Mitigation Strategies in Livestock Production
To reduce the environmental impact of livestock farming and adapt to changing climate conditions, several climate-smart practices can be implemented.

a. Feeding Intervention

- High-quality feeds with better nutritional value can reduce methane emissions per unit of animal product (e.g., meat, milk). Improving digestibility and protein content can help animals grow faster and use less feed.
- Feed additives, such as those that reduce methane production in ruminants, can also be used to reduce emissions.
- Rotational grazing systems, where livestock move between different pasture areas, can improve soil health, increase carbon sequestration, and enhance pasture productivity.
- Agro-forestry (integrating trees into grazing systems) helps store carbon, improve soil quality, and provide shade for animals during hot weather.
- Use of complete feed block, hydroponic fodder, urea-molasses block etc. can be practised.

b. Breeding intervention (Climate-Resilient Livestock Breeds)

- Breeding livestock for climate resilience, such as selecting animals that are better adapted to hot climates, drought-prone areas, or disease-resistant traits, can help maintain productivity despite environmental changes.

c. Manure Management

- Implementing better manure management practices, like using anaerobic digesters to capture methane for energy, can help reduce emissions and improve farm energy use.
- Proper composting and spreading of manure can reduce nitrous oxide emissions and enhance soil fertility.

d. Integrated Farming Systems

- Combining livestock farming with crop production, such as growing forage crops or integrating agroecological practices, can diversify farm income and reduce vulnerability to climate shocks.

e. Health Management

- Digital Technology like use of sensor based neck collar and other wearable technologies, drone, sensor based mobile apps, Near-infrared devices for nutritional management, block chain technology etc. can be employed apart from routine vaccination and deworming.

Empowering Women in Livestock Farming

Women workforce in livestock is rising with time (Vijayamba and Swaminathan, 2024). Empowering women in livestock farming not only improves their livelihoods but also contributes to broader community development and sustainability. Providing women with access to credit, loans, and insurance help them invest in livestock, veterinary care, and sustainable farming practices. Microfinance programs targeted at women can significantly improve their ability to access financial resources. Ensuring that women have access to agricultural extension services that offer information, advice, and support on best practices in livestock farming is essential. These services should be gender-sensitive and tailored to women’s needs. Women often lack access to formal markets for selling livestock products. Building women’s capacity to participate in market systems, through cooperatives or market information systems can help them achieve better prices for their products and reduce market-related risks. Providing women with training on modern farming techniques, animal health, disease management, and climate-smart livestock practices equips them with the skills needed to increase productivity. Supporting women to diversify their livestock-based products, such as producing cheese, yogurt, or wool goods, can increase their income and make them more competitive in local and regional markets. Women are often key adopters of sustainable farming practices. When equipped with the right knowledge and tools, they are more likely to implement environmentally friendly livestock management techniques.

Conclusion

Livestock farming both contributes to and is affected by climate change. Reducing greenhouse gas emissions from the sector through sustainable practices is essential, while adapting to the changing climate is necessary for continued viability. Women play a crucial role in livestock farming, yet their contributions are often overlooked, and they are often unaware of available climate-smart technologies. By providing women with access to resources, education, and decision-making power, we can harness their full potential to improve both productivity and environmental resilience. Empowering women in livestock farming enhances their livelihoods, strengthens food system resilience, and contributes to broader social and environmental goals, promoting sustainable agricultural practices that benefit both farmers and the planet.

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Improved Input Use Efficiency Through Sustainable Agricultural Mechanization

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Agriculture is the backbone of many economies, providing food, employment, and raw materials for industries. However, challenges such as declining soil fertility, water scarcity, and labor shortages necessitate the adoption of efficient and sustainable farming practices. One such approach is sustainable agricultural mechanization, which enhances input use efficiency while reducing environmental impacts.Farm mechanization is crucial to boost input use efficiency along with increased production and productivity The farm mechanization level in India is 40 % with average 2.24 kW/ha farm power availability. On the other hand, Punjab has reached 4.4 kW/ha whereas in the hills of Uttarakhand, it is 1.05 kW/ha. (Modi, R.U. *et.al*., 2020). Hence, there is need for location specific targets, target specific objectives.

What is Sustainable Agricultural Mechanization?

Sustainable agricultural mechanization refers to the use of energy-efficient and environmentally friendly machinery and tools to optimize farm operations. It integrates precision technologies, renewable energy sources, and conservation techniques to maximize productivity while minimizing waste and resource depletion.

Benefits of Sustainable Agricultural Mechanization:

1. **Enhanced Input Efficiency**: Mechanized farming improves the precise application of inputs such as seeds, fertilizers, and water. Technologies like precision seed drills, variable rate applicators, and drip irrigation ensure optimal use, reducing wastage and enhancing crop yields.

    a) **Fertilizer usage:** Research has shown that precision agriculture technologies can reduce 20% and 15% cost of crop protection and fertilizer usage, respectively, without compromising productivity. There is a positive relationship between the adoption of PA and farm returns for larger-scale farms. (Sanyaolu, M. and Sadowski, A. 2024). Compared to uniform fertilizer treatments, variable-rate fertilizer applications reduced the amount of nitrogen fertilizer used by 56% and 50% in 2012 and 2013, respectively (Aggelopoulou, K.D., 2011).

    b) **Water usage:** Studies by Lakshmi et. al. found a 46% decrease in water consumption and higher crop yield using an SIS compared to a conventional watering system.Laphatphakkhanut et al. used an IoT-based SIS and found water usages were decreased by 40.29% (alternating wet and dry) and 29.22% (basin irrigation) compared to the traditional irrigation method. Barkunan et al. reported a 41.5% (conventional flood) and 13% (drip irrigation) reduction in water usage for paddy cultivation using an automated drip irrigation system. Additionally, FAO (2019) highlights that laser land levelling can improve water use efficiency by 25-30%, significantly reducing irrigation demands. Another study by Jat *et al.* (2020) highlights that conservation agriculture-based Rice-Wheat and Maize-Wheat systems enhanced the crop productivity by 10 and 16%, water productivity by 56 and 33%, and profitability by 34 and 36%, while saving in irrigation water by 38 and 32%, compared with their respective Conventional Tillage based systems, respectively.

2. **Reduced Labor Dependency**: Labour is the largest cost component in agriculture and a key limiting factor in the growth of agricultural industries worldwide. Labour shortages negatively impact farmer revenue, crop yields, and long-term sustainability. In regions with low wages, the transient nature of the workforce further reduces production capacity and quality. Additionally, certain manual tasks pose risks of musculoskeletal disorders and chronic health issues for workers. With rising labor costs and shortages, mechanization helps in timely and efficient farm operations, ensuring higher productivity with minimal manual effort. In a survey taken in the mid-1970s, bedding plant growers attributed about 25% of plant production costs to labour (Aldrich & Bartok, 1992). Bechar and Vigneault (2016), studied that in Southern Spain, the labour cost for greenhouse production of tomato, lettuce, pepper, melon, watermelon, squash, cucumber and bean amounts to 36-40% of the total cost, hence automation and robotics in agriculture reduce dependency on manual laborthus saving the cost up to 40%, leading to more efficient production. Studies by Caunedo, J. and Kala N. 2021 found that, family labor decreases in response to the subsidy and farmers reduce hired labor in all farming processes, including those not directly affected by mechanization. They document that family labor is mostly occupied in supervision activities, likely due to contracting frictions, and that their lower engagement in farming is associated with higher non-agricultural income. Lakhiar, I.A., *et. al*., 2024 stated that smart irrigation systems can eliminate the requirement for the manual data collection of several variables. They can help reduce the labor engaged in field data collection, data collection errors, and the entire operational efficiency of the system. Conservation agriculture reduces labour requirements by about 50%, and particularly the heavy work of soil tillage and deep cultivation is eliminated (Bishop-Sambrook, C., 2003)

3. **Soil Conservation**: Conservation agriculture tools such as zero-tillage planters and laser land levelling minimize soil disturbance, enhance moisture retention, and reduce water consumption. Research by Derpsch *et al.* (2014) suggests that no-till farming, when combined with mechanization, reduces soil erosion by up to 90% while increasing soil organic matter. Due to erosion during last 40 years, about 30 % of the world's arable land has become unproductive and most of it has been abandoned for agriculture.The soil loss with surface mulch can be reduced by up to 50%. Mean runoff and soil loss with CA plots were ~45 and ~54% less, respectively than conventional agriculture plots.

Effect of conservation agriculture impact on crop productivity and conservation efficiency on a land with 2% slope at Dehradun, India

Particulars	**Conventional agriculture**	**Conservation agriculture**
Water loss (% of rain)	39.8	21.9
Soil loss (t ha^{-1} yr^{-1})	7.2	3.5
Grain yield of maize (kg ha^{-1})	1570	2000
Grain yield of wheat after maize (kg ha^{-1})	950	1700
Weed biomass for mulching (kg ha^{-1} yr^{-1})	-	2100

Moisture conservation for wheat (mm) compared to fallow	28.1	58.5

(Source: Singh., Y., 2020)

4. **Lower Carbon Footprint**: The adoption of energy-efficient machinery, solar-powered irrigation systems, and electric tractors reduces greenhouse gas emissions, contributing to climate change mitigation. According to Smith et al. (2020), mechanized conservation agriculture practices lower fuel consumption and CO2 emissions by 30-50% compared to conventional methods. Renewable energy-powered farm equipment, as highlighted by Lal (2018), also plays a critical role in reducing agriculture's overall carbon footprint. According to a study carried out by Bora *et al.* (2012) in North Dakota, United States, it was discovered that 34% of farms utilizing GPS guidance systems reduced fuel consumption by 6.32% and machine time by 6.04%, saving 1647 L of gasoline (USD 1305) per farm. Additionally, 27% of farms utilizing auto steering systems lowered fuel consumption by 5.33% and machine time by 5.75%, saving 1866 L of gasoline (USD 1479) per farm.According to World Economic Forum predictions, precision agriculture could cut greenhouse gas emissions by 5–10% by 2030 if the technology is installed on 15–25% of farms. In addition, a report by Soto et al. (2019) states that precision agriculture lowers agricultural greenhouse gas emissions in Europe by 1.5% to 2%. The key method used for this is variable rate application, which helps to decrease N2O emissions by providing plants with the exact amount of fertilizer they need (Marechal, A., 2022).

   Higher Economic Returns: By improving efficiency and reducing input costs, mechanization boosts farmers' income and supports sustainable rural livelihoods. Studies by Pingali (2012) indicate that farm mechanization can increase crop yields by 15-25%, translating into higher profits for farmers. Furthermore, mechanized post-harvest technologies, as reported by Hodges *et al.* (2011), significantly reduce post-harvest losses, increasing marketable surplus and economic gains.

Key Technologies for Sustainable Mechanization:

1. **Precision Farming Tools**: GPS-guided tractors, drones, and variable-rate technology (VRT) optimize input application and reduce waste. Research by Gebbers and Adamchuk (2010) highlights that precision farming can increase yields by 10-15% while reducing input costs by up to 20%. Additionally, Bongiovanni and Lowenberg-DeBoer (2019) suggest that site-specific nutrient management improves soil health and enhances long-term sustainability.

2. **Conservation agriculture**: It is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. (Friedrich, T., et. al., 2009). CA is characterized by three sets of practices which are linked to each other in a mutually reinforcing manner, namely:

a. **Continuous no- or minimal mechanical soil disturbance** i.e., direct sowing or broadcasting of crop seeds, and direct placing of planting material in the soil; minimum soil disturbance from cultivation, harvest operation or farm traffic; the disturbed area must be less than 15 cm wide or 25% of the cropped area (whichever is lower). No periodic tillage that disturbs a greater area than the aforementioned limits;

b. **Permanent organic matter soil cover**, especially by crop residues and cover crops; soil cover should ideally be above 100%, measured immediately after the planting operation. Ground cover of less than 30% is not considered as a CA practice;

c. **Diversified crop rotations** in the case of annual crops or plant associations in case of perennial crops, including legumes. Rotation should involve at least 3 different crops. However, monocropping is permissible as long as no other related problems occur.

3. **Renewable Energy-Powered Equipment**: Solar-powered irrigation systems, wind-powered grain dryers, and biomass-fuelled machinery reduce reliance on fossil fuels. According to Burney *et al.* (2010), solar-powered irrigation reduces diesel dependence by 40-60%, leading to significant cost savings for farmers. Studies by FAO (2021) indicate that renewable energy-powered farm operations can lower greenhouse gas emissions by up to 50% compared to conventional mechanization methods.

4. **Eco-Friendly Harvesting Machines**: Mechanized harvesters with advanced threshing and sorting technologies minimize post-harvest losses and improve grain quality. Research by Kumar and Kalita (2017) suggests that post-harvest mechanization reduces grain losses by 30-40%, increasing profitability for farmers. Additionally, smart harvesting technologies, as highlighted by Silalertruksa*et al.* (2017), improve efficiency and reduce environmental impact.

5. **AI and IoT-Based Monitoring**: Smart sensors, automated irrigation controllers, and AI-driven analytics enhance real-time monitoring of soil health, crop growth, and weather conditions. According to Wolfert *et al.* (2017), IoT-based smart farming solutions can improve resource efficiency by 25-30%, reducing costs and improving productivity. AI-driven predictive analytics, as studied by Kamilaris et al. (2018), enhance decision-making, leading to more precise and sustainable farm management.

Challenges and the Way Forward:

While sustainable agricultural mechanization offers numerous benefits, several challenges hinder its widespread adoption:

1. **High Initial Investment Costs**: Advanced mechanization technologies require significant capital investment, which is often unaffordable for small-scale farmers. Financial incentives such as subsidies, low-interest loans, and cooperative models can facilitate access to these technologies. According to Sanyaolu, M. and Sadowski, A., 2024, only the largest farms in the use of precision farming technologies were profitable. They suggested that, public support in the form of investment subsidies can significantly increase the number of farms and the area where it can be applied.

2. **Lack of Technical Knowledge and Training**: Many farmers lack the necessary technical skills to operate and maintain modern agricultural machinery. Expanding

training programs, extension services, and digital education platforms will be crucial in addressing this gap.

3. **Inadequate Infrastructure**: Poor rural infrastructure, including inadequate roads, electricity supply, and storage facilities, limits the effectiveness of mechanization. Investments in rural infrastructure development, such as electrification and logistics improvements, will enhance mechanization adoption.
4. **Limited Availability of Mechanized Services**: In many developing regions, access to mechanized services is restricted due to the unavailability of service providers. Promoting business models such as machinery-sharing cooperatives and pay-per-use services can increase accessibility.
5. **Environmental and Sustainability Concerns**: While mechanization improves efficiency, improper use can lead to soil degradation, increased fuel consumption, and environmental harm. Policies promoting eco-friendly technologies, precision farming, and conservation practices are essential for sustainable mechanization.
6. **Policy and Institutional Barriers**: The absence of clear policies, regulations, and incentives for mechanization hampers its expansion. Governments should establish supportive policies, including tax exemptions, research funding, and public-private partnerships to drive mechanization efforts.

Conclusion:

Sustainable agricultural mechanization is a game-changer for modern farming. By improving input use efficiency, reducing environmental impacts, and increasing economic returns, it paves the way for a more resilient and productive agricultural sector. Investments in innovative technologies and farmer training will be crucial in driving the widespread adoption of sustainable mechanization, ensuring food security and environmental sustainability for future generations.

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Empowering Farm Women through Enhanced Productivity of Goats by Adoption of Nutritional Interventions in Climate Resilient Animal Husbandry

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Introduction

Goat farming system plays a major role in sustenance of livelihoods of landless and small and marginal farmers, where crop production is a risk prone enterprise due to climatic adverse situations. The animals are reared under extensive system of grazing accustomed with high climatic stress wherein they cope up through physiological and behavioural adjustments, reproduce and survive. If the stress is dramatic, it might lead to increased stress on the animal's homeostasis, leading to reduced productivity and affecting its reproduction. Although climate change is a global occurrence, its negative impacts are more severely felt by poor people in developing countries who rely on the natural resource base for their livelihoods. Goats are more vulnerable to climate change as they are reared by poor, unprivileged landless/ marginal farmers under an extensive system of production. The impact of climate change on animal production is apparent in breed composition, population, and distribution, feed and fodder scarcity, shrinkage of grazing land, reproductive and productive disorders, the spread of diseases, poor performances, consumer demand, and market trend for meat, milk, and fibre, etc. The shift in population trend of goats in India is also a reflection of a climate-change impact besides other socio-economic and demand-driven policy and marketing issues. The frequent drought and famine situations and continuous decline of grazing resources, both in terms of quality and quantity are the persistent factors for this change. The impact on availability of feed, fodder and nutrient metabolism and health status of animals is adverse if the climatic changes and subsequent stress continue resulting huge economic loss to poor farming community.Feed availability was identified as one of the major constrains for small ruminant systems. Meeting the growing demand for animal-sourced food, prompted by population growth and increases in average per-capita income in low-income countries, is a major challenge. The main constraints to livestock producers taking advantage of growing markets include; lack of forage and feed gaps, communal land tenure, limited access to land and water resources, weak institutions, poor infrastructure and environmental degradation. Sustainable diets and feed systems have a potential for maintaining profitability of feed system while reducing their negative environmental and social impacts.

Effect of adverse climate on animal physiology and productivity

The impact of climate change in goat production system is found to be more due to dependence on grazing in an extensive system of production where as in intensive system of production, the impact is less severe and indirect but rearing of animals increase the production cost. However, other impacts are the emergence of livestock diseases, higher temperature and changing rainfallpattern, alter the abundance, distribution and transmission of pathogens Availability of the water is the major constraint that affects the animal production due to depletion of feed/fodder resources setting in migration process thereby putting pressure in limited resources available in adjacent area as well as chance of spread of diseases. Further, depending on the duration and severity of drought, the production and reproduction performance of the small ruminants are compromised as prolonged drought puts these animals under thermal, nutritional and water stress as well as to move long distances for want of feed and water leading to the disruptions in maintaining homeothermy, endocrine systems etc. Thermal stress leads to excessive heat dissipation through sweating and evaporative water loss, increases turnover of Na and K, elevated prolactin concentrations, lowered metabolic rate in chronic stress as evidenced by lower concentration of growth hormone, thyroxin and glucocorticoids in blood. Feed intake lowers as the environmental temperature reaches upper critical level. With reduction in feed resource availability, goats prefer for selective feeding thereby leading in depletion of nutritive herbs and shrubs with spreading of weeds and toxic plants. If drought is prolonged, animals are forced to feed on toxic plants which end up in nutritional/mineral imbalances. Protein is the first limiting nutrient in many grazing forages, particularly in hot humid climate and protein availability declines in forages as the plant matures towards the end of winter season. The animals decrease the nitrogen losses particularly when they are in low nitrogen intake regime conserving the nitrogen through efficient recycling of urea in the gut. Further, if rainfall follows period of drought, there is chances of nitrite poisoning in small ruminants. The excessive intake of forages containing nitrates which leads to methaemoglobinemia thereby resulting in muscle tremors, staggering, rumen paralysis and animal eventually dies. As climate change alters the rate of precipitation, increases solar radiation, heat waves and drought conditions, so pasture based animals like goats are affected. Basic physiology of the rumen and the nutritional status of ruminants alter under high ambient temperature conditions. Extreme heat reduces volatile fatty acid (VFA) production in rumen. Altered rumen fermentation results excess enteric methane (CH_4) emission. This adds to global warming and greenhouse effect. Sheep and goats are considered as seasonal breeder. They get cue from environmental factors to show estrus behaviour. Climate change altered their seasonal behaviour, prolonged the anoestrus period. High ambient temperature results reduced feed intake and increased stress that also results early embryonic mortality, birth of dead or under-weight kids reducing the profitability of farmers (Tufekci and Tozlu, 2021). The multiple stresses (thermal, nutritional and walking stress) had more adverse consequences that individual stress (Sejian et al., 2012). Small ruminant use multiple strategies to cope with climate change and its adverse effects. Their inherent adaptive quality like small size to reduce the radiant heat received from sun and surrounding sources, behavioural plasticity, feeding behaviour and excellent feed conversion efficiency, and low cost rearing make goats for livelihood and food security of millions.

Adaptation strategies for sustenance of animals in adverse climate

Small ruminants exhibit wide range of adaptive strategies to cope with climatic fluctuations i.e. behavioural, physiological, biochemical and genetic/morphological mechanisms. Under high temperature fluctuations they seek shelter and under cold and shaded areas they reduce their feed intake, increase water intake, decrease number and frequency of rumination increase sweating rate and reduce the quantity of urination and defecation. Under high ambient temperature they increase their heart rate and respiration rate. This helps in pumping more blood to periphery for efficient evaporative cooling. Vasodilatation of peripheral blood vessels helps in reducing heat load. In heat stressed animals rectal temperature also increases. Increase in PCV and haemoglobin, reduced thyroid hormone secretion are adaptive strategies to heat stress. Goats efficiently utilize wastelands, stubbles of cultivated corps, tree tops, farm wastes, weeds and convert them into meat, milk, fibre, skin, and manure. Animals which are hardy and more adapted to harsh climate condition may thrive well while others may either shift to the more suitable region or suffer stressful environment. Adverse climate condition is known to influence more severely to non-adapted and high producing goats. Extreme ambient temperatures may hamper the homeothermy of these most adaptive animals although they are well adapted to extreme climatic variables of arid and semi-arid regions. Many strategies including feeding and nutrition, strategic micronutrient supplementation, shelter management practices are delineated to counter thermal stress and production decline in small ruminants. Climate change has induced poor health and increased susceptibility to diseases which are adding to the cost of production (Shinde and Sejian, 2013). Exposure of animals to high ambient temperature in extensive rearing practice cannot be avoided and this leads to disturbance in animals normal physiological functioning and behaviour, viz. reduced feed and water intake, alteration in blood metabolites, plasma hormonal and enzyme levels and a negative impact on production, immunity, and welfare (Sahoo et al., 2013). Therefore, it is essential to explore new initiatives that could be simple, affordable, reducing the heat stress of animals. Catalytic supplementation of mineral mixture and antioxidants in concentrate mixture is reported to protect Malpura ewes against the adverse effect of heat stress on productive and reproductive efficiency (Sejian et al., 2014). Similarly, selenium-enriched yeast can be fed to improve resilience against heat stress during extreme summer and improve the reproductive performance of ewes. Moreover, seasonal variation has a severe impact on physiological responses to maintain thermo-regulations as evident from significant variation in physiological responses (De et al., 2017). Although the native breed is well adapted to the semi-arid tropical climate, they need protection during peak temperature and shelter at night during the winter season to maintain their body temperature and hence production.Adaptation to the changing climate is essential to maintain the productivity through technological back stepping, behavioral modifications, and managerial choice. The strategies should be focused on ensuring survival of livestock farmers with minimal loss of productivity as well as optimizing available resource utilization with minimal number of animals with no loss of reproductive efficiency and ability to augment the production optimally after the end of the drought (Ramachandra, 2009). The adaptation to climate change can be possible through following scientific managements through nutritional maneuvering.

Role of women in Goat farming for enhanced productivity in changing climate

Women form the backbone of agriculture and play a significant role in small ruminant farming. Even though women in India do most of the work in animal production, their work remains mostly invisible. Gender divisions in agriculture are stark, with all activities involving manual labour assigned to women, while all operations involving machinery and drought animals are generally performed by men. Small ruminants provide opportunities to capitalize on underutilized family labor. As the income from these livestock species is less seasonal, farmers, particularly women, depend on these animals as a vital source of income for household essentials, including payment of school fees and medical expenses. Goats also serve to empower women who have important and varied roles in raising them in many low and middle-income countries. Furthermore, income from goat farming allows farmers to make better dietary and health choices and provides the necessary resources. Various schemesand programsfrom Govt., and NGOs are being implemented to empower farm women. However, most of the farm women are illiterate and neglected or excluded from the mainstream development programs. Generating awareness, motivating, and mentoring through skill-based capacity development programs are most essential for ensuring their participation in the development programs. Women entrepreneurship in India is being recognized as a major initiatory source of economic growth leading a pathway for economic empowerment of farm women. Special attention needs to be oriented towards the role of women and enhancing their income through suitable community based technological interventions to empower farm women and make themself-sufficient, economically stable with independent decision making, better purchasing power and socio culturally more active abilities. Therefore, the challenge is to develop a novel amalgamated mechanism involving all stakeholders (researchers, extension workers, NGOs, and farmers) to provide a better environment to enable that developed technologies are need based and women friendly and hence increase the likelihood of adoption by the farm women for their upliftment. India has a rich diversity of small ruminant genetic resources having 223.14 million (148.88 million goats and 74.26 million sheep) (20th livestock census, 2019) mostly found in arid and semi-arid regions of the country. About 75 % of rural households are small and marginal farmers own 62 % of small ruminants contributing 4.8 and 3.4% of total world meat and milk production (Karim and Sahoo, 2012). The productivity of animals under the prevailing traditional production system is very low as they are maintained under the extensive system on natural vegetation on shrinking degraded common grazing lands and tree lopping. Moreover, adoption of improved production technologies/ management practices in the farmers' flock is very low. Therefore, rearing of small ruminants under intensive and semi-intensive system using improved technologies for commercial production has become imperative not only for realizing their full potential, but also to meet the increasing demand of meat in the domestic as well as international markets. The animal production system in India has been slowly moving from extensive to intensive system of management for commercial production and entrepreneurship development by farm women in which nutritional interventions play significant role contributing 60-70% of cost of production. However, inadequate availability and poor quality of feed and fodder, high incidence of diseases and inadequate knowledge on appropriate management of livestock were identified as the major problems in small ruminant production system (Joy et al., 2020). A favourable policy environment in terms of access to micro-credit, assured market and veterinary services will have to be provided and socio-economic and technical constraints needs to be addressed to enable farm women for livestock development.

The farmers adopted commercial farming which helped in increasing the productivity of small ruminants and bridging the demand-supply gap. However, use of improved technologies, particularly prophylaxis, superior germplasm, low-cost feeds and fodders and innovative marketing of the produce would be the pre-conditions for successful commercial production. Since sheep and goats are very well adapted to harsh environmental conditions, producers use them to diversify their livestock management portfolio and to decrease their risk in case of adverse weather conditions. Small ruminants protect the producer's capital against inflation and enable them to restock his farm when the environmental conditions improve. Another factor that decreases the investment risk in sheep and goats is their much shorter reproduction cycle that gives them the capability to rebuild population numbers much faster than large animals. Lack of improvement in the productivity of sheep and goats is often attributed to the lack of skilled labour. Most of the labour is provided by the family. The person responsible for the day-to-day care varies widely depending on cultural factors, the number of animals, the production system (extensive or intensive) and other reasons. The role of women in the case of sheep and goats varies considerably depending on the country, region, ethnic groups, etc. In many places women not only take care of the animals but also own them and market them. As production systems become more sophisticated, so do management skills. This is one of the most serious constraints in achieving higher production rates. Training and technology transfer, adapted to women's schedulescovering all aspects of production management may solve the problem.

During the initial phases of the animal farming, high mortality in sheep/goats due to PPR, diarrhoea, pneumonia, tetanus, etc. is a major concern of women farmers due to lack of knowledge about complete package of practices of improved goat farming, poor prophylaxis, non-availability of vaccines etc., poor preparedness, lack of personal attention of the entrepreneurs and poor access to veterinary doctor with experience of small ruminants. Difficulty in getting decent quality breeding animals is also a major constraint. The best male animals from the traditional flocks were sold for slaughtering to traders resulting in scarcity of quality breeding animals. Lack of organized efforts for breed improvement has been compounding this problem. Since large flocks of different breeds under commercial production are only few, the entrepreneurs had to select the breeding animals from the available traditional flocks mostly through intermediaries. Therefore, it takes a long time to establish a good flock. Non-availability of vaccines in time is another major constraint. The trade of live animals which is unorganized and is in the hands of a large number of intermediaries, traders and butchers, does not favour farmers. The live animals were sold not based on their body weight in the livestock markets resulting in under-estimation of the value of live animals. The availability of institutional credit was easy for large projects but was another constraint for the small women entrepreneurs with projects of 50-100 sheep or goats having lack of ownership of land and limited capital for collateral security.

Small ruminant production facets like decision-making, ownership, labour allocation, access to- and control over assets are gendered. Production tasks around small ruminants such as feeding, watering, selling milk and cleaning housing structures were mostly performed by the women. The prevailing gender dynamics and practices around livestock production substantially influence the ability of intervention programs aimed at empowering women using livestock assets (Farnworth et al., 2018). Gender dynamics and practices around decision-making, labour allocation, asset ownership, access to- and control over resources affect the success of women empowerment programs (Njuki and Sanginga, 2013). Women’s access to and control over productive resources, and their ability to access and use income from the sale of small ruminants are also influenced by the existing socio-cultural norms (Team and Doss, 2011; Farnworth et al., 2016;Maiorano et al., 2021). The gender dynamics and practices affect the success of intervention programs seeking to empower women through livestock production and it is therefore important to identify gender gaps and disparities that should be targeted or considered by interventions to uplift and empower women farmers. Small ruminant production is an important activity that complements other income-generating activities in the household. Women can only attain self-efficacy if they are supported to not only own small ruminants but also have control over financial and decision-making rights. Since ownership patterns of small ruminants tend to change over time, efforts should be directed towards ensuring women are not just ‘owners’ of small ruminants but also decision-makers on household livestock assets, access income and derive benefits from the livestock assets (Kristjanson et al., 2014).

Enhanced Productivityof Animals: Issues and approaches

Small ruminants are widely distributed and are of immense importance as a major source of livelihood of rural communities. Age at first parturition, parturition interval and litter size determine lifetime production as well as efficiency of production which can be improved because they are under the influence of environmental and ecological factors. These effects are clearly related to nutrition, health and management.For starting and maintaining a profitable and successful small ruminant farming, strategic planning is required (Caja et al., 2020).

Feed resources and feeding: Feeding management is essential for commercial farming. The natural ability of goat to eat a wide variety of vegetation and waste has been, in fact, a big motivating factor for small, marginal, and landless farm women. Stall-feeding in goats was very limited. So,the integration of forage legumes into the cropping system of small stock owners would go a long way to improve the productivity of their animals(Shalander and Upadhyay, 2009). By introduction of legumes like Siratro *(Macropteliumatro purpureum), Stylosanthes hamata, S. scabra, Glycine javanica, Dolichos auxilaris, Desmodium spp.* and *Centrosema pubescens* etc., the quantity as well as quality of herbage production can be substantially increased. Indigenous legumes such as clovers (*Trifolium pratens*, *T. repens*), *Medicago denticulata, Melilotus alba*, white clover, red clover have proved successful apart from Lucerne and berseem. *Leucaena leucocephala* and even perennial pigeon pea etc. are pruned frequently to provide leaf fodder to get better crop production.For augmenting fodder availability; emphasis needs to be given to cultivated fodder crops in large areas (Sahoo and Karim, 2010). Foliage of fodder trees could be fed to the livestock in mixture with crop residues and hay to improve their palatability and nutritive value. Propagation of fodder and legume trees in wasteland and community pastures and its judicious utilization can be taken up to mitigate scarcity of fodder (Shinde and Mahanta, 2020). Intercropping with twin objective, using seed for human and leaves for animals, short duration and quick growing leguminous forage crops should be promoted. The degraded grazing lands and community pastureland should be converted into asilvi-pastoral productive system. Drought tolerant grasses, shrubs and fodder trees need to be promoted on field bunds. Improvement in the natural rangelands by reseeding with perennial grasses (grass yield increase from 1.0 ton to 4.0 ton/ha/year), intercropping of legumes, plantation of fodder trees and most importantly judicious utilization of natural resources. Agroforestry should be popularized among farmers (Sahoo and Karim, 2010).

She goats are given kitchen waste, and the males are given inferior quality grains and grams for fattening purposes. Goats eat 4-5 times that of their body weight. They eat more of tree fodder and hence 40-50% of green fodder should contain tree leaf fodder in roughages. Goats should be fed with concentrate mixture consisting of maize, wheat, horsegram, groundnut cake, fish meal and wheat bran. Sheep are excellent gleaners and make use of much of the waste feed. They consume enormous quantities of roughage, converting a relatively cheap food into a good cash product (Sahoo and Karim, 2010). A sheep requires about 1-2 kg of leguminous hay per day depending on the age of sheep and its body weight. Proteins may be supplied through concentrate mixture having oil cakes when the pastures are poor in legumes or when scarcity conditions prevail. Normally 110-225 g of cake is sufficient to maintain an average sheep in good condition. Feeding a mixture of common salt, ground limestone and sterilized bone meal in equal parts is required to alleviate deficiency of minerals in the feed. Abundant clean fresh water should be made available to animals. Water should be changed every morning and evening (Shinde and Mahanta, 2020). The mineral mixture may be included in the concentrate ration at the rate of 2-2.5 per cent. Lumps of rock salt are hung up in some suitable place where animals easily get at them, or else they may be kept in the manger. The provision of salt licks and supplementation of vitamins A, D and E is also essential for optimum production (Sahoo and Karim, 2010).

Health care and management: Indiscriminate breeding is usually prevalent in small ruminants especially in unorganised farm/flock in rural areas. The development of awareness and gender sensitization may lead to improve the stock through selective breeding or by introducing high potential breeds of sheep and goats. Male goats are taken better care of than the female ones as these fetches competitive prices to the owners. Many do not like goat milk; hence, less priority is attached to milk traits of the goats. Genetic improvement and or efficiency of production can be more easily ameliorated in small ruminants because they have a faster population turnover rate. Such progress would be achieved if increased selection pressure is effectively applied. Artificial insemination should be encouraged providing door-to-door service and to serve as a training centre to promote entrepreneurship among the unemployed youths. For effective health, animals should not be provided contaminated food or polluted water. For commercial production, arrangement of separate housing of kids, bucks and does and extra care to the breeding bucks, kids and pregnant does should be provided. Only the improvement of management practices could earn 250–300% higher income, due to birth of healthy kids of elite breeds, proper care of selected male kids after weaning to make suitable buck, low mortality, high growth rate, good health, early maturity, sale of animals on weight and as breeding bucks. Motivation and popularization of package of improved management practices for small ruminant system is very essential. Animal owners should be made aware for improved management practices such as breeding calendar (optimum age and weight of breeding at first time, seasons/months of breeding to obtain maximum survival, production and profit, health calendar, low cost houses and taking hygienic measures of shed, better strategic feeding (timely colostrum feeding, supplementary concentrate feeding at advance pregnancy, first 60 to 90 days of lactation, 3-9 months of age during kids growth, efficient use of feed and fodder as per age, sex, productivity) and smart marketing and value addition of products (Shinde and Mahanta, 2020).

Stall Feeding:

Sheep and goats in the country are mostly raised on grazing resources in extensive systems. As these resources are gradually shrinking over the periods both in terms of areas and in yield and quality, semi-intensive and intensive systems are being advocated to meet the demand of meat. The intensive system (stall feeding) as an alternative to traditional grazing and semi-intensive system, may be useful to maintain pace with growing meat demand in the changing scenario of grazing resources in the country. Intensive feeding system for sheep and goats is better than extensive system and at par or better than semi-intensive system for lamb and kid fattening purpose from 3–6 months of age. Lambs and kids on stall feeding with adequate nutrition and management attain faster growth, attain slaughter weights at an early age and produce heavier carcass weights, more dressing yield and desirable lean, fat and bone contents (Devi et al., 2020). Although initially intensive systems seem costly due to more feed cost and more capital investment, this is justified by higher economic returns to farmers.

Goat farming: Technology adoption by Farm women

Promoting semi-intensive feeding management system through field demonstrations: Goat keepers (>95%) rear their goat on zero input and earn average profit of Rs. 12,500/year from a unit of five adult females. The profit from five goats becomes double or more than that i.e. Rs. 25,000/year by shifting goat management from extensive to semi-intensive system. Farm women may be charged cost of inputs and many farmers (>50%) are ready to pay if profit message spread horizontally remaining farmers also become ready to pay cost that incurred on vaccination, deworming, feed-mineral mixture, and service from high potential buck (Caja et al., 2020).

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Upgradation of genetic stock by supply of high potential pure-bred bucks: The women farmers need to be encouraged to breed local non-descript goat with improved breed suitable for that agro-climatic conditions. Progenies born out from superior bucks yield 40-75% more production and fetched 25-40% higher price in market as breed premium.

Promotion of prophylactic measures (goat health calendar): Goat keepers (>75%) were neither aware and nor adopted vaccination against infectious diseases such as Peste des petits ruminants, goat pox, enterotoxaemia, and Foot-and-Mouth Disease which are responsible for high economic losses (30 to 60% goat mortality). It was observed that vaccination and deworming of goats have reduced the mortality (<10%) increasing the survival of goat and net income of 3,500 to 4,500/year with a unit of five goats (Singh et al., 2018).

Motivation and popularization of package of improved management practices: Awareness should be created for improved management practices such as breeding calendar (optimum age and weight of breeding at first time, seasons/months of breeding to obtain maximum survival, production and profit from goats, health calendar, strategic feeding (timely colostrum feeding, supplementary concentrate feeding at advance pregnancy, first 60 to 90 days of lactation, 3-9 months of age during kids growth, efficient use of feed and fodder as per age, sex, productivity) and smart marketing and value addition of products (Singh et al., 2018).

Formulation of farmer's groups (FPOs), SHGs cooperatives, societies for transfer of technology: Such groups should be periodically empowered (linkage with financing institutes, govt. and NGOs, credit access, knowledge, and incentives etc.).

Value addition of products increases income and nutrition: Value-added products of goats have great potential. Processing goat products to value-added products can contribute to sustained demand for meat and milk and efficient marketing of these products to earn reasonable returns by farmers. Such added value can be obtained in shelf-stability, improved technological functions, better sensory quality, or even more convenience. Value addition of goat products may help farmers to increase their products' sale and to get more net return. By following improved methods of goat rearing and smart marketing the productivity of goats could be increased by 90 to 160 (Singh et al., 2018).

Feeding of Complete feed:

Feeding of small ruminants with crop residues-based complete rations appears to be the promising feeding system for improving their productivity in agricultural countries like India. Complete feed system improves nutrient utilization that supports higher growth performance and reduces the cost/ kg live weight gain, thus is economical in comparison to conventional feeding system. Feeding complete feed increased intake of DM and nutrients in different ruminant species on complete feed system compared to conventional feeding system stabilizing ruminal fermentation that improves efficiency of nutrient utilization in ruminants. Feeding of ammoniated lentil (*Lens culinaris*) straw based TMR to growing Barbari kids improved digestibility of various nutrients as well as DCP content. In a study carried out by Bhatta et al. (2020), while assessing the effect of feeding high tannin containing tree leaves in complete feed mixture on the performance of lambs, reported that feed efficiency ratio was the best in animals fed on complete feed containing 50% leaves. Several studies have observed the beneficial effect of feeding complete ration on the growth performance of animals. Malisetty et al. (2013) reported that Nellore lambs fed SSB-based complete diet had ADG almost like those animals fed lucerne hay plus maize silage ad libitum.

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Strengthening support services and extension network: Credit is an important asset for goat keepers to access technological interventions such as improved housing, purchase of concentrate, quality animals, value-added products etc. It will encourage goat keepers to switch their goat from extensive (zero-input) to semi-intensive management system and up-scaling the introduced innovations.

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Major Nutritional Interventions & Feeding practices for Enhanced productivity

The traditional goat production system in India is on grass-based range production, allowing the animals to graze on community pasture with little tree foliage supplementation. Community grasslands available for grazing either degraded due to over grazing or did not have sufficient biomass to meet the nutrient need of livestock with little supplementation during productive phase of life. Due to shrinkage of grazing land and pressure of urbanization the system of goat rearing is changing to intensive system. Intensive system of goat production recommended upon limited or lack of grazing resources and suitable under urban locations where higher returns from goat's products expected.

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Feeding of Complete pellet feed

Complete pellet feed is a technique provided synchronized nutrient availability in ruminants with higher nutrient use efficiency for production. It discourages the selective ingestion habits of animals providing the ease in using unconventional feeds, fortifying several limiting dietary components facilitates balanced nutrient delivery for fermentation. Processing of complete feed mixtures in the form of pellet reduces the bulkiness of the feed resources by three times, reduces feed wastages 10-20%, improves storage, transportation and keeping quality by 2-3 times, and improves overall nutrient use and production efficiency by 15-25 %. The intake of pelleted feed varies from 4-6% of body weight of goats depending upon physiological status. The monsoon herbages (*Tephrosia purpurea, Cenchrus ciliaris* and *Dactylotennium aegypticum*)had the potential of feeding in the form of complete feed during post monsoon season to kids for optimum growth. *Tephrosia purpurea* being the leguminous forage had higher CP and better nutrients density, while *Cenchrus ciliaris* and *Dactylotennium aegypticum* had the higher palatability to cater the need for optimum growth. Kids fed with these roughages at R:C, 60:40; consumed daily DM 663 to 781 g, TDN 393 to 425g, DCP 42 to 70g to have ADG 59 to 79 g with FCR 10 to 12 (Tripathi *et al*., 2014). Kumar *et al.* (2014) formulated complete pellet feed having herbal formulation to check the coccidia infection in 3-6 months kids and the production parameters affected due to coccidia infection get improved by feeding of pellets. Complete pellet feed formulated by incorporating sundried azolla replaced 15-25% of concentrate mixture resulting higher body weight gain in growing Barbari goats and improvement in milk yield in lactating goats (Kumar *et al*., 2015, 2016b). Feeding of Moringa based complete pellet feed to goats resulted higher body weight gain with lower FCR and higher carcass yield (46.39%), lower fat content (3.5%) and higher protein (20.37%) content.

Broiler goat rearing system

Broiler goat production system is an intensive women friendly technology of rearing goats to provide energy, protein and other nutrients in the desired quantity by feeding semi solid concentrate diet. Faster growth rates were found in stall feeding goats than feedlot goats, as it allows finishing at specific target weights (Prasad and Abraham, 2017). The body weight gain and average daily gain (ADG) was higher ($P<0.05$) in broiler goat rearing system in black Bengal goats showing better growth performance in animals. Total body weight gain (kg) and average daily gain (g/day) was higher with better feed gain ratio (9.05 vs. 5.52) showing better growth performance in broiler goat rearing system (Devi et al., 2020).

Feeding of Silage:

Silage preparation is usual form of fodder preservation and mostly used for large ruminants. However, feeding of silage in stall fed sheep and goats is also a good option when green fodder is not available. Feeding of silage was evaluated in growing and lactating goats. Kumar et al. (2022) reported an average daily gain (g/day) of 71.42 in goats fed with concentrate pellet + Maize-Moringa silage *ad lib* and 60.87 in goat fed with concentrate pellet + maize silage *ad lib* as compared to control (55.31g) in growing Barbari goats. Barbari lactating goats (avg. body wt. 27.2 kg) fed with concentrate pellet and *ad lib* maize silage has been reported to produce milk 700-850 g/day. There was no notable change in milk yield and milk constituents on feeding of silage-based ration in lactating goats.

Hydroponic fodder:

Feeding of hydroponic maize and barley fodder to goats showed increase in body weight gain, feed conversion efficiency and overall profit of the goat farm (Gebremedhin, 2015). Inferior quality roughages supplemented along with green hydroponic fodder showed that 25 percent replacement of concentrate mixture with hydroponically grown maize fodder is economical for rearing of goats (Roy et al., 2023)

Azolla feeding:

Inclusion of 25% azolla in ration of goats proved better as it increased return per day and increase milk production per liter. Azolla contains 25-35% protein, 10-15% minerals, 7-10% AA, bio-active substances,andbiopolymers, low in fats and carbohydrates (El Naggar and El-Mesery, 2022). It can be easily harvested with a scoop net, or grown in enclosed, floating rings which can be pulled to the edge for easy harvest.Azolla feeding improved semen quality in goats (Kumar et al., 2016a)

Feeding of Moringa Leaves:

Moringa *(Moringa oleifera)* is a rapidly growing soft wood plant. India is the largest producer of Moringa with a yield up to 650 metric tonnes of green leaves/ha (Rajangam et al., 2001). *Moringa* leaves are rich source of protein (23-30%), minerals, vitamins and other secondary metabolites (Su and Chen, 2020). Fresh *M.oleifera* leaves at 20 and 50% levels as a replacement for batiki grass (*Ischaemum aristatum* var. *indicum*) improved live weight gain and nutrient digestibility in growing goats (Aregheore, 2002). Moringa (*M. olifera*) is highly nutritious and economic fodder for goat due to its high biomass production. Growing female Barbari goats were fed *ad libitum* green moringa and supplemented concentrate pellet (1.5% of B. Wt.). The average daily dry matter intake was 491 g comprising of 235 g green moringa and 256 g concentrate pellet with ADG 54.26 g and FCR 9.94. Blood metabolites viz., glucose, total protein, albumin, globulin, serum enzymes and ruminal volatile fatty acids were within normal range. *Ad lib* green moringa feeding along with supplemental concentrate pellet is an economic option for feeding of growing goats.

Feeding of Cactus Plants:

Cactus (*Opuntia* spp.) can be used as a feed resource in dry areas because of its remarkable tolerance to drought conditions, high water use efficiency, growth, a high biomass yield and a multipurpose use. This is a promising range species that can promote livestock sector in dry areas and improve farmers' income. However, it is associated with high fibre and ash content and thus low energy and protein density, which requires specific supplementation when cactus species are used in feeding.*Cactus cladodes* are fed mostly as fresh to cows, sheep, goats. To avoid wastages, it is recommended to cut cladodes into small slices before offering to animals. Cactus cladodes could be dried then ground, and the meal obtained used as a supplement feed for animals. It might be advantageous to ensile cactus mixed with other ingredients such as cake and wheat bran. Cactus ensiling seems a simple technique and in addition to feed shortage, water scarcity compromises livestock performances in dry areas. Catunda et al. (2016) reported that Saanen goat milk fed with cacti varieties in the diet had no adverse effects on the sensory properties of goat milk and lipid composition profile.

Precision Feeding

Precision animal nutrition (PAN) is the effective utilization of available feed resources with the aim of maximizing the animals' response to nutrients. The term 'PAN' is defined as providing the animal with the feed that precisely meet its nutritional requirements for optimum productive efficiency to produce better quality animal products and to contribute cleaner environment and thereby ensure profitability. Reddy and Krishna (2009) mentioned the use of different tools like improved feed processing techniques, precise ration formulation, implementing phase feeding and the use of feed additives to achieve precision feeding.Strategic supplementation of nutrients enhances rumen fermentative digestibility, which stimulates intake of feed.Further, it also balances the end products of rumen fermentation in lowering enteric methane production from ruminants. Efficiency of ruminal fermentation and digestibility of the nutrients are key factors in improving the efficiency of feed use.Nutrient partitioning is the major component of productive efficiency that differs among individual animals with increase in productive efficiency. Use of restricted protein levels and supplementation of rumen-protected amino acids with matching ruminal energy and monitoring the milk urea nitrogen help assess efficiency of nitrogen use. Feed additives play a pivotal role in achieving increased efficiency and reduced environmental load per unit of the animal product. Reddy and Krishna (2009) further reiterated the role of supplementation of unsaturated fatty acids, ionophore antibiotics, organic acids, plant secondary metabolites, essential oils, probiotics and fibrolytic enzymes has been used to achieve precision animal nutrition.

Feeding Management of dairy goats

Goats produce more milk than a cow from the same quantity of nutrients. The nutrient conversion efficiency to produce milk in goats is 45.7 per cent, whereas a dairy cow average 38 per cent. It has been observed that goats are 4.04 per cent superior to sheep, 7.90 per cent superior to buffaloes, and 8.60 per cent superior to cows in crude fibre utilization. The goat uses more useless feeds for its maintenance than a cow. The secret of successful feeding is in devising a cheap and efficient ration. While preparing a ration for goats, factors like bulk, palatability, availability, price and digestibility should be considered along with the nutritive quality of the feed. Abundant clean, fresh water changed every morning and evening should be always made available to goats. Some of the most serious diseases of goats result from the drinking of dirty water from shallow pools. Water troughs should be thoroughly washed at least twice a month. Goats in milk require more water than dry goats and should be watered regularly at least three times a day.

Feeding of breeding does

If the availability of pasture is good, there is no need to supplement concentrate mixture. In poor grazing condition animals may be supplemented with concentrate mixture @150-350 g of concentrate/animal/day depending up on the age. The digestible crude protein level of concentrate mixture used in the adult feed is 12 per cent.

Feeding does during the first four months of pregnancy:

Pregnant animals should be allowed in decent quality pasture 4-5 hours per day. Their ration must be supplemented with available green fodder at the rate of 5 kg per head per day.

Feeding does during the last one month of pregnancy:

In this period fetal growth increases 60 – 80 per cent until parturition and lack of enough energy in the feed can cause pregnancy toxaemia in does. So, during this period animals should be allowed in particularly decent quality pasture 4-5 hours per day. In addition to grazing, animals should be fed with concentrate mixture @ 250 –350 g/animal/day. Their ration should be supplemented with available green fodder at the rate of 7 kg per head per day.

Feeding does at kidding time

As kidding time approaches or immediately after kidding the grain allowance should be reduced but decent quality dry roughage is fed free choice. It is usually preferable to feed lightly on the day of parturition, but allow plenty of clean, cool water. Soon after kidding the doe must be given just enough of slightly warm water. After parturition, the ration of the doe may be gradually increased so that she receives the full ration in divided doses six to seven times in a day. Bulky and laxative feedstuffs may be included in the ration during the first few days. A mixture of wheat bran and barely or oats or maize at 1: 1 proportion is excellent.

Feeding lactating does: The following rations may be recommended

6-8 hours grazing + 10 kg cultivated green fodder/day

6-8 hours grazing + 400 g of concentrate mixture/day

6-8 hours grazing + 800 g of decent quality legume hay/day

Feeding non pregnant does

If the availability of pasture is good, no need to supplement with concentrates mixture. In poor grazing condition animals may be supplemented with 150–200 g of concentrate/animal/day.

Feeding bucks for breeding

The frequent practice is allowing the bucks to graze with does. Under such conditions the bucks will get the same ration as the does. Usually, it will meet the nutritional requirements of the buck. Where there are facilities for separate feeding of the buck, it may be given half a kilogram of a concentrate mixture consisting of three parts oats or barley, one part maize and one part wheat per day.

Feeding kids
Immediately after birth feed the young ones with colostrum. Up to 3 days of birth keep dam and young ones together for 2-3 days for frequent access of milk. After 3 days and up to weaning feed the kids with milk at 2 to 3 times a day. At about 2 weeks of age the young ones should be trained to eat green roughages. At one month of age the young ones should be provided with the concentrate mixture (Creep feed). Kids should be allowed to suck its dam for the first three or four days @ 100 ml per kg live weight. The creep feed @50-100 gm/animal/day (22% CP) from one month of age and up to 2-3 months of age to provide more nutrients for their rapid growth. An ideal creep feed should contain Maize- 40%, Ground nut cake - 30 %, Wheat bran-10 %, Deoiled rice bran-13 %, Molasses- 5%, Mineral mixture- 2%, Salt- 1% fortified with vitamins A, B2 and D3 and antibiotic feed supplements. Supplementation of concentrate mixture @ 100-200 g/animal/day with protein of 16-18% up to 3 months. Dry fodder during night in summer months and during rainy days helps the animal in many ways (Sahoo and Karim, 2010).

Flushing: Increasing the level of energy offered to does should continue throughout the breeding season and for 30 to 40 days after removing the bucks, for adequate implantation of the foetuses in the uterus. Body condition is used to determine whether flushing will be of benefit to breeding does. Does in extremely good body condition will tend not to respond to flushing. On the other hand, does that are in relatively poor condition because of poor feed quality and supply, high worm loads, late kidding of twins or triplets, will respond favourably to flushing by improving their body condition. Flushing can be accomplished by moving breeding does to a lush nutritious pasture 3 to 4 weeks prior to the introduction of the bucks. A complete goat mineral should be offered free choice year-around in most production situations (Sahoo and Karim, 2010). Low to medium quality forage (> 10% protein) will meet requirements of dry does and non-breeding bucks. When forage or browse is limited or of low quality (< 10% protein), weanlings and yearlings should be fed diet containing 16% protein mixture. Goats can be forced to eat very low-quality feed including twigs, tree bark, etc., but this practice will hurt the productivity of superior meat and fibre goats.

Strategic feeding of animals for reducing Methane mitigation strategies:
Methane gas from ruminants contributes global warming. Methane emission was lower (P<0.05) in subabool (*Leucaena leucocephala)* supplementation in grazing goats by 18.30 % due to improvement in nutrient utilization and plant secondary metabolites like tannins (Kumar et al., 2020). Complete pellet feed containing dried *L. leucocephala* and *Ficus infectoria* leaves fed to growing male Barbari goats showed reduction in methane production (g/day) by 10-19% as compared to control group (Kumar et al., 2018). In pastoral systems, the mitigation potential can be achieved by improvements in pasture management through production system on intensification food supplementation, implantation of the intermittent pasture management system and alternative systems such as crop-livestock integration and silvopastoral systems (Berchielli et al., 2012).

Nutritional manipulation for value addition of products
Goat meat and milk is a reliable source of animal protein consumed by people in developing countries. Goat milk has many advantages over bovine milk on digestibility, lower concentration in fat, protein, and sugar (Mandal et al., 2014). Kholif et al. (2016) reported that feeding soybean or flaxseed oils 20 mL/day to lactating Anglo-Nubian goats increased total VFA, propionate and blood glucose. Oil supplementation has been reported to affect milk composition, especially increasing the concentration of fatty acids and increase in USFA and CLA in milk with concomitant decrease in saturated fatty acids. Mir et al. (1999) also

reported an increase in CLA in goat milk, when goats were supplemented with canola oil. Li et al. (2012) and Martínez Marín (2011) also reported comparable results on the effect of milk fatty acids. Alteration of the milk fatty acid content is due to dietary lipids and their fatty acid profile available at intestinal level. However, enrichment of essential fatty acids is also seen in other goat products such as meat. Roy et al. (2013) reported that feeding of soybean oil and sunflower oil at a concentration of 45 g/kg of total diets did not affectdigestibility and performance but increased the PUFA and CLA content in muscle and adipose tissues in Black Bengal goats with the greatest effect noted for sunflower oil.

Conclusion

Goat farming as a source of supplementing household income are getting increasing attention especially among the landless agricultural laborers and small and marginal farmers. Women are increasingly finding it as a potential source of earning cash income to meet their personal requirements. Proper nutrition of goat is very much important for improved productivity along with economic return. The traditional bound communities currently not rearing goat though economically poor should be motivated through educational and incentive based developmental interventions to take up goat husbandry in entrepreneurship mode for their upliftment. Education through training on improved practices of goat farming may develop access to resources, skill, and marketing channel, improve decision making ability and women empowerment which in turn improve socio economic status, self sufficiency, welfare of the rural farm women.

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Integrated Homestead Aqua-horticulture : A Sustainable Climate Resilient Approach for Livelihood Diversification

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Integrated farming is a farming system that combines multiple agricultural components to create a sustainable and productive system. It works on the concept of "zero waste" or "model of circular economy" as the output of one component can be used as he input of another component. Integrated farming is considered as a sustainable agriculture method for the future since it produces good quality organic food products through natural farming process. Application of integrated farming principles in to aquaculture can sustainably increase the profitability of small and marginal farmers. The integration of aquaculture with other components like horticulture holds great promise for improving women's contribution for the food nutrition, security and income of rural families. The consumption of high-quality diverse diets is crucial for optimal growth, health, and wellbeing. One way to increase the intake of nutrient-rich foods is via increased aquaculture and/or horticulture. Households engaging in such activities may have the potential to improve their diets through direct consumption of nutrient-rich foods (e.g., fish, fruits and vegetables) from their own production and/or indirectly, through purchasing other nutrient-rich diverse foods from the market, through income generated by selling homegrown produce.

Role of women in vegetable farming and aquaculture

Women contribute towards the major share of work in vegetable cultivation right from the preparation of land to the sale of produce in the market. She is actively involved in operations like levelling of field, preparation of seed beds for raising seedling, transplanting, weeding, hoeing, irrigation, earthing, harvesting, etc. Likewise, women have assumed a leading role in the rapid growth of aquaculture around the world with their participation along the aquaculture value chains. Active participation in aquaculture can empower women, notably by facilitating women's decision-making on the consumption and provision of nutritious food to their families. Historically aquaculture started as a backyard activity for recycling waste and as a source of family income. Women were involved in fish feeding and harvesting (Williams et al. 2005; Napati et al. 2016**)** considering it as an extension of their domestic work.The type of work a woman has to do makes it necessary for her to be close to a pond where she has to wash, bathe, collect water and perform other household tasks. There exists, therefore, a natural condition for women to explore the possibilities for fish cultivation. Diets of small/marginal households are often dependent on food supplied from their own production. Evidences suggest that households' own horticulture production supports lower micronutrient deficiencies. Integration of available resources for its optimum utilization will help in achieving the nutritional security of a rural family. In a study by Akteretal (2020) it was reported dietary micronutrient and energy intakes were significantly ($p < 0.01$) and positively associated with aquaculture and horticulture combined. Dietary calcium intake was also strongly correlated with households engaged in aquaculture and horticulture, followed by riboflavin, niacin, and folic acid. Limbu et al (2016) reported that integrated aquaculture–agriculture (IAA) system involving fishes and vegetables resulted in three and 2.5 times higher net yield than the culture of fishes alone and farming of non-integrated vegetables respectively. Moreover irrigation with pond watr resulted in 1.8 times higher yield in vegetables than those irrigated with stream water. The practice of fish–vegetable integration and growing of vegetables irrigated with pond water produced 14 and 13 times higher net annual yield, respectively, than the culture of fishes alone

Integrated Aqua-horticulture farming system

The horticulture-cum-fish farming system includes the culture of fruits, vegetables and flowers on the embankment of the pond. The fruits and vegetables contain various nutritive elements and the Indian Council of Medical Research has recommended 85g of fruits and 300g of vegetables to consume daily. For horticulture crop production the inner and outer dykes of the pond and adjoining areas are used. The selection of plant is the main criteria for the success of this system. The plant should be dwarf, seasonal, evergreen, remunerative and less shady. The fruit crops which can be used are Mango, Banana, Papaya, Coconut, Lime etc. and the vegetables like brinjal, tomato, cucumber, gourds, chilli, carrot, radish, turnip, spinach, peas, cabbage, cauliflower, ladies finger can be grown according to their season throughout the year. The flower plantation on the embankment is also useful. We can use the plants like Rose, Jasmine, Gladiolus, Marigold and Chrysanthemum etc. which provides additional income to the farmer and beauty to the farm. This system provides 20-25% more return in comparison to aquaculture alone

Integrated Aqua-horticulture has several advantages:

- The farmer gets additional income and nutrition from growing fruits and vegetables on the pond embankment that normally lies fallow.
- The nutrient-rich pond mud is used as fertilizer for growing crops, eliminating the cost of organic manures.
- Manured pond water is used for irrigation of plants.
- Fruit and vegetable residues are used as feed for the fish.
- The plants on the embankment strengthen the dikes.

Establishing the system

Aquaculture

Homestead ponds are ideal for integrating aquaculture with horticulture as it enables easy access to and management by women. The dykes of pond should be checked and repaired. It is necessary to guard the inlet and outlet of ponds with mesh screens to prevent the entry of wild fishes and predatory animals and also escape of stocked fishes. The pond should be deep enough so that it retains more than 1 m water during the dry period. The dikes should be strengthened and terraced before planting crops and fruits

Pond preparation

Aquatic weeds if left unmanaged in the ponds will result in reduced pond productivity because of the absorption of nutrients by them. They can also harbour predatory and weed fishes and will hinder free movement of stocked fishes and netting operations. Manual method of removal is the commonly advocated and environment friendly method for removal of these weeds. Since the size of rearing ponds is small, the activity will not be uneconomical to the farmers.

Eradication of predatory or weed fishes: The presence of predatory and weed fishes will pose a double threat to the stocked fishes by way of competition for food and predation. As these fishes are generally autobreeders, they will outnumber the stocked fishes in the pond leading to reduced production due to competition for food and space. Dewatering followed by sundrying is the most effective method for their eradication. If the pond is situated in a flood prone area or is not possible to be drained, Mahua oil cake @2500kg/ha can be applied three weeks before stocking. The Mahua Oil cake also serves as organic manure after its decomposition.

Pond fertilization: application of cow dung (@ 3-4tonneMT/ha) as basal dose one week prior to stocking followed by fortnightly equal doses @0.5 tonne/ha after stocking. Sporadic application of inorganic fertilizers viz., NPK mixtures @ 60-75 kg/ha., urea @ 100-125 kg/ha. to pond water to facilitate better natural fish food production is advised.

Stocking of fingerlings: Grass carps can be stocked @ 1000/ha which feel feed on rotten or pest affected vegetables. Catla:rohu: mrigal: grass carp stocked in the ratio 50:15:15:20 @ 5000 fingerlings- can yield 3 t/ha/year.

Feeding: Feed is provided @ 4-3%, 3-2%, 2% and 1% of fish biomass during 1-2, 3-4, 5-6 and above 6 months respectively. Commercially available feed can be fed to the fishes. Alternatively, farm made feeds can be prepared using locally available oil cakes and rice bran @1:1

*Harvesting:*_The fish that attain marketable size should be harvested and the rest allowed growing further. Final harvesting may be done 10-12 months after stocking.

Horticulture

The dikes are to be strengthened, terraced, prepared and fertilized by application of pond silt. Bananas, papayas, pumpkins, gourds, spinach, brinjals, tomatoes, cucumbers and leafy vegetables are grown on the dikes. Inorganic fertilizer is also applied to the plants in addition to pond silt at 10 kg/year divided into installments. Water the crops with manure pond water. Planting of papaya is done in July and banana in October/November and harvesting starts after 6 and 8 months following planting, respectively. The farmer consumes a portion of the harvested fruits and the rest are sold in the market.

The vegetable crops are grown and harvested twice in a year--once during August/September and another in March/April. After meeting the requirements of the farm family, the vegetables are sold. Below is a list of some crops that can be grown on the pond embankment:

Calendar of activities for fish-horticulture farming

Month	Activities to be undertaken
April-May	Pond Preparation
July	Stocking of fish
August	Dike preparation and planting of fruits and vegetables

September	Application of inorganic fertilisers to crops
October	Pest control if necessary
November	Harvesting of vegetables, Inorganic fertilizer application
December	Harvesting of vegetables
January	Harvesting of vegetables
February	Preparation of dyke for second crop of vegetables Harvesting of papaya
March	Partial harvesting of fish
April	Harvesting of papaya and Banana
May	Harvesting of vegetables (P&B), Final Harvesting of fish
June	Harvesting of veregatbels, Papaya and Banana

If the pond dyke is surrounded by prennial trees, the farmer can make use of land adjacent to the homestaed pond for growing the vegatles. The cropping calendar is given below.

Season	**Crop**
Rabi (October-March)	Leafy Veg (Palak, Fenugreek)
	Solanaceous Veg (Tomato, Brinjal, Chilli, Capsicum)
	Cruciferous Veg (Cauliflower, Broccoli, Cabbage)
	Legume Veg (French bean, Dolichos bean)
	Root Veg (Carrot, Radish)
	Pineapple
Pre-kharif (March-June)	Leafy Veg (Basella/Indian spinach, Amaranthus)
	Cucurbitaceous Veg (Pumpkin, Bitter Gourd, Ridge gourd, Cucumber)
	Okra, EFY
Kharif (July-October)	Drumstick, Papaya, Banana
	Okra
	Leafy Veg (Water Spinach, Basella/Indian spinach)
	Sweet Potato (Biofortified), Taro
	Cucurbitaceous Veg (Pumpkin, Bitter Gourd, Ridge gourd, Bottle Gourd)

Aquaponics: An innovative integrated aqua-horticulture for improving nutrition and income

The word 'aquaponics' is a combination of 'aquaculture' (fish farming) and hydroponics (cultivation in water). It raises both vegetables and fish in a limited space enabling diversification in culture technique. This technique is a way of using an aquaculture site for vegetable production and may help to overcome the increasing nutrition demand. Shrinking total agriculture land, uncontrolled population growth and complex and unpredictable weather create new challenges to the country's agriculture (Islam et al., 2018) that highlight the developing new crop production systems like aquaponics (Salam et al., 2014).

An aquaponic system combines the two different systems

1. Re-circulating aquaculture system

2. Hydroponics system

Recirculating aquaculture system: It is very important component of aquaponics as it ensures continuous water supply in the culture system and also maintains the quality of water by mechanical and biofiltration processes. The recirculating aquaculture system helps in removal of solid waste like uneaten fish feed, fish residues or other large size materials through mechanical filtration, conversion of toxic ammonia to non toxic nitrate with the help of aerobic bacteria (Nitrification) and de-nitrification wherein excess amount of nitrate is converted into nitrogen by the anaerobic bacteria and released in to the atmosphere.

Hydroponic system: There are three main types of hydroponic plant growing systems that are suitable as the plant growing component in aquaponic systems (Resh, 2013). These three main techniques used for hydroponics system are briefly explained below:

a) Nutrient film technique (NFT): In this system a pipe in which the holes are drilled is used on the upper side and a continuous water flow is provided with good amounts of nutrients. Simultaneously, proper aeration is ensured in the flowing water so that the nutrients will be absorbed in good amount by the plants.

b) Floating raft method: In this system a grow tank of polystyrene rafts with a 20 to 30 cm depth is used. This tank is filled by the nutrient rich water and aeration is ensured by the aerators for better nutrient uptake by the plants.

c) Media based systems: In this system for growing the plants some media are used like gravel, clay balls, small stones, vermiculite etc. These beds may be "trickle fed" by the nutrient solution, or subjected to periodic flooding and draining ("ebb and flow") to maximize exposure to both air and nutrients. This media acts as mechanical filter or biofilter or both. Nutrients are typically supplied from three stock tanks using an automated dosing system to maintain nutrients at optimal concentrations for the plants.

Working of Aquaponics system: It combines hydroponics and re-circulatory aquaculture system both and this is suitable for both as the nutrients requirements is fulfilled by the disposing of nutrient-rich fish waste from aquaculture unit to the hydroponics unit thus eliminating the use of a nutrient media. The fish waste provides an all-natural nutrient solution for plant growth and this nutrient-rich effluent is used to irrigate a connected hydroponic bed while fertilizing its plant crops at the same time. The filtration of water is done by the hydroponic unit as the plants absorb the nutrients and filter the water through the sand filter so this media based hydroponic system serves as an aerobic biofilter, converting ammonia to nitrate. The ammonia is converted by denitrifying bacteria in the hydroponic grow bed into forms readily up taken by plants for energy and growth. Essentially, the hydroponic bed and its crops serve as a bio-filter for the fish waste water before it is cleaned and returned back into the fish tank. Out of total nitrogen input used into the system as feed, up to 30% may be captured as fish flesh, and 40% or more may captured as plant biomass. The complex mix of nitrifying bacteria, rhizobacteria, fungi, and micro plankton in the recirculated water appears to benefit the plants due to both positive interactions at root level, and the higher resilience of the system against some plant pathogens (Savidov, 2005) . To improve the water flow and minimize the dead areas it is better to have circular tanks for fish rearing. In such a system Nile Tilapia (Oreochromisniloticus) can be stocked at up to 60-70 kg/m3 stocked at up to 60-70 kg/m3. Generally, leafy vegetables and herb like lettuce are preferable for culture in an aquaponicsystem. Fruits, due to their long production cycle the fruits are not suitable for this culture technique. The recommended plants species are Lettuce, Basil, Coriander, Spring onion, vegetables such as tomato, cucumber, Beets, Okra etc can also be grown.

Oreochromisniloticus (Nile Tilapia) is the most preferable fish for tropical and sub tropical areas because this fish can survive in high stocking densities, lower oxygen level (0.2 ppm), high ammonia or nitrogen concentration (>90 ppm @ pH 6.0), it can tolerate low pH level (< 5.0) and it can easily breed in tanks.. Cyprinuscarpio (common carp) can tolerate the low temperature and high stocking density. Other common desirable fishes are Asian Barramundi (Latescalcarifer) Mullet (Mugilcephalus), Perch (Percaflavescens) Largemouth bass (Micropterussalmoides) Grass carp (Ctenopharyngodonidella) and ornamental fishes (Sharma et al, 2018).

Gender Responsive Integrated Homestead Aqua-horticulture Model (GRIHA)- a Sustainable Climate Resilient Approach towards Livelihood Diversification'

Men and women are impacted differently by climate change. Rural women's vulnerability to climate change is much more as compared to men. This is because they constitute the majority of world's poor and they rely heavily upon natural resources. Moreover, they have limited access to productive resources, technologies, services, education and employment opportunities. These pre-existing gender inequalities in the society are amplified by climate change which results in serious setbacks in achieving food security though reduced availability, accessibility, utilisation, and system stability. Climate-resilient agriculture aims for sustainable development (environmental, economic and social dimensions) by addressing both food security and climate challenges. Women in agriculture play a crucial role in climate action by leading community-based initiatives, utilizing their indigenous knowledge, and advocating for sustainable practices. women are "just as likely as or more likely than men to adopt CRA practices" given adequate information, training, and resources with which to implement them thus increasing women's productivity and reducing the gender productivity gap. The GRIHA model focusses on the improvement of nutrition and income of coastal rural households with the active participation of women by adopting climate resilient aqua-horticultural practices. The model was validated among 58 rural households of the flood prone districts of Puri and Bhadrak

The Gender responsive Climate resilient practices popularized under the model are

- Integrated homestead aqua-horticulture with participation of women
- Community fish seed nursery
- Delayed stocking of homestead ponds with stunted/advanced fingerlings
- Farming of short duration fish species
- Production of farm made fish feed and feeding management
- Multiple stocking and multiple harvesting of fish
- Women friendly fish and vegetable harvesting
- Open pollinated/disease resistant/ biofortified vegetable varieties
- Crop calendar for proper planning & growing of seasonal vegetables
- Vegetable rotation (shallow with deep rooted, tuber with leguminous)
- Use of biofertilizers

- Integrated Pest Management
- Vertical farming of vegetables
- Mushroom cultivation
- Vermicompost production and use
- Women Farmer Interest Groups and Custom Hiring centres

Establishment of Community nurseries for production of stunted juveniles of Indian Major Carps facilitated the late stocking and for replenishment during multiple harvesting. Integration of aquaculture with horticulture was done in the farmers field through establishment of nutrigarden with cropping calendar. Farmers were provided with critical inputs like fish and vegetable seeds, planting material of horticultural crops, protrays, nets, ecofriendly pest control measures, prophylactic fish medicines etc. Demonstrations and capacity building on different aspects like nursery rearing of fish seed, post stocking management, portray cultivation of vegetables, layout preparation of nutrigarden, vermicompost production (for organic vegetable cultivation), mushroom cultivation as an alternative livelihood option, farm made fish feed preparation, water quality testing, sampling of fish etc were carried out ensuring the participation of women farmers. Introduction of minor carps (Puntius gonionotus) as a candidate species for polyculture with Indian Major Carps and also as a short term species in seasonal ponds has resulted in added income and nutrition of rural families.

With the adoption of the practices, the average household availability of vegetables increased by more than 200% and that of fish increased by more than 150%. The farming of short duration species like barbs ensured added income and nutrition to the farm families The fish production from homestead aquaculture increased by 66% to 1.06t/acre with an average gross income of 135000/acre. The adoption of mushroom cultivation as an alternative income source is helping the women farmers to earn an average income of Rs 460/day.

Women's participation in various aqua cultural and horticultural activities also showed a marked increase. The highest increase was in the stocking of fingerlings with proper acclimatization in homestead ponds followed by farm made feed preparation. The highest increase in participation in horticultural operations were in vegetables harvesting followed by transplanting of seedlings. The CHC's managed by women FIG's in the villages are serving as alternate livelihood options for women to cope up with the adverse effects of climate changes. The empowerment of women with respect to access to resources and decision making by adopting GRIHA model was assessed. As per the response from the women farmers there was a 37% increase in access to good quality fish and vegetable seeds. This could be attributed to the establishment of community fish nursery in the villages which helped them to replenish the fish stock in their ponds regularly. Also the convergence/linkage that was established with the respective KVK and State Fisheries department hatcheries helped the farmers to procure fish seed in times of need. There was a 31% increase in access to timely skill trainings because of the project interventions. The farmers were regularly given trainings on homestead aquaculture, vegetable farming, ecofriendly pest management, mushroom cultivation, vermicompost production etc. With the participation in gender inclusive climate resilient homestead aqua-horticulture, there has been a 39% increase in the participation in decision making of women farmers regarding how much of their farm produce is to be retained for home consumption or sale. The increase in decision making power will eventually transform the power relations in the family and society bringing about a recognition for the contribution that women makes towards nutritional security and livelihood of their families. The evident increase in the women's participation in decision making regarding what when and how to grow fish and vegetables indicate the confidence they have gained through the skill training and capacity building activities.

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Gender-responsive Extension Approaches for Promotion of Climate Resilient Farming

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Agriculture is an engine of growth and poverty reduction worldwide and women are an integral part of it. In India, women's involvement in agriculture is complex and diverse. They participate in wide range of activities in farming. There is a considerable variation in women's participation across regions from north to south, from one socio-cultural group to another and even two production systems. As per census data, share of total women workers in agriculture was 71.8% in 2001 and has come down to about 65% in 2011.

In the agricultural sector, women participate in a number of agro-production systems that govern the nature and extent of their involvement. There is a significant heterogeneity across regions, states, locations and context in the role of rural women and their participation in agricultural and other economic activities. Most significant agricultural activities undertaken by women include farming, post-harvest management, horticultural crop production, livestock management, fisheries and homestead resources. In paddy, women are mainly involved in transplanting, weeding, harvesting, drying harvest, winnowing and seed storage. As far as total workload is concerned, women spend 40.2 percent of their time per season, performing transplanting (39.1 hours), harvesting (29.8 hours) and weeding (19.0 hours) as the major activities (AICRP Report). In sugarcane based cropping system, women participate in activities like manure and fertilizer application at first step, preparation of sugarcane sets for sowing, placing these sets into the ridges, irrigation, weeding, harvesting, tying the bundles, carrying sugarcane bundles and loading it in to the vehicle. Again these are not women dominant or exclusive activities and are performed jointly with males. The data on role profile indicates that joint participation of rural women with men was higher than independent participation of women in all activity areas.

Gender analysis in various sub activities in livestock management reveals that women play significant role in milk production, processing and marketing of milk products, acting as care providers, feed gatherers, and birth attendants. Women are typically responsible for milking, processing and selling milk products, providing fodder and water, caring for new born calves and sick animals. The data reflects that independent participation of women is highest in homestead garden related activities followed by livestock management. Similar is the case for responsibility profile as activities in these two areas are confined to household vicinity.

Women are involved in fish production, drying/curing, marketing, shrimp processing and net-mending in the coastal areas including Maharashtra, Tamil Nadu, Andhra Pradesh and Odisha. In addition, in Andhra Pradesh, women are engaged in mollusk and shell collection on seasonal basis. Among the mangroves of Bhitarkanika on the Odisha coast, both women and men fish in the freshwater. Apart from the homestead activities that are traditionally considered to be women's domain, their independent role is the highest in livestock production management, one of the highest water consuming area, followed by post-harvest management. The joint participation of men and women is the maximum in fisheries, followed by horticulture and post-harvest management. Analysis of the sub activities in this area reflects that women are involved in home based post-harvest operations whereas more men were involved not only in field based activities but also activities outside home such as processing, sale, etc. The livestock management performed by women is more laborious and time consuming than the activities performed by men.

Gender-responsive innovations for climate change mitigation and food security

Women and girls in developing countries are usually expected to look after household energy needs, manage waste and collect water. Gender inequalities hinder their ability to adopt climate-smart agricultural practices that can reduce greenhouse gas emissions. When pursuing practices that contribute to climate change mitigation, it must be acknowledged that women and men are often not in the same position to take up these practices. For example, for people with weaker tenure rights, agroforestry may be less accessible or deliver fewer benefits. If hiring labour is not possible, some soil and water conservation practices may be difficult to implement. However, some technologies and practices, like improved cooking stoves and the use of biomass for energy and biogas, may be more attractive to women because they save time and labour. Programmes that support women farmers to adopt efficient agricultural production practices, including water management for irrigation and use of bioslurry as fertilizer for crops, should be encouraged.

It has been demonstrated across a wide spectrum of field interventions that effective partnerships and collaboration with local groups and institutions, and participatory community-led development approaches can generate substantial synergies and speed up the adoption rate of climate-smart agriculture practices by women and men.

In general, group participation is a widely used mechanism for protecting or enhancing assets and encouraging the pooling of risks, particularly for women. Groups and community-based institutions represent a key strategy for climate change adaptation. They serve primarily as a mechanism to facilitate the development of assets through group purchase of large farm appliances (physical capital), group loans (financial capital) or capacity development (human capital).

Farmer Field Schools (FFS), originally championed by FAO, can serve as hotbeds for farmer innovation and experimentation. Because women and men participate fully during all stages of cultivation, marketing and decision- making, FFS permit gender inequalities to be addressed in a comprehensive manner. This includes the incorporation of gender considerations in the development of innovative and climate-smart agricultural technologies practices, such as alternative fodder/food for livestock (for example, paddy/grass varieties that tolerate saline soils); new poultry and cattle genotypes; introduction of mulching; wet resources utilization; and homestead plant nurseries.

There is a gender productivity gap as a result of differences in access to and control of productive and financial resources between male farmers and their female counterparts. Since agriculture production is more vulnerable to climate change and variability, the gender differences in accessing and controlling resources have serious implications on the household's adaptive capacity to adverse effects of climate change. Women are affected more than men when climate-related disasters occur. This result in disruptions to livelihoods and the gap between the vulnerable members of society and those with a better capacity to cope widens. Women and men are changing their cropping practices and this has different impacts on access to and control over income from crops, as well as their respective workloads (Jost*et al*., 2015; Nelson andStathers, 2009).

When the gender gap in agriculture is increased as a result of climate change; women take on more agricultural work as men migrate for labor, they have less access to agricultural resources such as land, climate information services (CIS), extension services and inputs with which to adapt to variability and change, gendered social norms and roles inhibit their adaptive capacity, and they are absent from decision making at community, national and global levels); When they do have access to information and the resources to implement CSA, they are often just as likely as men to adopt and can experience increased empowerment in the process (Twyman*et al* 2014).

If the causes of the gender productivity gap between men and women farmers are not addressed, the development of new CSA technologies will reinforce existing inequalities. These inequalities can be addressed through the promotion of gender-responsive technologies. These are technologies that are based on the interests of both female and male farmers; technologies that reduce time and labour for women farmers, and technologies that are accessible and affordable to both men and women.

Approaches to Gender and Social Inclusion

A gender-responsive approach to CSA is essential to address the gender gaps for climate resilience in agriculture and requires that the needs and priorities of men, women and youth are recognized and addressed (Nelson &Huyer, 2016). Research has shown that the additional integration of women's empowerment approaches and dimensions into this scaling framework provides the opportunity to promote gender equality while scaling up (Huyer et al., 2021). The literature demonstrates that more equal gender relations within households and communities lead to better agricultural and development outcomes, such as increases in farm productivity and improvements in family nutrition" (World Bank, FAO and IFAD, 2015).

A Gender-responsive Approach to Climate-Smart Agriculture

Overview of gender-responsive approach

The gender gap in agriculture is a pattern, documented worldwide; in which women in agriculture has less access to productive resources, financial capital and to advisory services compared to men (FAO, 2011). In the context of Climate-Smart Agriculture (CSA), this gap means that men and women are not starting off on a level playing field. While gender shapes both men's and women's lives, the tendency is for women to have a more disadvantaged position in comparison to men. This can have significant implications for the adoption and sustainability of practices under a CSA approach. Further, there is a risk that, if this gap is not taken into consideration, the development of site-specific CSA options could reinforce existing inequalities.

The aim of this brief is to explain how to take into account the gender gap in agriculture in the development of site-specific CSA-sensitive practices, such as those described in other briefs in this series, through the adoption of a gender-responsive approach. This approach means that the particular needs, priorities, and realities of men and women need to be recognized and adequately addressed in the design and application of CSA so that both men and women can equally benefit (World Bank, FAO and IFAD, 2015). It also means that, as changes in agriculture are pursued in response to a changing climate, there needs to be a consideration of ongoing socio-economic changes. An example of a socio-economic change is the move of more women into agriculture as men exit, and the related inequities in rights over resources including land, water, trees, livestock, grazing and fisheries (Huyer*et al*., 2016). Lastly, a gender- responsive approach means that the monitoring and assessment of CSA needs to include gender-sensitive indicators which help track progress in closing the gender gap in agriculture1 (Huyer*et al*., 2015).

It is important to note that this brief was developed under the Global Alliance for Climate-Smart Agriculture and is part of a series of briefs on practices. As such, the focus here is primarily on practices, but a gender- responsive approach across the entire field of CSA is needed to enhance them. Additional gender-responsive efforts in the field of CSA, which are outside the scope of this brief,include the following: giving attention to gender issues in CSA policymaking; building an evidence base on gender in CSA; developing financial instruments that respond to women's and men's needs; and introducing institutional change to develop capacity and build commitment on gender equality and women's empowerment (Huyer et al., 2015; Lipper et al., 2014).

How to adopt a gender-responsive approach to CSA

As explained above, the gender gap in agriculture is of relevance to CSA as it potentially puts women and men in unequal positions in terms of participating in and benefitting from site-specific CSA practices and options. How can CSA-sensitive practices be identified, designed and implemented in a way that takes into account the local, existing differences and inequalities between men and women, and contributes to the promotion of gender equality?

Reaching women farmers with climate-smart agriculture information: How can we do better?

One needs to make sure that the climate-smart agriculture policies, technologies, and tools also work for women who, despite being a significant percentage of the world's women farmers, face major gaps in capturing the benefits provided by CSA. Women are experiencing increased responsibilities and workloads, especially in situations where there are climate driven outmigration of men and young people. For example, workloads increased for women in rainfed farming households in Maharashtra, India, due to fluctuating crop yields and longer distances to travel for fuel, fodder and water for their livestock. Women are usually hesitant to adopt new adaptive practices in agriculture because of apprehension that their workload may increase. So, how to streamline with climate-smart agriculture information to women farmers?

1) Through PRA and RRA in the village level women farmers should be sensitized regarding climate-smart agriculture information. Facilitator must enlighten women farmers that ensuring equitable access to technologies that reduce women's burden and increase their productivity is quintessential, and in few cases can lead to increased diversity of crops, improving household nutrition.
2) Climate-smart agricultural technology should be gender friendly for that Participatory Technology Development (PTD) may be a helpful tool.
3) UN Women estimates that the gender productivity gap in agriculture is $100 million in Malawi, $105 million in Tanzania, and $57 million in Uganda. If in India it would be measured it may be much higher. So, it's high time for capacity building for the women farmers with climate-smart agriculture.
4) Illiterate farm women can be informed through Climate-smart agriculture videos.
5) Convergence of different training institute can be materialized for better output and outcome for knowledge enhancement of women farmers with climate-smart agriculture.
6) Training should focus on Climate-smart agriculture including environmental restoration activities, processing of agricultural produce as well as financial management.

Climate Smart Gender Equity Approachfor Livelihood Enhancement

Considering farm women as potential stakeholders in modifying the Indian subsistence farming to commercial agriculture, a project was implemented in a cluster of two villages*viz.,* Sankilo and Tentalpur under Nischintakoili block of Cuttack district of Odisha with the major objective of women empowerment in agriculture by promoting livelihood in rice-vegetable based farming.In this context, a '*Climate Smart Gender Equity Approach'* was developed, which appeared instrumental in enhancing farm income to many-folds among the small and marginal women farmers by increasing the production potential of the major crops of the region. The approach targeted to bridge the yield gap in paddy and several periodic vegetable crops through potential varieties and package of practices. The approach claims to be gender sensitive as it adopts a women-based, women-centric and women-responsive approach in every step of problem prioritization, constraint analysis, technology dissemination and final demonstration. With farm women as the major clientele, a considerate approach was used, which were resource inclusive, simple and easy to adopt. The choice of varieties was on the basis of location-specific performance, yield potential and market preferability. A strategic approach was adopted in initially creating a gender sensitized environment, wherein the women farmers were gradually molded and made adaptable with the extended technologies. The entire period of demonstration was fostered with concurrent training, skill impartation and complete hand holding. The output of the approach in terms of income enhancement through improved production, resulted in confidence built up among the farm women of the region, which embedded the initial seed for entrepreneurial ignition among the women SHGs and FPOs.

Supplementing rice farming with potential varieties and technologies

As a normal cultivation practice, the women of adopted villages tend to use traditional varieties year after year, which results in decline of yield potential over years of cultivation as a result of superimposition of various biotic and abiotic stresses. To complement the rice farming in the region with a perspective to make it lucrative, a strategy was adopted to introduce some promising potential cultivars. In this aspect, crop planning meeting was conducted at least twice a year, before *kharif* and *rabi*season with key farm women stakeholders and farmers from the cluster villages. Eventually, varietal demonstration of 3 newly released high yielding rice varieties *viz.,* CR-Dhan 307 (*Maudamani*), CR-Dhan 409 (*PradhanDhan*) and CR-Dhan 312 suitable for all the available ecologies, accompanied with complete package of practices were conducted in the year 2020-21 during wet seasons, involving 40selected small and marginal farm women of the adopted cluster villages. As critical inputs, farm women were provided with seed mini-kits of 6 kg each along with fractional quantity of fertilizers and pesticides. They were skilled and inspired to practice seed treatment with carbendazim agro-chemical and *Trichodermaviride* (bio-agent), nursery bed management, line transplanting with young seedlings and fertilizer management. Seed production technologies for producing quality seeds for future use and post-harvest interventions for value addition were also disseminated for additional income enhancement. Other interventions extended included application of need-based pesticides, fungicides and weedicides; pest monitoring and surveillance, use of pheromone traps, Tricho-cards, Drachon-cards (bio-agents), light traps; nitrogen fertilizer management and green manuring with *sesbania* (*dhaincha*). The entire period of technology impartation was accompanied with training and capacity development programmes, continuous monitoring and technical backstopping.

Outcomes

Introduction of high yielding rice varieties, having yield potential of 11.0 t/ha and the grain yield advantages of about 30-60% in farmers' fields, resulted in an incremental income of ≈50-200% over previously grown varieties, depending upon the land type, varieties, crop management practices and prevailing market prices.

Paddy-relay pulse cropping: A step towards crop diversification

After harvesting of *kharif* rice, high yielding black gram (var. PU-31) was introduced in the rice-fallow and rice local pulse system for obtaining additional farm income and maintaining soil health conditions. Additionally, the technology appears to be input inclusive as the sequential crop (black gram) grows in the residual soil moisture without use of fertilizers and other agro-chemicals. An average yield of 2.95 t/ha was recorded in the black gram, variety PU-31, with an increase yield of ≈25-30% over previously grown varieties.

Varietal replacement in vegetable farming as a possibility to increase profitability

The farm women of the region grew several types of seasonal vegetables, usually before and after rice crop. As a practice, traditional varieties were cultivated without following improved production practices. Being ignorant about suitable high yielding and hybrid varieties in different vegetable crops, scientific package of practices pertaining to management of nutrients, pests and diseases, post-harvest care and packaging for marketing, resulted in incurring marginal profits from vegetable farming. Therefore, with an objective to enhance vegetable production in the region with a vision to maximize their net profits, introduction and demonstrations of high yielding and hybrid varieties of vegetables like cowpea (var. Kaveri), pumpkin (var. Arjuna), bitter gourd (var. VNR-28), brinjal (var. VNR-Utkal), ridge gourd (var. VNR-102), okra (var. Radhika), cucumber (var. VNR-Krish), chilli (var. Daya) were expansively carried out in the cluster villages. Under the Livelihood Enhancement Model, over 40 farmwomen were provided with quality vegetables seeds along with fractional inputs comprising of fertilizers, pesticides, fungicides and plant hormones as critical requisite materials. They were trained and motivated particularly to practice seed treatment before sowing to minimize the subsequent crop protection cost. Other simple yet effective technologies such as raising vegetable seedlings in pro-trays to obtain an early and healthy planting material; fertilizer management especially judicious use of nitrogen fertilizer and application of micronutrients; crop health management technologies such as application of need-based pesticides, fungicides, weedicides and hormones; pest monitoring and surveillance, use of pheromone traps, tricho-cards were also extensively disseminated. Other interventions included pre-cooling to remove field heat and to extend shelf life. The women farmers of the region were constantly supported with training and capacity development programmes, continuous hand-holding and technical backstopping.

Outcomes

With the introduction of high yielding and hybrid vegetables varieties among the farm women of the adopted village cluster, there was an increase in average gross return of ₹72,500/year and the average net return was ₹43,500/annum. With the introduction of high yielding vegetable varieties, having good yield potential, an average yield advantages of about 25-50% was realized in the farmers' field. This resulted in an incremental income of ≈155-203% over previously grown varieties. The group approach in vegetable farming has generated a total income of ₹6,59,300/- out of which a value of ₹98,895/- of vegetables has been used for household consumption and ₹5,60,405/- of vegetables sold in nearby market.

Gender-smart Agriculture: The only way forward for women and climate

Climate Smart Agriculture (CSA) is the only way forward for food and nutrition security and the planet's resilience. But we need to make sure that the climate-smart agriculture policies, technologies, and tools also work for women who, despite being a significant percentage of the world's farmers, face major gaps in capturing the benefits provided by CSA.

Over the years the World Bank has worked hard at ensuring that investments in the agriculture and foods sector match the urgency of the climate crisis. Agriculture projects are also overwhelmingly inclusive of women and their enormous roles in the rural sector. The FAO estimates that women make up 43% of the agricultural workforce globally. This number goes up to over 60% in least developed countries.

Women are experiencing increased responsibilities and workloads, especially in situations where there are climate driven outmigration of men and young people. For example, workloads increased for women in rainfed farming households in Maharashtra, India, due to fluctuating crop yields and longer distances to travel for fuel, fodder and water for their livestock. Women may also be hesitant to adopt new adaptive practices in agriculture out of concern that their workload might increase.

Ensuring equitable access to technologies that reduce women's burden and increase their productivity is essential, and in some cases can lead to increased diversity of crops, improving household nutrition.

Women have less access to technologies, information, resources, and finance for their agriculture activities across the globe. The cost of the gender productivity gap in agriculture – inequalities in access to and control of productive and financial resources -inhibits agricultural productivity, reduces food security, and costs millions to countries. For instance, UN Women estimates that the gender productivity gap in agriculture is $100 million in Malawi, $105 million in Tanzania, and $57 million in Uganda.

However, policymakers do not yet always make these connections. A recent analysis of nationally determined contributions (NDCs) submitted before October 2021 found that only 43 countries (22%) addressed gender in relation to agricultural adaptation or mitigation actions. A total of 48 NDCs were submitted by African countries, and only 23 included a reference to gender in relation to agriculture.

We need to continue to find more ways to support women's agriculture activities that will overcome the gender gap in productivity and promote gender equality for the benefits of their communities and society, while also understanding the critical role women play in mitigating and adapting to climate change.

Let's make sure that climate-smart is gender-smart !!

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Reducing Vulnerability of Women Farmers through Climate Smart Poultry Practices

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Livestock sector is regarded as a crucial part of Indian economy. Almost two-third of the Indian rural community are engaged in this sector for their livelihood. Livestock sector provides employment to around 8.8 % of the population in the country (Khan and Tomar, 2022). India is bestowed with vast livestock resources. The Economic Survey reported that the Indian livestock sector risen at a remarkable Compound Annual Growth Rate (CAGR) of 7.38 % at constant prices from 2014-15 to 2022-23. The share of livestock to the total Gross Value Added (GVA) at constant prices in agriculture and allied sectors hiked from 24.32 % in 2014-15 to 30.38 % in 2022-23(Economic Survey of India, 2023-24. GOI).The livestock sector shared5.5% of the total GVA in 2022-23, substantially boosting the per capita availability of milk, eggs, and meat in the country. Currently, India possesses highest livestock population in the globe (BAHS, 2024, GOI).

Indian Poultry Sector: Current Scenario:

Poultry – one of the key component of livestock sector producing eggs, meat, feather and manure. Poultry meat and egg are powerhouses of nutrition and thereby support the national food and nutritional security. Eggs are considered as the best and most easily available source of protein with a high biological value of 94%; packed with essential amino acids, vitamins and minerals. Poultry meat is considered lean and a cheaper source of high-quality animal protein, thus in high demand by the consumers. India ranks second in the globe in terms of egg production (142.77 billion Nos) and the per-capita availability of eggs is 103 eggs/annum which much less than the recommended value of 180 eggs/annum by the Indian Council of Medical Research. Egg production has increased by 3.18% over the previous year. The commercial poultry sector produces 84.59% (120.77 billion Nos) of the total egg production while backyard poultry contributes15.41% (22.01 billion Nos) of total egg production in the country. The top egg producing states in India are Andhra Pradesh, followed by Tamil Nadu, Telengana, West Bengal and Karnataka which together share 64.37% of the total egg production in the country. The contribution of improved fowl and desi fowl to national egg basket are 86.33% and 12.62%, respectively. The contribution of improved duck and desi duck to national egg basket are 0.83% and 0.22%, respectively. India holds 5th rank in global meat production (10.25 MMT) after China, USA, Brazil and Russia. Meat production has increased by 4.95 % over the previous year. The national average per capita availability of meat is 7.39 kg/annum which is much less than ICMR recommendation value of 10.5 kg/annum. The top meat producing states in India are West Bengal, followed by Uttar Pradesh, Maharashtra, Telengana and Andhra Pradesh which together share 57.46% of total meat production in the country. A total of 3.35 billion poultry were slaughtered in the country for meat production and contributed 48.96% of total meat production during the year 2023-2024 (BAHS, 2024, GOI). As per the 20th livestock census, 2019, the poultry population in the country increased by 16.81% over the previous livestock census showing the increased demand for poultry products in the country (GOI, 2019). Growing population, rising income and the purchasing power of the middle class, urbanization, shifting dietary preferences among the consumers are the few major causes of the heightened demand for poultry products (Kumar, 2016). The Indian poultry sector observed a transformational revolution during 2000-2001 due to policy innovations like liberalization of the grandparent poultry stock import, vertical integration and introduction of the concept contract farming between the large integrators and the small-scale farmers, thereby shifting backyard farming to commercial poultry farming. Commercial poultry farms contribute nearly 80% of the egg and broiler meat production in the country (BAHS, 2024 GOI).

Indian Poultry Sector and Gender Equity:

The livestock sectorcampaign for gender equity since more than three-fourth of the labour requirement in livestock sector is met by women. (Kumar, 2016). The livestock sector plays crucial role in aiding the livelihood of resource poor rural women. Nearly two-third of the rural women are engaged in livestock husbandry (BAHS, 2024, GOI). In livestock sector, the concept of gender equity is more evidentbecause women contribution is 71% of the labour force compared tojust 33% in crop cultivation (GOI, 2010). As many as 75 million women are engaged in the livestock sector as against 15 million men (GOI, 2016). The role of women in livestock production system is pivotal, majority have competent knowledge on livestock behavior and locally available feeds and fodder. Among the different types of assets, livestock can be easily owned by women and thus can help in sinking gender asset gap within the family (Kristjanson et al., 2010) and livestock is the only asset which is owned and controlled by rural women andaworthy source of cash for them during time of need (World Bank, 2009).

In the livestock sector, poultry sector plays important role in women empowerment especially in the rural community. Poultry are birds that includes fowl(chicken), duck,turkey, goose, guinea fowl, emu,ostrich,etc. which provide high quality human food (meat and egg), raw materials for industries(feathers, waste products); ultimatelyprovide income and employment (Avila,1985; Demeke, 2004).Agriculturists and nutritionists advocated that in developing countries like India, the poultry industry serves as the rapidest way of bridging the protein deficiency gap.The poultry sector shares around 1% of national GDP and 11% of total livestock GDP ofour country. The projectedannual growth rate of layers is 6-7% and 10-15% for broilers (Bhaduria et al., 2016). Ivo (2009) advocated village poultry as a viable sector to alleviate protein deficiencies.Poultry sector in India has made notableexpansionin last few decades and effectivelyconverted itself to a dynamic industry from the ancient backyard farming. Availability of high yielding layer and broiler strains along with improved package of practices on feeding, breeding, housing, management and disease control are major factors responsible for this spectacular growth.Due to the consistent rise in productivity, the per capita availability of eggs and meat has increased to 103 eggs and 7.39 kg of meat per annum. However, it is still lagging the ICMR recommended value of 180 eggs and 10.8 Kg poultry meat per person per annum. Therefore, to meet the nutritional requirements, the layer and broiler industry must grow by several folds (Panda and Samal, 2016).

Indian poultry sector- a tool for empowering rural women

Poultry production especially in rural/backyard areas is one the promising tool for empowering rural women. Poultry based intervention can promoteinclusive participation of women and women empowerment, thuswarranting poverty alleviation, food and nutritional security and gender equality.Poultry farming is a potentialmeans for women's empowerment due to high accessibility, flexibility, and potential tool for women'seconomic independence.Among the different livestock species poultry sector is more appealing for the women since:

i. These small birds are easy to handle, easy to manage
ii. Low initial investment: do not need expensive housing and farming system
iii. Less time and labor needed: managed by women after fulfilling their household responsibilities
iv. Provide early return: at 6-8 weeks broiler birds can be sold for meat purpose and at 4-5 months layer birds start laying eggs
v. Poultry products – meat and egg are power packed with protein, minerals, vitamins and other macro and micro-nutrients that would support the family nutritional security
vi. providing additional source of income to women thus providing financial security
vii. women can rear alternate poultry (other than fowl) like duck, turkey, goose, quail farming based on market demand and generate more profit.
viii. The rearing of poultry in the backyard of the house or the family poultry can be source for empowering the rural women by providing additional source of income that can be used by the women during family needs.

Poultry farming is one of the major sources of the rural economy. The degree of women involvement in poultry farming at household level is significant in poultry sector. Although, the poultry sector has very high potential for uplifting the standards of women especially in the rural India, this sector is facing several challenges amongst which the climate change is the foremost issue in a tropical country like India. Since women participation is central in this sector and women are more vulnerable to the impacts of climate change, it further worsens the scenario.

Climate Change-Women and Poultry:

What is climate change:

Climate change is a long-standing change in the average weather patterns of earth's local, regional and global climates. The key indicators of climate change as observed from climate dataare-increase in global land and ocean temperature; rising sea levels; ice loss in mountain glaciers and at the poles; increase in frequency and intensity/severity of extreme weather events such as hurricanes, cyclones, tsunamis, cold waves, heatwaves, wildfires, droughts, floods, and precipitation. The global temperature is currently rising by more than 0.2^0C (0.36^0F) per decade. The earth's warming trend at the present scenario is obviously the result of anthropogenic activities since the 1950s and is progressing at an unparalleled rate over the millennia(science.nasa.gov).Earth's surface temperature has risen by 1.1°C by 2011-2020 compared to 1850-1900(IPCC, 2023).

Climate Change and Vulnerability of women:

Climate change affects human health by increased exposures to heat, deteriorating the air and water quality, frequent occurrence of extreme weather events like flood, cyclone etc, vector-borne disease transmission, scarcity of food and water thus shaking the food security;however, impactsboth the genders differently due to differential biological, physiological, socio-economic and cultural facets.In developing country like India, where fastecological changes are taking place, climate change further widen the current gender-based health discrepancies. Poverty further intensifies women's health vulnerabilities which expand risk on a regional scale (Sorensen et al., 2018). The growingindustrialization and urbanization, ever-growing population, technological and economic progress has led to amplifyingthe per capita CO_2 emissions. The net outcome is that women, especially poverty-stricken, are vulnerable towards the negative health impacts from the emission of heat trapping greenhouse gasses (GHGs). In India, the annual temperature is projected to rise between 1.7 to 2.2 °C in 2030, compared to1970(Barros et al., 2014) ensuing more people being exposed to extreme temperature.

Climate change has greater impact on women than the men

- Women experience disparate mortality and reduced life expectancy after/during disasters (Kuehn and McCormick, 2017; Van Zutphen et al., 2012).
- Women facemore deposition of inhaled particles in their lungs thus more susceptible to respiratory disease (Beggs and Bambrick, 2006),
- Women and girls vulnerable for physical and sexual violence, after/during disaster notably those who are very socially backward and poor (International Federation of the Red Cross and Red Crescent, 2007)
- Women delivering during the time period following disasters are vulnerable for complicationslikelow birthweight infants,preeclampsia, bleeding etc. (Tong et al., 2011)
- Women more vulnerable formalnutrition, food insecurity and nutritional deficiencies due to increased nutritional requirements during menstruation, pregnancy and lactation.
- Water scarcity forces consumption of water from sources that may be contaminated, resulting in bacterial/viral/protozoan infections as well as toxin exposure (Duncan, 2006)
- Traveling to long distances to fetch water prolongs the heat exposure (Shiva and Jalees, 2005)
- Scarcity of water and sanitation forms unsafe conditions for women, specifically during menstruation (Birch et al., 2012)
- Increased risk of dengue and malaria: pregnant women are three times more vulnerable for severe malaria than non-pregnant women (Steketee et al., 1996).
- Women differ from men in their thermos-regulatory mechanism for regulating heat during high elevated ambient temperature Women dissipate less heat compared to women by sweating, possess higher working metabolic rate, possess thicker subcutaneous fat thatdeclines radiative cooling (Duncan, 2006).
- Cultural liabilities include deprived access to hospital and health care facilities, cooling facilities because of personal safety worries,wearing the culturally approved heavy garments limiting the heat dissipating evaporative cooling mechanism.
- Women aremore sensitive to toxicologic impacts of airborne pollution as they suffer more rates of anemia (Sørensen et al., 2003).
- Women are vulnerable to mortality in disaster events like cyclones and floods (WHO, 2014). In 1991 cyclone in Bangladesh among the 140,000 deaths, 90% were women (Aguilar, 2004) and in 2008 Nargis cyclone in Mayanmar, among the 130,000 deaths, 61% were women (WHO, 2014). Social disparities in terms of approach to basic social goods/facilities, culturally recommendedgender roles, biologic vulnerabilities are the reasons for the gender discrepancies (Moosa and Tuana, 2014). The gender difference in mortality is widened when women are from a poor socioeconomic class in a specificlocality (WHO, 2014).

Climate Change-a challenge to Indian Poultry sector:

The most obvious limitation on poultry production is the adverse climate, especially high ambient temperature. Poultry seems to be intensely sensitive to heat stress caused by high ambient temperatures and worsened by high humidity resulting in poor performance of the birds in terms of reduced meat and egg production. Researchers haveproposed that modern poultry genotypes/strainsgenerate more body heat, owing to their intense metabolic activity (Settar, 1999 and Deeb and Cahaner, 2002). Therefore, realizing and controlling the environmental conditions is necessaryforefficient poultry production. Pant (2011) reported that poultry farmers face direct cost of climate change fromreduced egg and meat production and indirect costs by measures of adaptation liketo alleviate the heat stress extraexpenses will be installation of air cooler or sprinklers on roof (NAAS, 2016).Furthermore, poultry are more vulnerable since birds can only tolerate a narrow temperature range (Costa, 2009). Compared to other domestic animalspecies, poultry is more vulnerable to heat stress as they lack sweat glands, higher basal metabolic rate/body weight and feather covering over the body. The negative effect of heat stress starts to be observed when Temperature Humidity Index (an index developed combining the temperature and humidity of the environment to measure thermal load/heat stress on the animals/poultry) goes beyond 72 (Behera et al., 2019). Poultry, specifically, is vulnerable totemperature fluxes, resulting in drop in eggproduction and reduced growth in these birds (Behera et al., 2023).The internal body temperature of domesticated gallinaceous fowlranges 41.2°C to 42.2°C is significantly higher than human and livestock (36°C to 39°C). The upper temperature limit beyond which living cells graduallystop operating is determined by the temperature at which enzymic proteins are denatured. This starts at around 46°C and thus poultry hasnoticeably less flexibility than other livestock species;swiftly succumb to higher ambient temperature.Lack of sweat glands limits the natural evaporative cooling, though some directdiffusion of water occursvia the skin tissue. Only the comb has profuse blood vessels and serves as sites for direct heat loss. Domesticpoultry ismore vulnerable to heat than cold and more likely to succumbfrom hyperthermia than hypothermia (Bhadouria, 2016).

Reaction of adult poultry to environmental temperatures

Temperature Range	Impact on Poultry
55^0 to 75^0 F	Thermal neutral zone.
65^0 to 75^0 F	Ideal temperature range.
75^0 to 85^0 F	Marginaldrop in feed intakebut if nutritional intake is satisfactory, doesn’t affect the production. Reduced egg size shell quality as thetemperature touches the upper limit of this range
85^0 to 90^0 F	Furtherfall in feed intake. Reduced weight gains, egg production, deteriorated egg size and shell quality. Cooling mechanisms should be operated on before reaching this temperature range.
90^0 to 95^0 F	Feed intake continues to fall. Chance of danger of heat prostration in layers, especially the heavier birds that are in full production. Cooling systems must be

	switched on.
95^0 to 100^0 F	Heat prostration occurs. Emergency actionsmight be required. Severe drop in egg productionand feed intake. Water intake is much more.
Over 100^0 F	Emergency measures are essential to cool the birds. Survival of the birds is the prime concern.

(Source: Bhadauria et al., 2016)

Heat stress on poultry can be acute orchronic. Acute heat stress occurs when birds are exposed to sudden extremely hightemperature for a short period, while chronic heat stress occurswhen birds are exposed toprolonged periods of raisedtemperature. Chronic stress detrimentallyaffects birds kept in open-sidedhouses chieflyby reducing the feed intake and increasing the waterconsumption. In such a situation, feed efficiency,growth rate and carcassquality are adversely affected in broilers. The broilers take more time to reach market weight, and more mortality is observed.In hens, heat stress drops egg production, egg quality, besidesshortening the shelf life of eggs. In breeder birds, elevated temperature combined withhigh humidity reduces fertility and hatchability. During heat stress the hens engage their body energy in major thermo-regulatory adaptations, thus, the full genetic potential is often not reached.Climate change can adversely affect meat quality. In broilers, heat stress islinked with decline of chemical composition ofmeat and thus its quality (Dai*et al*., 2012 and Imik *et al*., 2012).Furthermore, climate change in terms of natural calamities like cyclones, drought flood etc. will lead to loss of feed and crop production leading to feed scarcity for the poultry.

Minimization of climatic stress on poultry and reducing the vulnerability of women Adaptations and Mitigation strategies:

Possible adaptive responses include technological interventions (e.g. more heat-tolerant poultry breeds/strains); behavioral modifications (e.g. changes in dietary choices); managerial choices (e.g. different farm management practices); improving the digital literacy of women, access to the technologies and sensitization of gender in different policiesetc.

Climate Smart Poultry Farming by women in climate vulnerable zones:

Areas exposed to high thermal radiation (arid and semi-arid regions, hot and humid tropics), areas experiencing heavy precipitation, low lying areas, coastal regions near to sea basin are mainly the climate vulnerable zones. Five-fold surge in these extreme climate events; a four-fold rise in extreme floods were observed during the last decade. Districts in eastern India are more vulnerable to extreme floods, closely followed by the northeastern and southern parts.There has been a two-fold upsurge in drought events, specifically in the agricultural and meteorological droughts. Cyclone occurrence has been increased by four-folds.More than 85 percent of Indian districts are subjected to severe climate events. More than 60% of districts in states like Bihar, Odisha, Andhra Pradesh, Gujarat, Rajasthan, Uttarakhand, Himachal Pradesh, Uttar Pradesh,Maharashtra and Assam facemore than one extreme climate event.The current catastrophic climate extremitiesexpose nine out of 10 Indians to extreme climate events and is theoutcome of a temperature rise (0.6^0C) in the last century (The Hindu, 2024).

According to FAO (2010) compared to cattle, poultry emit less methane, less phosphate and carbon dioxide compared to other meat-producing livestock. Genetic diversity in fowl is greater than any other livestock species. It is estimated that the production of chicken meat andeggs contributes 8% of the annual worldwide greenhouse gas emissions from the livestock industry or 606 million tonsof CO2equivalent (Liu et al., 2015). It is estimated that the average emission intensity for layers is 3.5 kg of CO2equivalent per kg ofeggs. For broilers, it is 5.4 kg of CO2equivalent per kg of carcass weight (Safder et al., 2023). Furthermore, most of the indigenous strains/breeds have good adaptability against harsh climate and diseases(ILRI, 2006). However, amongst all environmental factors, the poultry sector is least tolerant to temperature extremes, resulting inreduced egg production and growth.

Women are the major stakeholders of the poultry especially in the rural areas, therefore practicing climate smart poultry husbandry in the climate vulnerable areas where the women frequently suffer from loss of finance, deterioration of health, loss of life due to extreme climate events- will not only save the poultry birds from extreme events but also be a tool to empower the women of the climate vulnerable regions. In addition, rising sea levels, saline water intrusion, and natural disasters such as cyclones, droughts, and floods canhave negative effects on the economy, human lives lost, traditional lifestyles lost, biodiversity lost, disease outbreaks,and starvation(Scissa, 2024).

Climate smart poultry husbandry practices:

Housing Management

Scientifically designed poultry houses with proper orientation,height and open space for ventilation and optimalstocking density of birdsprovide comfortable micro-environment inside the house. Several climate smart poultry house management components are:

i. Insulating the roof: it is done to maintain a uniform temperature, to conserve heat and to reduce heat stress on the birds. It benefits in enhancing bird's performance both in summer and winter. During winter, insulation helps in conserving the heat of the house and makes the wall, ceiling and floor warmer, thus a comfortable environment for the birds. In hot days, it reduces the amount of heat entering the house and thus provides a cooler environment inside the house.

   Examples of Insulating materials:Polystyrenes, Polyurethans, Vermiculite, Cellulose, Fibre glass, various wool products, aluminium foils, polyethylene sheets, reflecting roof paints etc.

ii. Air movement: Raising the volume of air movement over a bird canaccelerate the heat removal from the birds.Air movement enhances convective heat loss from the birds, eliminates trapped heat between the birds and from cages. With rise in air speed, heat removal increases, and the bird feels comfortable.

iii. Ventilation: when the temperature and humidity are high, poultry shed ventilation is crucialfor removal of heat and thus maintaining theoptimal productivity of the flock.Proper ventilation in the poultry house ensures easy flow of outside air into and out of the house. Increased air-exchange results in increased air flow over the birds, consequentlyraising heat loss by convection.The long axis of the naturally ventilated poultry shed should bein east–west direction which protects direct entry of sunlight into the house. Presence of obstructions like other buildings or trees can block natural air flow into the house, thus should be taken into consideration while construction of poultry houses.Another system known as forced ventilation systems where all air current is generatedthrough fans installed in the walls.Use exhaust fans to provide air movement further improves the cooling system.Stale air is propelledout of the shed by fans at a marginally higher rate than speed at which air enters through the vents. This ultimately builds a partial vacuum; air enters the shed at a high speed.

iv. Evaporative cooling: Chiefly 2 types of evaporative cooling systems are in use in poultry sheds: Pad system and fogging systems. Pad systems can only beused in power-ventilated/force ventilatedhouses, whereas fogging systems can be installed in both in power ventilated and naturally ventilated buildings. Another system, sprinkling, getsrestricted useonly in very dry climates.Foggers decreaseambient temperature inside the building when temperature is high but humidity is low, markedly during mid-day. The foggers shoot up fine water particles into the warm house. The effective environmental temperature is reduced as when the water vaporizes, heat is absorbed from the air.Foggersmust beused intermittently to preventundue water flowing into the house; that will increase the humidity beyond the threshold point where birds fail to cool themselves by evaporation. The water flow rate should be 50 to 100 gallons/hour. The water pressure should be minimum 100 psi (pounds per square inch); 200 psi is desired.Evaporative cooling pads work on the same principle, butthe air is cooled when it flows through wet pads.Wet pad method prevents the issue of wet litter occasionallyconfronted with foggers, hence can be used continuously as compared to foggers which are to be used intermittently.Most popular wet pad materials are aspen fiber and corrugated cellulose used as cooling pads.

v. Stocking density: Maintaining optimal stocking density is required for ameliorating heat stress in birds. The accumulation of radiant heat between the birds observed when stocking density is high.The ideal floor space requirement per broiler chicken is 1.5 sqft and for layers 1.7 to 1.9 sqft.

Feeding management:

The aim is to enhance nutrient intake during heat stress to minimize the drop in egg and meat yield. Following feeding managements can be adopted in the poultry house:

i. Increase the nutrient density of the feed:
   - The concentration of energy oughtto beenhanced by 10% and other nutrients by 25%.
   - A low protein feed with balanced critical amino acids like methionine and lysine isdesirableoverhighprotein feed during hot periods.
   - Vitamin C and E can be supplemented in the poultry ration for their anti-stress effects during the heat stress (Njoku, 1986 and Richards, 1997).Vitamin Cdecreases the synthesis of hormone- corticosteroid thus,minimizes the adverseimpacts of stress (Kutluand Forbes, 1993).
   - Extra calcium (oyster shell grit or limestone chips)should be offered@ 1g/bird during summer.
   - Biotin supplementation 150 micrograms /Kg feed.
   - Toxin binders: Thehot and humid conditions during the summer months accelerate mould growth and toxin formation in the stored feed. Therefore, good quality toxin binders should be added while feed formulations.

ii. Feed during the cooler part of the day- early morning and evening.Do not feed the birds during the afternoon.

iii. Sudden fluctuations in feeding times should be averted.

iv. During the evening hours, the birds should be cooled, preferably using fans.Layers or broilersaccumulate body heat during the prolonged hot period during the summer days. If their body temperature can be lowered during the evening, the birds will consume more feed in the subsequent early morning.

v. Economic feed processing techniques like grinding, pelleting, wet mash feeding, addition of fat or molasses to increase palatability of the feed etc should be adopted.

vi. Non-conventional feed resources like azolla, earth-worm meal, moringa meal will help to address the feed scarcity issue generatedcaused byhostile climatic conditions.

vii. Provide sufficient cool and clean water for birds continuously. Double the watering space in the farm.Offering cool water during the noon time aids inheat sinks (internal cooling of body).

viii. Preventive treatment for heat stress through drinking water (Bhadauria et al., 2016):

a) In moderate hot weather
Ascorbic acid (Vit C):62.5 mg/litre
+ Acetylsalicylic acid:62.5 mg/litre
+ Sodium bi carbonates: 75 mg/litre
+ Potassium chloride(KCl): 125 mg/Litre
b) In heat stress
Ascorbic acid (Vit C): 400 mg/ L
+ Electrolytes
+ Acetyl salicylic acid (Disprin 1 tablet/5 L)
+ Sodium bicarbonate 1g/Litre

Breeding Management:

Genetic approach for selection for heat tolerance traits Many genes affect heat tolerance, like:

- Dominant gene for naked neck (Na)- reducesfeather cover, increases heat tolerance
- Sex-linked recessive gene for dwarfism (dw)- bodysize reduced and decreased metabolic heat production
- Frizzle (F) gene-contour feather curve outward and away from the body.
- Marker assisted selection for heat tolerant SNP/polymorphic variants by molecular approaches like selection of marker genotype
- Identifying and propagating stress tolerant species/breeds/strains that are adaptable/suitable for bioclimatic zones.
- Encouragement of rural/backyard poultry rearing in villages. Backyard poultry strains likeGrampriya,Vanaraja, Girirajaand other dual-purpose poultry canimprove the livelihood of small-scale rural farmers.
- Enhancing eggs and meat production through alternative poultry species like ducks and quails, and utilization of local feed ingredients to economize the feed cost.
- Indigenous village poultry birdscan be upgraded by breeding them to males of improved indigenous strains, by crossbreeding with exotic poultry birds with high productivity to get progenies with both genes for stress tolerance and productivity.
- Thermal conditioning/acclimatization of eggs and chicken to hot climate during pre-hatch or early post-hatch stages can enhance the heat tolerance and survivability during heat stress periods in adult stage (Bhadauria et al., 2016).

Building resilience by integrated farming system

An integrated farming system is a farming system where in the same land and resources more commodities are being used. By-product/waste of one unit is being used by the other unit and vice versa. This system ensures full potential use of the available resources for efficient usage, more productivity and resilience. Example-rice-duck and fish integrated farming system, rice-duck farming system.

Weather forecasting and early warning system

Weather forecasting helps in pre-informing the farmers regarding bad weather like heat waves, col waves, thunderstorms, cyclones, heavy rainfall etc., which is vital for the farmers to take preventive measures to safeguard the birds from bad weather conditions. Establishment government supported regional demonstration units for climate resilient poultry production system and technologies and training of rural women on backyard poultry rearing chicken, duck, quail etc. (Policy PAPER - 81, NAAS, 2016; Behera et al., 2019)

Conclusion:

Climatic change in terms of increased ambient temperature, altered rainfall and shifts in precipitation patterns, heat waves, heat stress, droughts, floods and erratic changes in seasonal patterns are emerging challenges for livestock sector and global, regional and local level. The poultry sector is more vulnerable for the environmental temperature fluctuations. Impact of climate change is gender biased, and women are more vulnerable. Under the present changing climatic scenario, poultry farming with scientific interventions like rearing improved breeds/strains that are climate resilient, adopting integrated farming for more profit, scientifically incorporation of locally available feeds, housing design of the poultry farm, adoption of heat ameliorating strategies to protect the poultry birds from heat stress etc. can empower the rural women.

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Hydroponic Fodder Cultivation: Enhancing Resiliency and Adaptive Capacity of Landless Farmwomen

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In India agriculture and animal husbandry are intricately linked and mutually dependent in various aspects like economically, culturally, and even religiously. Mixed farming, which integrates both crop cultivation and livestock rearing, is a vital part of the rural livelihood sustainability of majority of small and marginal farmers (Maitra et al., 2021). Although agriculture's contribution to India's GDP has declined from 51.81% to 20.2% from 1950 to 2021, it still supports 54.3% of the workforce, directly or indirectly.

The livestock sector, in particular, has seen remarkable growth. It is expanding at a much faster rate (4.6% annually) compared to the crop sector. Livestock contributes 4.11% to India's total GDP and a substantial 25.6% to the Agricultural GDP. The sector also provides livelihoods to two-thirds of the rural population and accounts for about 8.8% of employment in India. India ranks first globally in total livestock population (535.78 million), buffalo population (109.85 million) and cattle (192.49 million) population. It ranks second in goats (148.88 million), and sheep population (74.26 million. The total livestock population has grown consistently, with a 15.8% increase in the past two decades (Halli et al., 2018).

The livestock sector is also a significant contributor to export earnings, with products such as meat, leather, and wool having high export potential. However, the sustainability and growth of livestock husbandry depend on addressing critical challenges related to feed and fodder production. Quality feed and fodder are essential for the health, productivity, and well-being of animals. It provides vital nutrients like proteins, carbohydrates, fats, vitamins, and minerals, supporting growth, reproduction, and maintenance. Proper nutrition enhances livestock performance, such as increased milk production in dairy cows, improved egg-laying rates in poultry, and faster weight gain in meat animals. A balanced diet strengthens the immune system, helping animals resist disease and reducing veterinary costs. Additionally, good nutrition promotes reproductive success, ensuring healthy offspring and higher conception rates. Economically, optimizing feed can reduce costs and increase profitability for farmers. Sustainable farming practices are also supported by efficient feed usage, minimizing waste and resource consumption. Moreover, adequate feed improves behavioral well-being, reducing stress and promoting comfort. Finally, quality feed impacts the quality of milk, meat, and eggs, ensuring better-tasting and nutritious products. Therefore, quality feed and fodder is key to maximizing health, efficiency, and productivity. Without it the productivity of livestock is limited. Given that India houses approximately 15% of the world's total livestock population, it is essential to focus on augmenting the quality and quantity of feed and fodder production to ensure the continued growth and sustainability of the livestock sector.

Current Fodder Scenario in India

Animal nutrition consists of various types of feed that provide essential nutrients for livestock, and it is generally categorized into concentrates, green fodder, and dry fodder. Concentrates are high-energy, nutrient-dense feed ingredients that are typically low in fiber.

It provides essential nutrients, particularly proteins, energy, and minerals, which are necessary for growth, milk production, and reproduction in animals. They are used to supplement the nutritional requirements of livestock when forage is insufficient. Out of the 3 types of livestock feed it is of higher cost. Green fodder is essential for livestock as it provides vital nutrients like vitamins, minerals, and fiber, promoting overall health and growth. Its high fiber content aids digestion, supports gut health, and prevents digestive disorders. For dairy cattle, it boosts milk production and improves quality, while for meat animals, it promotes growth and weight gain. Green fodder also provides hydration, especially in hot climates, and acts as a natural source of antioxidants, boosting immunity. Additionally, growing it locally is cost-effective and sustainable. Overall, green fodder is crucial for maintaining livestock health, productivity, and well-being. The shortage of feed and fodder in India is largely due to increased pressure on land for food crops and inadequate focus on fodder cultivation. Grazing lands are decreasing due to degradation and grazing restrictions, and the area under fodder cultivation remains almost static at 8.4 million hectares. Despite improvements in fodder availability, there is still a significant gap between supply and demand, especially during lean periods or extreme weather events like droughts and floods. Currently, India faces a deficit of 35.6% in green fodder, 10.95% in dry crop residues, and 44% in concentrate feeds. While deficits in green and dry fodder have decreased, the growing livestock population, which increases at 1.23% annually, puts additional strain on fodder availability. States experiencing rainfall deficits, such as Gujarat, Rajasthan, and Maharashtra, face worsened conditions, necessitating measures to enhance fodder production, particularly during adverse weather conditions. Improving forage productivity is complicated by diverse agro-climatic conditions and farming practices.

Hydroponic fodder cultivation:

Hydroponic fodder cultivation can play a significant role in enhancing the resilience and adaptive capacity of landless farmwomen. By adopting this method, farmwomen who may not have access to large plots of land for traditional farming can still engage in productive agriculture, particularly in the area of livestock management, which is often a crucial source of income and nutrition in rural areas. Advantages of Growing Hydroponic fodder include:

1. Efficient Resource use

- Water Use: Hydroponic systems typically use less water compared to traditional soil-based farming, which is especially beneficial in areas where water resources are limited.
- Space Optimization: These systems can be set up in smaller spaces, such as rooftops, small plots, or even indoors, making them ideal for landless women or those with limited agricultural space.

2. Economic Empowerment

- By cultivating fodder hydroponically, women can grow nutritious feed for livestock, thereby improving the health and productivity of their animals. This could lead to increased milk, egg, or meat production, directly improving their income.
- Additionally, they could potentially sell surplus fodder to other farmers or even supply local markets, creating an opportunity for small-scale business ventures.

3. Improved Livelihoods

- Hydroponic fodder cultivation can ensure a year-round supply of nutritious feed, reducing dependency on external fodder suppliers, which can be costly or unreliable.
- It supports better animal husbandry, leading to improved milk yields or meat quality, contributing to better food security and financial stability for these women.

4. Climate Resilience

- Traditional fodder cultivation can be highly dependent on weather conditions, and climate change has made crop failures more common. Hydroponic systems are less vulnerable to the impacts of droughts, floods, and soil degradation.
- This increased resilience helps landless farmwomen manage the risks associated with unpredictable weather patterns, giving them a more stable source of livelihood.

5. Skill Development

- Hydroponic cultivation requires a different set of skills, which can enhance the overall knowledge and capabilities of farmwomen. This includes understanding system setup, nutrient management, and crop care. These skills can also be shared within the community, fostering collective growth.
- Learning and applying sustainable farming techniques also empower women, helping them take on leadership roles in their communities.

6. Sustainability and Environmental Impact

- Hydroponic systems are more sustainable than conventional methods, as they typically use fewer chemicals and fertilizers, reducing the environmental footprint. This aligns with broader goals of sustainability and ecological health, which can be important to the women involved in the initiative.

Fig. 1: Advantages of Growing Hydroponic Fodder

By integrating hydroponic fodder cultivation into their daily activities, landless farmwomen could not only strengthen their economic position but also contribute to sustainable agricultural practices, fostering greater community resilience and adaptive capacity. This approach has the potential to create lasting impacts on their livelihood and the well-being of their families. Hydroponic fodder cultivation stands out as a promising and sustainable method for producing nutritious livestock feed with a variety of advantages. By utilizing soilless, water-based systems, this method minimizes the need for land and water resources, making it an ideal solution for farmers with limited space or those located in areas with water scarcity. Hydroponics fodder is more palatable, digestible and nutritious, it improves the immune status of the animals, and augments their productive and reproductive performance (Naik et al., 2017). Thus, hydroponic fodder can become the best alternative to feed livestock to improve their productivity.

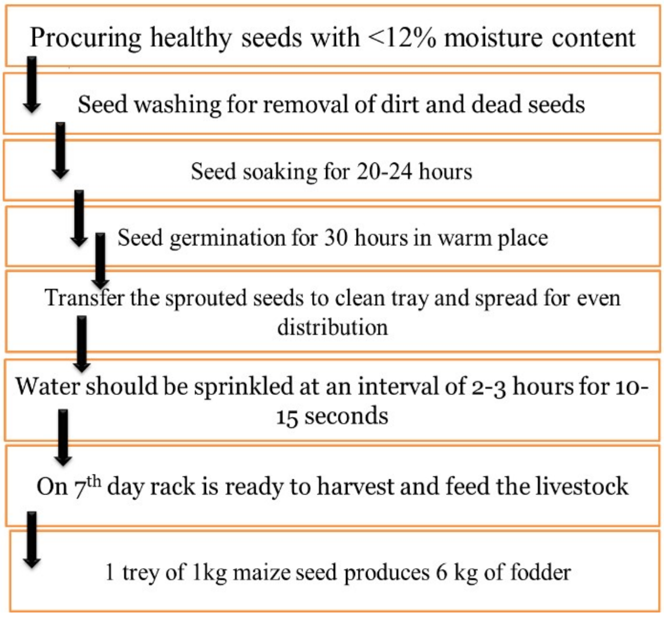

Fig. 2: Stepwise Procedure of growing Hydroponic Fodder

However, the adoption of hydroponic fodder cultivation is not without challenges:

1. **Initial Investment**: Setting up a hydroponic system requires an upfront financial investment for equipment such as trays, water pumps, and nutrient solutions. While the system is cost-effective in the long run, this initial cost can be a barrier, particularly for small-scale or resource-poor farmers.
2. **Technical Expertise**: Successful hydroponic fodder cultivation requires a certain level of technical knowledge and skill to manage water quality, nutrients, and system maintenance. Training and expertise are crucial for ensuring optimal growth and maximizing yields, which could pose an obstacle for those new to the practice.

Hydroponic fodder cultivation offers a highly efficient, sustainable, and nutritious solution for livestock feed. Despite the challenges related to start-up costs and technical requirements, the potential benefits such as resource efficiency, reduced dependency on external feed, and improved livestock health make it a compelling option for modern farming practices, particularly in landless, water-scarce, or urban environments. The hydroponic fodder system helps alleviate the challenges faced by women, such as limited control over land and restricted mobility and also serves as a valuable resource for women livestock farmers, especially in areas prone to natural disasters. Its nutrient richness also brings higher productivity in livestock. Women farmers can get nutritious fodder for their livestock round the year from their backyard without strenuous physical activity.

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Role of Artificial Intelligence (AI) & Internet of Things (IoT) in Mitigating Climate Change

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The role of Artificial Intelligence (AI) and the Internet of Things (IoT) in mitigating climate change is crucial, as both technologies have the potential to significantly reduce carbon emissions, improve energy efficiency, and provide better decision-making capabilities for addressing environmental issues. Climate change, driven by the increase in greenhouse gas (GHG) emissions from various sectors such as energy, transportation, and agriculture, poses a grave challenge to the planet. The agriculture sector is a major contributor to climate change, accounting for a significant portion of global greenhouse gas emissions, particularly methane from livestock, nitrous oxide from fertilizers, and carbon dioxide from land-use changes. The challenge of producing enough food to meet the demands of a growing global population, while simultaneously reducing environmental impacts, requires innovative solutions. Artificial Intelligence (AI) and the Internet of Things (IoT) have the potential to revolutionize agriculture, providing tools to mitigate climate change by improving efficiency, reducing resource use, and enhancing sustainable practices.

Artificial Intelligence in Agriculture and Climate Change Mitigation

AI involves the use of machine learning, neural networks, and advanced data analytics to interpret large datasets, identify patterns, and make predictions. In agriculture, AI's ability to process complex data from various sources can optimize farming practices, leading to improved sustainability and reduced environmental impact.

1. Precision Agriculture

Precision agriculture uses data-driven technologies to monitor and optimize field-level management regarding crop farming. AI is instrumental in analyzing data from various sources such as satellites, drones, and sensors to make real-time decisions that improve crop yields and reduce waste.

- **AI-Driven Crop Monitoring**: AI-powered systems can analyze data from remote sensing devices, including drones and satellites, to monitor crop health and predict potential issues like pest infestations or disease outbreaks. For example, AI algorithms can process imagery to identify areas of a field that require attention, whether for irrigation, fertilization, or pest control (Kamilaris&Prenafeta-Boldú, 2018).
- **Optimizing Fertilizer and Pesticide Use**: AI can reduce the overuse of fertilizers and pesticides, which are significant sources of greenhouse gas emissions and pollution. Machine learning models can predict the precise amount of fertilizer needed by crops based on factors such as soil conditions, weather, and crop type. This reduces waste and prevents the leaching of chemicals into the environment (Liakos et al., 2018).

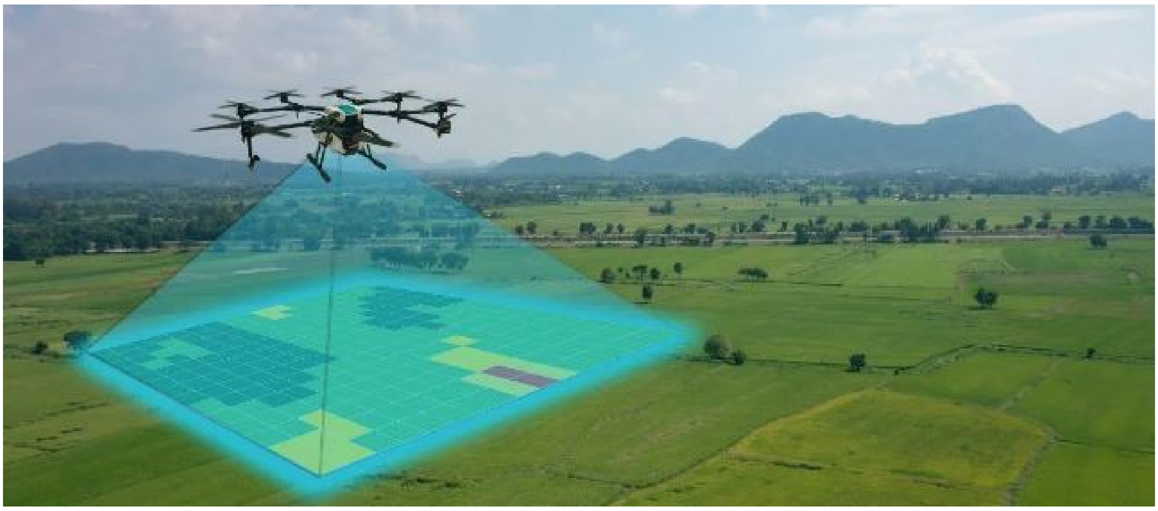

Figure 1: Drone Technology in Agriculture for crop monitoring and fertilizer application

2. AI for Climate-Smart Crop Selection

AI can play a key role in climate-smart agriculture by predicting which crops are most suited for specific regions, especially as climate change alters weather patterns. By analyzing historical climate data, soil characteristics, and crop performance, AI models can identify the most resilient crop varieties that are less sensitive to extreme weather conditions, helping farmers adapt to changing climates.

For instance, AI can help identify drought-resistant crop varieties or those that require less water, thus reducing the agricultural sector's reliance on water resources, which is becoming increasingly scarce in many regions due to climate change. By fostering the adoption of such climate-adaptive crops, AI helps farmers maintain productivity while reducing water use and improving resilience against climate variability (Liu et al., 2020).

3. AI for Greenhouse Gas Reduction

The agriculture sector is also a significant source of methane emissions, especially from livestock such as cows and sheep. AI can help reduce methane emissions through precision livestock management. Machine learning algorithms analyze data from sensors attached to animals to monitor their behavior, diet, and health. This information can be used to optimize feeding practices, reducing methane production from enteric fermentation.

Moreover, AI can be used to monitor and control manure management systems. By improving manure handling, AI can reduce methane emissions that arise from decomposing organic matter. Additionally, AI models can predict the potential release of nitrous oxide (another potent greenhouse gas) from soil, allowing farmers to adjust their fertilization practices to minimize emissions (Hristov et al., 2018).

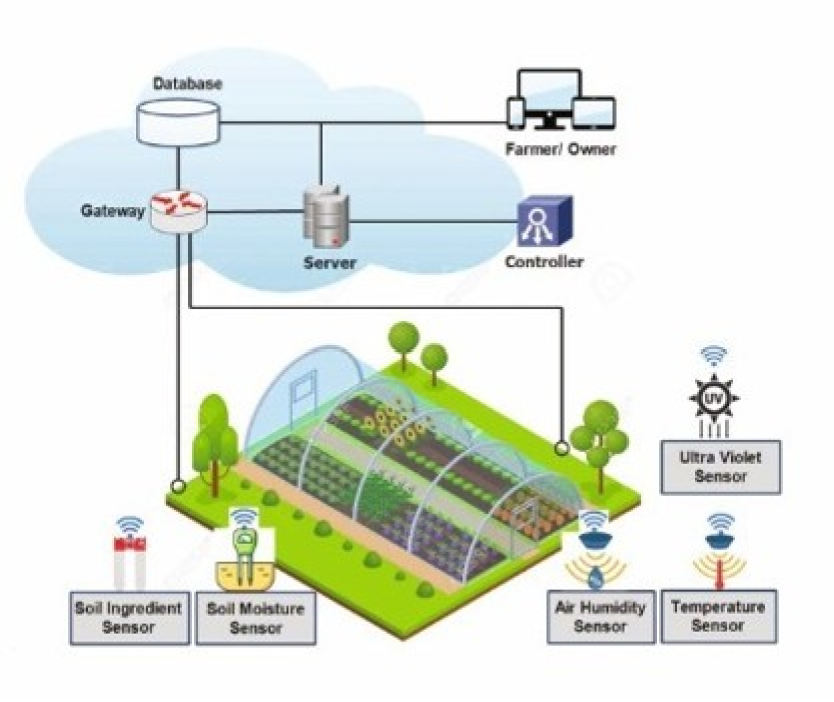

Figure 2: Sensor based farming

Internet of Things (IoT) in Agriculture and Climate Change Mitigation

The Internet of Things (IoT) refers to a network of interconnected devices that can communicate and share data. In agriculture, IoT involves the use of sensors, weather stations, drones, and other connected devices to monitor environmental conditions and crop health, providing real-time insights that help farmers make more informed decisions.

1. Smart Irrigation Systems

Water scarcity is one of the most pressing issues in agriculture, particularly in areas vulnerable to climate change. IoT sensors can monitor soil moisture, weather conditions, and crop water requirements to optimize irrigation systems. Smart irrigation systems, powered by IoT and AI, ensure that crops receive the exact amount of water they need at the right time, reducing water waste and energy consumption.

By using data from IoT devices, farmers can prevent over-irrigation or under-irrigation, both of which contribute to environmental degradation. IoT-based irrigation systems can also be integrated with weather forecasts to adjust watering schedules based on predicted rainfall, further conserving water resources (Mulla, 2013).

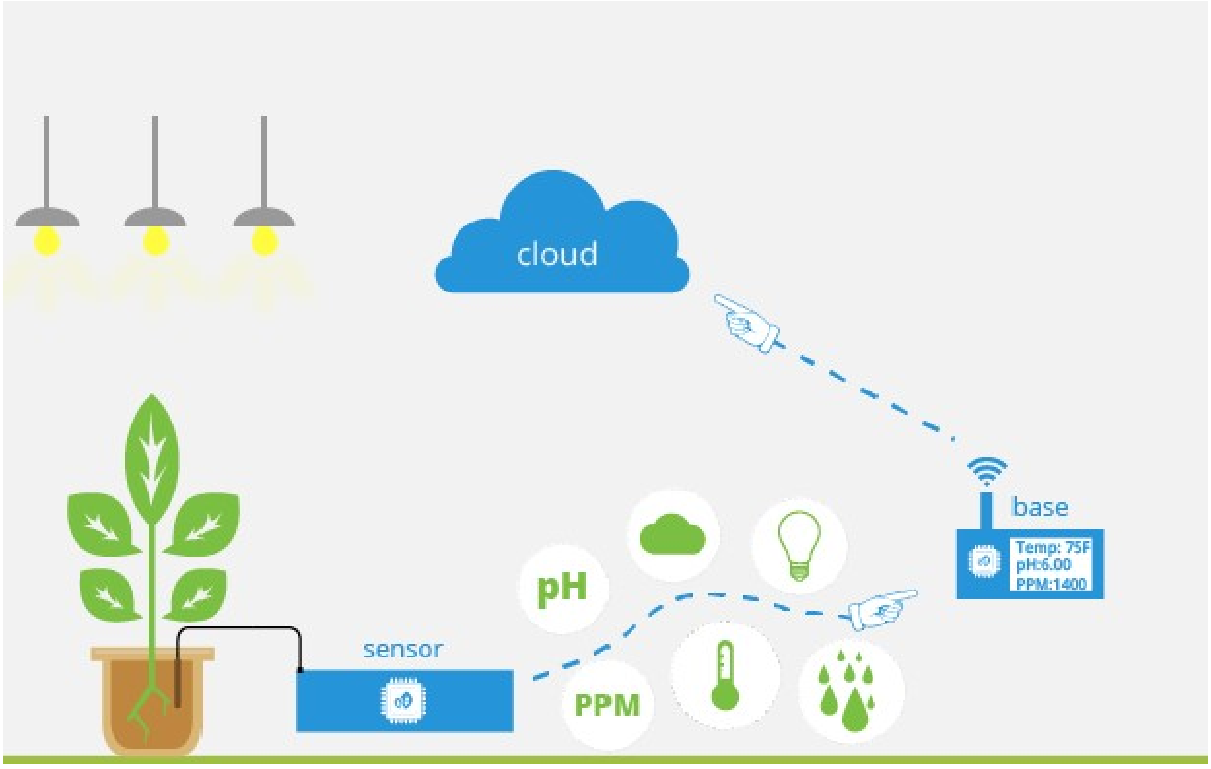

Figure 3: Data driven Agriculture

2. Precision Soil Management

IoT sensors are used to collect data on soil health, including factors such as pH levels, temperature, and moisture content. This data can be transmitted to central systems where AI algorithms analyze it to determine the best conditions for planting, fertilization, and irrigation. By understanding soil conditions at a granular level, farmers can optimize crop production while minimizing the use of harmful fertilizers and pesticides.

The integration of IoT with AI in soil management allows for a more targeted approach to resource use, thus reducing the environmental impact of agriculture. For example, by monitoring soil nutrient levels in real time, IoT sensors can provide recommendations for precise fertilizer applications, reducing the likelihood of nutrient runoff into water systems (Zhang et al., 2019).

3. Livestock Monitoring and Management

IoT devices can track the health and behavior of livestock, helping farmers detect early signs of disease or discomfort, which can reduce the need for antibiotics and other treatments that can have environmental consequences. For example, IoT sensors in the form of wearable devices can monitor temperature, heart rate, and movement patterns in animals, transmitting data to farmers who can then take action to prevent disease outbreaks or improve animal welfare.

This data can also be used in conjunction with AI algorithms to optimize feeding practices and reduce the production of methane, as well as monitor grazing patterns to avoid overgrazing, which can lead to soil degradation (Fernández et al., 2020).

4. Supply Chain Optimization

IoT enables farmers to track products along the supply chain, from farm to consumer. With IoT-enabled supply chain systems, farmers can reduce food waste, improve storage conditions, and ensure that products are delivered in a timely manner, minimizing energy consumption and spoilage. By monitoring factors such as temperature and humidity in storage facilities and transport vehicles, farmers can reduce energy use and prevent the need for chemical preservatives, leading to lower environmental impacts (Norris et al., 2020).

Synergy Between AI and IoT in Agriculture

The combination of AI and IoT provides a powerful, integrated solution to climate change mitigation in agriculture. IoT devices collect real-time data on environmental factors, crops, and livestock, while AI processes this data to generate actionable insights and predictions that optimize farming practices.

For instance, IoT sensors can monitor soil moisture and weather conditions, while AI models predict irrigation needs and adjust water usage in real-time, optimizing both crop health and water conservation. Similarly, IoT-enabled climate monitoring systems can provide data on temperature and humidity, allowing AI systems to predict pest outbreaks or disease risks and help farmers take preventive measures (Khan et al., 2020).

Moreover, AI can improve the functionality of IoT devices by enhancing their ability to detect and interpret environmental signals. For example, machine learning models can analyzeIoT sensor data to identify patterns in plant growth, pest behavior, and environmental conditions, enabling farmers to make more informed decisions about pest control, fertilization, and irrigation.

Challenges and the Future of AI and IoT in Agriculture

While the integration of AI and IoT in agriculture offers significant potential for climate change mitigation, several challenges must be addressed. These include:

- **Data Privacy and Security**: The use of IoT devices generates vast amounts of data, which must be securely stored and managed to prevent misuse. Ensuring data privacy and protecting against cyber threats are critical considerations.

- **Cost of Implementation**: The adoption of AI and IoT technologies can be expensive, particularly for small-scale farmers. Subsidies, financial incentives, and government support are needed to make these technologies accessible to all farmers.

- **Lack of Digital Literacy**: In many regions, farmers may not have the necessary skills to implement and manage AI and IoT technologies. Training programs and support for digital literacy are essential to ensure that farmers can maximize the benefits of these tools.

Despite these challenges, the future of AI and IoT in agriculture is promising. With continued advancements in technology, increased collaboration between tech companies and agricultural stakeholders, and supportive policies, AI and IoT can play a key role in mitigating climate change by transforming agricultural practices into more sustainable, efficient, and resilient systems.

Conclusion

AI and IoT have the potential to dramatically reduce the environmental impact of agriculture, a key sector contributing to climate change. By enabling precision farming, optimizing water and fertilizer use, improving livestock management, and reducing emissions, these technologies provide farmers with the tools needed to produce more food sustainably while minimizing greenhouse gas emissions. As AI and IoT technologies continue to evolve, they will be integral in driving climate-smart agriculture, helping to meet the global challenge of mitigating climate change.

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