Review Article

The Potential of Indigenous Technological Knowledge for Sustainable and Climate-Resilient Agriculture

Abstract

India's diverse agricultural landscape has been shaped by centuries of indigenous knowledge, which offers valuable insights and practices for sustainable and climate-resilient agriculture. Indigenous Technical Knowledge (ITK) is a vast repository of traditional practices developed by local communities over generations, including a variety of techniques for sustainable agriculture and resource management. This paper provides a comprehensive overview of various ITK practices used throughout India, emphasising their importance in soil fertility and health, water management, climate adaptation, and animal health management. This study highlights the importance of ITK in promoting ecological sustainability and resilience in agricultural systems by documenting practices such as green manuring, vermicomposting, traditional irrigation systems like Khadin and Zing, climate-adapted crop varieties cultivation, and ethnoveterinary remedies. The preservation and integration of these traditional knowledge systems into modern agricultural practices can enhance resource utilization efficiency, support biodiversity conservation, and contribute to the overall well-being of rural communities.

Keywords: Climate-resilient agriculture, Green manuring, Indigenous Technological Knowledge,Sustainable agriculture, Modern agricultural practices.

Introduction

Indigenous Technological Knowledge (ITK) encompasses knowledge systems unique to specific cultures, distinct from modern scientific knowledge (Niyitunga, 2024). ITK delivers a sustainable measure in pest and disease control in crops thus providing chemical residue-free agricultural commodities for the market (Yamunarani *et al.*,disease). It is regarded as a resource that is appreciated but underexploited by organizations with the capability of creating, storing, and disseminating knowledge for the improvement of the countryside (Howes & Chambers, 2023). To supplement this finding, ITK should be included in education most especially in learning area of science because ITK helps to transmit knowledge, attitude and skills from one generation to another for better understanding hence

making learning culturally relevant while appreciating diversity (Handayani& Triyanto, 2023). ITK seems to be a part and parcel of society that helps in enhancing the scientific researches and gives the real solution for the number of disciplines for example agriculture and education. It has a great potential in enhancing the resilience to climate change, particularly in matters relating to agriculture by enhancing pro-active agricultural practices that can guarantee the health of the agriculture sector through improved water resource management. Research stresses the importance of combining ITK with scientific information to obtain climate-smart and low-emission Agriculture (Chaudhary *et al.,* 2022). The documentation and dissemination of ITK are vital as highlighted in the strategies to encourage youths in pursuing farming to embrace, appreciate and apply both indigenous and scientific knowledge for maximum gains by the farming communities (Limpo *et al.,* 2022). Furthermore, practices which involve the use of indigenous agricultural knowledge have contributed to the sustainability of agroecological systems in the past and continued incorporation into conservation schemes, therefore helping both the ecosystems and cultures of Indigenous people (Johnson *et al.,* 2021). It is for this reason that the incorporation of ITK into present day farming methodologies form the basis of availing sustainable farming practices, many of which will help deal with fundamental farming issues such as water rationing and climate change.

Agriculture can be improved for sustainability and be climate resilient with the help of indigenous knowledge systems (IKS) which fuses conventional and modern farming practices. On the same note, culture, as a social practice, is recognized for complementing best practice strategies such as indigenous land management to do away with land degradation, indigenous water conservation practices to address water conservation and indigenous biodiversity management practices in addition to CSA to address losses in biodiversity and climate change impacts(Risiro*et al.,* 2024). Studies on the use of indigenous knowledge systems are evident in the Vhembe district in South Africa where indigenous knowledge is applied in farming, disease forecasting, and other related purposes which depicts their impact in combating climate shocks (Phoobane& Masinde, 2023). Through incorporation of indigenous technological knowledge, a people improve on food security and nutritive agriculture; combating impacts of climatic change and infecting diseases that are likely to eradicate nutritive agriculture and lead to insuperablelivelihoods in rural areas. India with its extensive areas of agriculture and a rather wide range of agro-climatic zones has

several issues threatening its development. Unpredictable weather conditions, and higher temperatures undermine production in agricultural land and food stability.

Overview of Indigenous Technological Knowledge (ITK)

Indigenous Technological Knowledge (ITK) is an extensive repertory of sustainable techniques and approaches with origins in Indian farmers' thinking and experience in handling adversity. ITK in line with the current manipulation is the invention and practice as formulated by dugites concerning their native proficiencies and communal memories to solve various requirements and problems (Rugedhla*et al.,* 2023; Goswami *et al.,* 2006). It is socially and economically remunerative, environmentally innocuous and low risk; such knowledge is beneficial for involving sustainable developments and the enhancement of productivity in several sectors including agriculture and fish farming (Goswami *et al.,* 2006). This argument stresses the need for applying ITK in the education systems with the view that this will increase the practical relevance of curricula and the local communities' capacity for self-governance through the application of their knowledge and skills (Rugedhla*et al.,* 2023). Furthermore, the growth of knowledge as a factor concerning models of endogenous growth of which ITK is an example requires a comparison of implications for the past model as well as likely results for plausibility which plays a major role in sustainability (Hakenes& Irmen, 2006; Hakenes& Irmen, 2005). The analysis of the historical view of the ITK application shows its importance in traditional agriculture. The early planning and construction of a systematic ITK for traditional agriculture in China served as the appropriate strategy (He, 2023). Different aboriginal tribes have retained several forms of traditional knowledge in India which had assisted in the area of agriculture among others (Sindhu & Malik, 2020). However, after gaining independence and the new cooperation of modern medicine, people rarely used ITK in livestock rearing despite its advantages over other conventional and allopathic medicines (Shubeena*et al.,* 2022). Multiple researches conducted in Bangladesh have identified different level of ITK integration with regard to farming and the level of its integration depend on factors such as family size and size of the farm (Khan *et al.,* 2022). Scientific investigation and validation of ITK formulations are crucial to promote continued improvement and efficiency (Biswas & Das, 2023).

Diversity of ITK

The Indigenous Technical Knowledge (ITK) in the context of the indigenous people of India means the availability of a vast array of practices prevalent in different regions and of various

ethnical backgrounds. Local traditional knowledge used by farmers in dairy farming; North, South, East, West and North East regions incorporate various ITKs (Ponnusamy *et al.*, 2016). Different forms are used in the North Eastern region of India for Organic Farming and all of them starting from seed germination up to storage emphasized in ITKs for agro-biodiversity and sustainable crop management (Santosh &Chhetry, 2012). Besides, the population mobility from one area to another has a net effect of augmenting the new culture and skill which enhances the economic development and human capital of different regions of India. Collectively, the varying traditions and cultures of the Garhwal, Kumaon, and Jaunsar areas are also evident again enshrining the diversities of India as such (Sati, 2023).

Concerning different regions of Indian agriculture ITK shows a myriad of its development from the cultural and geographical diversities. Agronomists of different states have passed on and documented appropriate ITK from generation to generation with practices like termite management, soil fertility, and pest control (Praveen *et al.*, 2018; Mahapatro*et al.*, 2017; Ponnusamy *et al.*, 2009). The five regions of the North, South, East, West, and North East explores diversified form of ITK practices where each has tradition health care practices in dairy farming, weather prediction and methods of organic farming (Ponnusamy *et al.*, 2009). This signifies that these ITKs have origins in the interactions with the environment with issues of sustainable, ecological and economic practices in agriculture.

ITK and Sustainable Agriculture

The incorporation of Indigenous Knowledge Systems (IKS) into modern farming practices is a very vital practice in the advancement of sustainable farming as it reduces cases of land erosion, loss of biodiversity, and effects of climatic change in the rural farming society (Risiro*et al.*, 2024). Different indigenous techniques like indigenous land management, water and Bio-diversity management systems can go hand in hand with the advanced technologies to enhance the increase in the utilization of water in agriculture especially in the dry areas (Shahraki*et al.*,2023). On the same note, indigenous measures for evaluating land degradation, for instance, the loss of soil fertility through water erosion have been presented as key positives in managing land health, and practices like the construction of stone bunds, crop rotation and the like as methods that need to be preserved by farmers in the rural areas.

Biodiversity Conservation

Biodiversity conservation comprises many values and controversies and reflects conservation as a social and political practice, not only and not mainly an objective and technical

endeavour of biological sciences, but an outcome of globalized economy and global power relations (García-Frapolli, 2023). Bio-diversity forms the main foundation of sustainable agricultural practices in India. Integration of cultures that result in the diversification of crops and the species of livestock results in improvement of ecosystem stability. This biodiversity comes as an insurance for climate variation, this means availability of food even during the worse climate. For instance, cultures of agro-biodiversity in the North-East and Western Ghats of India involve several polyculture systems and several crops at once to avoid total crop losses at instance due to pests, diseases or even bad weather. As applied by the tribal people of the Western Ghats and Meghalaya in agriculture, medicine, and veterinary sciences, ITK include practices that play a massive role in conservancy and efficient management of available natural resources (Mettupalayam&Fernandaz, 2020; Kharbani&Sawian, 2022). The following table also gives an idea about the different working methods of these ITKs practised by different communities of India in Biodiversity Conservation.

Table 1: Indigenous Technical Knowledge for Biodiversity Conservation

Name of ITK	**Location and Community**	**Purpose**	**Source**
Sacred Groves	Various regions, multiple communities	Protection of forest fragments due to religious beliefs	Gadgil & Vartak,1975
Traditional Agroforestry Systems	Northeast India, Tribal communities	Cultivation of multiple crops with trees and livestock, maintaining ecological balance	Kumar, 2006
Vrikshayurveda	Various regions	Maintaining soil health, pest management, and promoting plant growth through natural means	Manhas & Singh,2023
Zabo Farming System	Nagaland, Angami tribe	Combining forestry, agriculture, and animal husbandry in a sustainable way	Giri*et al.*, 2020
Community Seed Banks	Various regions, multiple communities	Preserving traditional seed varieties and genetic diversity	Vernooy&Sthapit, 2015

Participatory Forest Management	Various regions, multiple communities	Involving local communities in sustainable forest management	Poffenberger & McGean, 1996

Water Management

Effective water management is crucial for climate-resilient agriculture. Indian farmers have developed various techniques to conserve and efficiently use water resources. The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Water Management.

Table 2: Indigenous Technical Knowledge for Water Management

Name of ITK	**Location and Community**	**Purpose**	**Source**
Khadin	Rajasthan, Local communities	Rainwater harvesting for agriculture	Rani & Paul, 2023
Zing	Ladakh, Local communities	Traditional irrigation system using snowmelt and glacial water	Angchok*et al.*,2014
Ahar-Pyne System	Bihar, Local farmers	Traditional floodwater harvesting and management	Sukanya & Joseph,2024
Katta	Kerala, Rural communities	Temporary check dams to store and recharge groundwater	Nair*et al.*,2017
Kuhl System	Himachal Pradesh, Local communities	Gravity flow irrigation systems using channels to divert water from streams	Baker, 2003
Phad System	Maharashtra, Tribal communities	Diversion-based irrigation using earthen dams and channels	Kulkarni*et al.*,1995
Bamboo Drip Irrigation	Meghalaya, Tribal communities	Using bamboo pipes for efficient water distribution to terrace fields	Jeeva*et al*., 2006
Johads	Rajasthan, Local communities	Traditional water storage structures for groundwater recharge	Agarwal& Narain,1997
Surangam	Kerala, Karnataka,	Horizontal wells to tap	Joji*et al.*,2021

	Local communities	groundwater from hard rock areas	

Soil Fertility and Health

Maintaining soil health is fundamental to sustainable agriculture. Indigenous practices such as crop rotation, intercropping, and the use of organic fertilizers (e.g., compost, manure) help sustain soil fertility and structure. Healthy soils are more resilient to erosion, retain moisture better, and support robust plant growth, which is vital under changing climatic conditions.The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Soil Fertility and Health.

Table 3: Indigenous Technical Knowledge for Soil Fertility and Health

Name of ITK	**Location and Community**	**Purpose**	**Source**
Panchagavya	Tamil Nadu, Traditional farmers	Applying a mixture of cow dung, urine, milk, curd, and ghee to improve soil health and plant growth	Naresh & Dhaliwal,2020
Jeevamrutha	Karnataka, Rural communities	Using a fermented mixture of cow dung, urine, jaggery, pulse flour, and soil to enhance soil fertility	Palekar, 2005
Compost Pit	Various regions, multiple communities	Creating compost pits to decompose organic waste and produce nutrient-rich compost	Singha & Singha, 2024
Tank Silt Application	Andhra Pradesh, Rural farmers	Applying tank silt to fields to enhance soil fertility and water-holding capacity	Reddy*et al.*,2018

Pest and Disease Management

Indigenous knowledge includes natural pest and disease control methods, reducing the reliance on chemical inputs. The use of neem extracts as a natural pesticide is widespread in India. Traditional practices like the use of cow urine and dung as bio-pesticides and soil conditioners are also effective in pest and disease management.Several Studiesreveal diverse

ITK practices among, showcasing varied concoctions like Meenamilam, Neem oil, and Panchagavya used for pest management in brinjal cultivation. The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Pest and Disease Management.

Table 4: Indigenous Technical Knowledge for Pest and Disease Management

Name of ITK	**Location and Community**	**Purpose**	**Source**
Neem Extracts	Various regions, multiple communities	Using neem leaves and oil for pest control due to its insecticidal properties	Schmutterer, 1990
Marigold Intercropping	Various regions, multiple communities	Planting marigold alongside crops to repel nematodes and other pests	Hu, 2021
Ash and Charcoal Application	Tamil Nadu, Tribal communities	Sprinkling ash and charcoal on plants to deter insects and prevent fungal growth	Srinivasarao,2021
Cow Urine Sprays	Various regions, multiple communities	Using fermented cow urine as a natural pesticide to control pests and diseases	Gahukar, 2013
Garlic and Chili Sprays	Various regions, multiple communities	Preparing and spraying garlic and chili solution to repel insects and pests	Flordeliza& Leonard, 2024
Fermented Plant Extracts	West Bengal, Tribal communities	Using extracts from fermented plants like lantana and papaya for pest control	Ghosh, 2000
Turmeric and Ginger Paste	Assam, Tribal communities	Applying turmeric and ginger paste on plants to prevent fungal infections	Koku*et al.*,2020

Animal Health Management

There are various Indigenous Technical Knowledge practices for animal health management in India. These traditional remedies and techniques used by different communities to maintain

livestock health and treat common ailments.The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Animal Health management.

Table 5: Indigenous Technical Knowledge for Animal Health Management

Name of ITK	**Location and Community**	**Purpose**	**Source**
Herbal Deworming Remedies	Various regions, Rural communities	Using herbs like neem, garlic, and pumpkin seeds to expel intestinal worms in livestock	Dutt *et al.*, 2015
Turmeric and Mustard Oil Application	Various regions, Rural communities	Applying a mixture of turmeric and mustard oil on wounds to prevent infection and promote healing	Sharma & Sharma, 2021
Traditional Veterinary Practices	Various regions	Use of herbs and natural resources for animal healthcare	Mathias, 2004
Traditional Knowledge of Wildlife	Various regions, multiple communities	Indigenous knowledge about animal behavior and habitat preferences	Gadgil & Berkes, 1991
Fumigation with Cow Dung Cakes	Himachal Pradesh, Rural communities	Using smoke from burning cow dung cakes to keep flies and mosquitoes away from livestock	Katoch, 2004

ITK and Climate Resilience

Introducing the concept of Indigenous knowledge is another significant way of improving climate success in agriculture since traditional practices are long-tested and proven techniques and practices (Barua & Mitra, 2024). Combining Indigenous Technological Knowledge and Climate Smart Agriculture measures can greatly improve agricultural practices and, ability to adapt to climate change, as well as reduce its effects. Research also highlights the role of capacities to adopt and utilize received knowledge, including the social organization of livestock management in the face of difficult biophysical environments, hence the need to adopt local knowledge systems in agriculture to mitigate on natural

adversity in such areas as climatic harshness and drought. The assessment of ITK, conservation tillage practices, as well as mixed cropping practices could help in coming up with decisions regarding low emission and climate smart agriculture.

Climate-Adapted Crop Varieties

Local communities in different parts of India have evolved and maintained those crop varieties that are more suitable to certain levels of environmental heat stress, water scarcity environment, waterlogged environments or saline-proneenvironments. Traditional rice varieties in the Sundarbans, for example, are known for their resilience to saline conditions and flood tolerance. The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Climate-Adapted Crop Varieties.

Early Warning Systems

Indigenous knowledge systems often include traditional weather forecasting based on observations of natural phenomena, such as animal behaviour and plant flowering patterns. These early warning systems can help communities prepare for extreme weather events. In coastal areas, fisherfolk use traditional knowledge to predict cyclones and storm surges, which can be invaluable for planning agricultural activities.

The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Early Warning Systems.

Table 6: Indigenous Technical Knowledge for Early Warning Systems

Name of ITK	**Location and Community**	**Purpose**	**Source**
Cloud Observation	Various regions, multiple communities	Predicting weather changes and rainfall based on cloud patterns	Gupta& Tomar,2014
Animal Behavior Observation	Various regions, multiple communities	Using changes in animal behavior to predict natural events like earthquakes and	Berkes & Jolly,2001

		storms	
Bird Migration Patterns	Various regions, multiple communities	Using the timing and patterns of bird migrations to predict seasonal changes	Gadgil & Berkes, 1991
Plant Phenology	Various regions, multiple communities	Predicting weather patterns and seasonal changes based on plant flowering and fruiting times	Sarkar *et al.*, 2015
Insect Behavior	Various regions, agricultural communities	Using insect behavior (e.g., ants moving to higher ground) to predict rain and floods	Lytle *et al.*, 2008

Resource Utilization Efficiency

ITK promotes the efficient use of local resources, reducing waste and enhancing sustainability. Agroforestry systems, which integrate trees and shrubs into farming systems, provide multiple benefits such as shade, wind protection, and additional food or income sources. The traditional practice of agroforestry in Karnataka, known as "home gardens," integrates various trees, crops, and livestock, enhancing biodiversity and resource use efficiency. The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Resource Utilization Efficiency.

Table 7: Indigenous Technical Knowledge for Resource Utilization Efficiency

Name of ITK	**Location and Community**	**Purpose**	**Source**
Mixed Cropping	Various regions, multiple communities	Efficient use of land by growing different crops together to maximize yield and minimize pests	Altieri, 1995

Agroforestry	Northeast India, Tribal communities	Integrating trees with crops and livestock to enhance productivity and sustainability	Kumar, 2006
Use of Biofertilizers	Various regions, multiple communities	Enhancing soil fertility using natural fertilizers like compost and green manure	Sharma, 2004
Drip Irrigation using Bamboo	Meghalaya, Tribal communities	Using bamboo pipes for efficient water distribution to terrace fields	Jeeva*et al.*,2006
Traditional Seed Preservation	Various regions, multiple communities	Ensuring seed viability and quality through traditional storage methods	Altieri& Merrick,1987

Community-Based Adaptation

Indigenous practices are typically community-based, fostering collective action and social cohesion. This collective approach enhances the capacity of communities to adapt to climate change through shared knowledge, labour, and resources. Community-managed seed banks in Andhra Pradesh, for instance, preserve diverse crop varieties and provide farmers with access to resilient seeds adapted to local conditions. The following table provides a comprehensive overview of various ITK practices employed by different communities across India for Community-Based Adaptation.

Table 8: Indigenous Technical Knowledge for Community-Based Adaptation

Name of ITK	**Location and Community**	**Purpose**	**Source**
Water Sharing Agreements	Tamil Nadu, Local communities	Community-based management of water resources through collective agreements	Babu & Shereef, 2008
Joint Forest Management (JFM)	Various regions, Forest communities	Collaborative management of forest resources between communities and the government	Poffenberger& McGean,1996

Traditional Fishermen Cooperatives	Coastal regions, Fishing communities	Sustainable management of fishery resources through cooperative societies	Kurien, 2007
Community Grain Banks	Various regions, Rural communities	Ensuring food security during periods of scarcity through communal grain storage	Meethal Reji, 2013
Traditional Seed Banks	Rajasthan, Tribal communities	Preserving traditional seed varieties and ensuring access to diverse genetic resources	Gupta, 1999
Community Pasture Management	Gujarat, Pastoral communities	Sustainable management of communal grazing lands through traditional practices	Venkatasubramanian, & Ramnarain, 2018
Local Biodiversity Registers	Karnataka, Local communities	Documenting and conserving local biodiversity through community participation	Gadgil & Rao, 1998

Integrating ITK with Modern Practices

There is a need to incorporate the specified ITK into modern scientific understanding and deployment in the face of climate change and its devastating effects on agriculture. Applying Indications and scientific initiative can help in reaching the middle ground which is achievement of high yields and low risks of being affected by natural conditions outburst, such as drought or frost. The use of this blended mode of operation can result into quite effective and sustainable solutions to the problems occasioned by climate change. For this integration, combinations of research and development with an active participation of local people and scientific community are beneficial (Sharma *et al.,* 2024). Thus, the coupled usage of ITK and other contemporary technologies such as IoT and deep learning may help optimise the protection of the earth's biological diversity in the future with the support of contemporary technology in addition to indigenous people's knowledge and experiences.

Conclusion

The knowledge existing among the technological indigenous people has the potential to foster sustainable and climate smart agriculture in India. Incorporating these indigenous farming practices with the modern farming practices hence bridging the gap between knowledge that is older as well as modern knowledge can therefore lead to the development of farming systems that are more resilient to the changes in climate. This review underscores the importance of ITK enriching the agricultural processes and strengthening their resilience as seen in the case studies and examples. In this regard, such attempts should be made in the future to encourage the interaction between the indigenous and modern systems of knowledge to speak to issues of climate change challenges adequately. Policymakers in both governments and international organizations should acknowledge and promote the functions of ITK for climate-smart agriculture through policy and financial means. Since there is still comprehensive research and documentation of ITK, the accomplishment of its goal of promoting the documentation and dissemination of valuable practices can be realized. Such training and education should be instituted so as to build up the capacity of local communities to apply and adapt it with conventional ways of farming. Education, communication and consultation help in the outlining of strategies to suit the communities hence; acceptance of adaptation strategies by the respective communities.

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