INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

Bio-Cultural Regenerative Food and Beverages System among the Indigenous Communities in Assam Vis-à-vis South-East Asian Nations

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DOI: https://doi.org/10.51583/IJLTEMAS.2026.150500236

Received: 25 May 2026; Accepted: 30 May 2026; Published: 19 June 2026

ABSTRACT

This study investigates the bio-cultural regenerative food and beverage systems of indigenous communities in Assam, comparing them with those of Southeast Asian nations, utilising a secondary, evidence-based meta-synthesis framework. By integrating ethnobotanical, microbiological, and socio-ecological datasets, the research analyses traditional fermentation systems, including Xaj-pani, Jou, Judima, Apong, Tapai, Tapuy, and Look-pang, as dynamic regenerative models rooted in local ecological knowledge systems. The results indicate substantial evolutionary convergence across the Assam–Southeast Asia bio-cultural corridor, particularly in the prevalence of functional microbial phyla, such as Firmicutes, and in the incorporation of wild edible plants into fermentation starter cultures. These systems enhance food security, microbial diversity, nutraceutical health, and community resilience, while maintaining local agrobiodiversity through low-energy traditional biotechnology. Nevertheless, rapid marketisation, monocultural agriculture, environmental change, and the decline of Traditional Ecological Knowledge (TEK) pose significant threats to their persistence. The study contends that indigenous fermentation systems constitute decentralised, regenerative sustainability models with considerable relevance for post-2030 ecological restoration, food sovereignty, and community-driven bioeconomy.

Keywords: Bio-cultural regeneration, Indigenous fermentation, Traditional Ecological Knowledge (TEK), Regenerative sustainability, Ethnobotany, Microbial diversity, Food sovereignty, Traditional biotechnology

INTRODUCTION

Tribal food worldwide represents a sophisticated bio-cultural knowledge system in which food, beverages, medicines, ecology, and community health are deeply interlinked (Kuhnlein & Receveur, 1996; Toledo & Burlingame, 2006; Barman, 2011). Within the geographical outlines of Northeast India, Assam serves as a crucial epicentre for this biocultural continuum. The Brahmaputra and Barak river basins, combined with the surrounding terrain, provide a distinct, rich tapestry of ethnic groups, including the Deoris, Bodos, Mising, Dimasas, Karbis and Rabhas. Each tribal community possesses highly evolved traditional ecological knowledge (Bhattacharya & Deka, 2023; Das et al., 2016).

The neighbouring Southeast Asian region is part of a contiguous biocultural corridor characterised by extraordinary ethnic, linguistic and biological diversity (Barman, 2012; Bhattacharya & Deka, 2023; Das et al., 2016). Historically connected through migratory paths, shared geoclimatic conditions, and trade networks, these regions are hotspots of agrobiodiversity and ancient ethno-dietary practices (Bhattacharya & Deka, 2023; Ray, 2025). Furthermore, traditional resource management strategies such as the rotational shifting or fallow-based cultivation systems in the highlands, alongside integrated fish-rice agricultural systems in the floodplains, parallel practices found throughout both South and Southeast Asia (Gonsalves, 2025; Goodridge, 2025).

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The term "regenerative" here refers to the restoration and maintenance of human psychological health, microbial diversity, ecological balance, and environmental sustainability. The indigenous food system is grounded in profound ecological knowledge and embodies holistic models in which land, water, humans, and spiritual rituals are inextricably intertwined (Goodridge, 2025; Sangha, 2026). However, these systems also operate on active biocultural regeneration, balancing food production with the structural maintenance of ecosystem services (Gonsalves, 2025; Sangha, 2026).

Agriculture and natural resource extraction in these communities operate as deeply integrated social institutions rather than purely economic activities; this is exemplified by adaptive practices such as flood-resilient paddy cultivation, rotational forest fallows, and seasonal community-led resource harvesting in local floodplain wetlands (beels) (Das et al., 2016). Central to this localised adaptive framework is the widespread practice of traditional biotechnology, particularly the production of rice-based fermented beverages like Xaj-pani, Jou, Judima, and Nogin, Sujen and Apong, which are prepared using complex starter cakes infused with a vast array of wild edible plants (WEPs) (Bhattacharya & Deka, 2023; Yumnam et al., 2024). These botanically enriched beverage systems provide critical household food security, deliver distinct probiotic and nutraceutical benefits, and fortify community cohesion during major socio-religious festivals (Bhattacharya & Deka, 2023; Yumnam et al., 2024). By addressing these limitations, this study aims to examine the bio-cultural regenerative food and beverage systems among indigenous communities in Assam, vis-à-vis those in Southeast Asian nations, to map their shared functional properties and resource management mechanisms.

By linking micro-level traditional ecological assets to macro-level sustainability needs, this research provides an empirical framework to guide policy and intervention strategies for food sovereignty and biocultural preservation from 2030 onwards.

Statement of the problem

Despite ecological resilience and socio-cultural values, the indigenous biocultural food and beverage system faces an unprecedented crisis of genetic erosion, cultural marginalisation and disruption (Jaggi et al., 2024; Ray, 2025). The centralised market structure and agrochemical-dependent monocultures dominate the modern globalised food chain. They have systematically undermined the local ecological knowledge across the Northeast and Southeast Asian countries (Bhattacharya & Deka, 2023; Gonsalves, 2025).

The fluctuating riverine dynamics and top-down agricultural transitions threaten the seasonal resources on which indigenous resource management in Assam is based, displacing native crops and traditional land practices (Das et al., 2016). Furthermore, formulating traditional fermented cakes requires complex ethnobotanical knowledge, as in Xaj-pani, Jou, Judima, Sujen, and Apong, which is rapidly declining among younger generations due to demographic shifts and rapid rural-urban migration (Yumnam et al., 2024).

Looking at global environmental governance after 2030, biocultural vulnerability stands out as a major concern. As the world reaches the 2030 deadline for the United Nations Sustainable Development Goals (SDGs), both international policy and sustainability science show that traditional approaches to 'sustainable mitigation'—which focus on reducing harm or maintaining a weakened status quo—are not enough to address the growing climate shocks and ecosystem collapses expected by mid-century (Abrahams, 2026; Edgar-Webkamigad, 2026).

Contemporary sustainability discourse increasingly advocates for both conceptual and practical shifts toward regenerative sustainability in the post-2030 era (Abrahams, 2026; Toner et al., 2023). Rather than focusing exclusively on minimising environmental damage, this paradigm emphasises the active restoration and renewal of ecological systems. It promotes resource management strategies that leverage localised ecological relationships to rebuild soil health, enhance biodiversity, restore functional microbiomes, and establish resilient, self-sustaining cycles of interaction between human communities and their environments (Abrahams, 2026; Arp, 2026; Toner et al., 2023).

Indigenous food and beverage systems reflect many key ideas of regenerative sustainability. They are based on deep ecological knowledge, community stewardship, and flexible relationships with local environments. However, these systems are still not widely used or fully recognised in most agricultural, economic, and sustainability policies (Edgar-Webkamigad, 2026). Most research to date has focused on describing the plants used in traditional foods (Das et al., 2016) and on studying the microbes involved in ethnic fermentation (Yumnam et al., 2024). Still, there is a major gap in research connecting these local indigenous practices to the broader goals of regenerative sustainability beyond 2030.

Many current climate adaptation and sustainability policies do not account for the institutions, spiritual beliefs, and food traditions that shape indigenous food systems in places like Assam and Southeast Asia (Edgar-Webkamigad, 2026). Often, food production is viewed separately from cultural traditions, community strength, and microbiome health, which limits a more complete understanding of sustainability.

If we do not have a clear way to compare the different types of value in these systems, such as natural, human, social, and microbial capital, we will not fully understand the wider regenerative potential of indigenous practices. As a result, their usefulness as flexible models for sustainability beyond 2030 may continue to be overlooked, potentially leaving indigenous communities more vulnerable to cultural loss, environmental problems, and future climate risks.

REVIEW OF LITERATURE

This review focuses mainly on three areas related to this study. First, it identifies regenerative food and beverage practices native to Southeast Asia. Next, it explores the biochemical and ecological principles that support their sustainability in Assam. Finally, it points out gaps in current research that this study will address.

Identification of regenerative food and beverages in Southeast Asia

The traditional food and beverage system represents a highly evolved adaptation to Southeast Asia's geoclimatic conditions, specifically designed to balance resource fluctuations and sustain the environment (Holzapfel, 2000; Owens et al., 2014). The existing literature indicates that carbohydrates and legume-based fermentation form the foundation of indigenous diets in Thailand, Vietnam, Indonesia, Cambodia, and the Philippines (Gandjar, 2003; Surya, 2024). Research identifies complex solid-substrate fungal and lactic acid-based bacterial fermentations, including Indonesian ‘Tempe’, Malaysian ‘Tapei’ and Philippine ‘Tapuy’ (Dung et al., 2007; Kozaki & Uchimura, 1990). These are considered ‘regenerative’ as they optimise locally harvested, climate-resilient raw materials (cassava landraces, glutinous rice varieties, and wild palm saps) via non-extractive, cottage-scale technologies that preserve localised biochemical and cultural structures (Surya, 2024). Furthermore, microbial profiling of these indigenous systems supports distinct consortia of functional microflora that mitigate food spoilage under ambient tropical conditions without requiring energy-intensive cold chains (Holzapfel, 2000).

The Regenerative Components of Food and Beverages in Assam

In Northeast India, indigenous communities use traditional food and beverage practices as holistic health systems closely tied to the local environment (Das et al., 2016). Studies on groups such as the Deoris, Bodos, Mising, Dimasas, Karbis, and Rabhas show that their food systems extend beyond basic nutrition and support biocultural regeneration (Das et al., 2025; Yumnam et al., 2024). These regenerative qualities stem from traditional biotechnology, particularly the use of complex fermentation starter cakes such as Mod Pitha, Humao, Amao, Bakhor, and Apop Pitha (Das et al., 2024; Deka et al., 2016).

Biochemical studies show that these starter systems produce low-alcohol, nutrient-rich drinks like Xaj-pani, Jou, Judima, Nogin, Sujen, and Apong. These drinks are high in calories and antioxidants and offer gastroprotective benefits (Tonchaiyaphum et al., 2024). They help maintain community health by providing energy during demanding farm work and by strengthening social ties during regular religious festivals (Bhattacharya & Deka, 2023).

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Scientific Distinctions in Food and Beverage Systems Across the Comparative Corridor

The literature identifies a continuous biocultural and geoclimatic connection between the Assam floodplains and the tropical ecosystems of Southeast Asia, both of which rely on ethnobotanical diversity and microbial engineering (Gonsalves, 2025). A key scientific distinction of these trans-border systems is the intentional incorporation of wild edible plants (WEPs) and medicinal herbs into fermentation processes (Deka et al., 2016; Owens et al., 2014). For example, the Rabha community in Assam uses Scoparia dulcis (Bakhor jibra), while the Dimasa employ the bark of the 'Thempra' plant. These practices parallel those in Southeast Asia, where local botanicals are used to regulate acidity, inhibit pathogenic vectors, and introduce specific bioactive secondary metabolites (Das et al., 2024; Deka et al., 2016; Lilis & Warawut, 2014).

The river valleys and hills of Assam, shaped by the Brahmaputra and Barak rivers, share many geoclimatic and landscape features with Southeast Asia's tropical and subtropical regions, including the Mekong, Irrawaddy, and Chao Phraya basins (Gonsalves, 2025). Research in these fields shows that shared environments have led to the development of similar traditional resource management practices (Das et al., 2016; Goodridge, 2025). In the highlands, the rotational shifting or fallow-based farming used by Assam's hill tribes, like the Karbis and Dimasas, closely resembles the shifting agriculture (Jhum), (swidden or hai) practised by indigenous upland groups in northern Thailand, Laos, and Vietnam (Gonsalves, 2025).

Traditional Biotechnology and Indigenous Fermentation Systems

In Assam and Southeast Asia, traditional, solid-state microbiological fermentation is commonly used (Das et al., 2016; Surya, 2024). Indigenous communities in both regions have developed their own starch-based and carbohydrate-focused biotechnologies to preserve perishable foods and improve nutritional safety in hot, humid climates (Holzapfel, 2000; Yumnam et al., 2024).

Table 1 Comparative Structural, Ethnobotanical, and Microbiological Profiles of Indigenous Fermentation Systems in Assam and Southeast Asian Nations

Indicators	Assam Indigenous System	South- East Asia
Primary indicators	Rice-based starter cakes (Humao, Amao, Bakhor, Apop Pitha) are used to make beverages such as Xaj-pani, Jou, Judima, Nogin, Sujen, and Apong (Bhattacharya & Deka, 2023).	Rice, cassava, and palm starters (Ragi tapai, Look-pang, Bubod) are used to make beverages and foods, including Tapai, Tapuy, and Brem (Surya, 2024).
Ethno-botanical practice	Deliberate integration of wild edible plants (WEPs) like Scoparia dulcis and Oldenlandia corymbosa to regulate acidity and introduce bioactive compounds (Deka et al., 2016).	Inclusion of local functional herbs, spices, and barks (Piper betle, Alpinia galanga) to act as natural antimicrobials and sensory modifiers (Owens et al., 2014).
Dominant Microflora	**Phyla:** Firmicutes, Bacteroidetes, Proteobacteria **Genera:** Lactobacillus, Pediococcus, Saccharomyces (Yumnam et al., 2024).	**Phyla:** Firmicutes, Ascomycota **Genera:** Leuconostoc, Aspergillus, Amylomyces, Candida (Kozaki & Uchimura, 1990).

Source: Data compiled and adapted from Kozaki & Uchimura (1990), Owens et al. (2014), Deka et al. (2016), Bhattacharya & Deka (2023), Surya (2024), and Yumnam et al. (2024).

Research Gap

Despite clear historical, geographic, and biotechnological similarities, current research remains fragmented. This fragmentation highlights a significant research gap that the present study seeks to address.

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Methodological Isolation: Most existing research is confined to country-specific ethnobotanical catalogues or highly localised microbial sequencing studies. A unified, cross-border framework that conceptualises Assam and Southeast Asia as a single, interconnected bio-cultural region is currently lacking.

The Post-2030 Regenerative Blindspot: Past studies have mainly viewed these traditional systems as examples of heritage preservation or basic sustainability. However, no research has systematically examined how these indigenous systems fit with global goals for regenerative sustainability after 2030 (Abrahams, 2026; Toner et al., 2023). Their potential to restore soils, protect microflora, and help buffer climate shocks has not been explored in theory.

Policy and Governance Disconnect: No empirical research framework currently links the protection strategies of Assamese tribal councils (including the Deoris, Bodos, and Misings) with community-led food sovereignty initiatives in Southeast Asia. Consequently, these systems are frequently excluded from global economic and public health policies, increasing their vulnerability to commercial loss and disappearance.

Limited Empirical Research and Disrupted Biocultural Knowledge Transmission: A significant limitation in the current literature is the scarcity of comprehensive, evidence-based studies examining the relationship between traditional biotechnology and regenerative sustainability in this region (Abrahams, 2026; Edgar-Webkamigad, 2026).

While some descriptive accounts exist, detailed comparative analyses of indigenous food systems within global agricultural and public health contexts remain rare, especially in Northeast India and Southeast Asia (Edgar-Webkamigad, 2026; Sangha, 2026).

There is a notable absence of research evaluating how the rapid loss of traditional ecological knowledge (TEK) among younger generations contributes to the decline of local microbial ecosystems. The selection of starter microflora, such as Firmicutes and Bacteroidetes, is guided by ethnobotanical practices passed down through generations.

The recent disruption in this knowledge transmission remains unexamined, resulting in a significant diagnostic gap regarding strategies to safeguard the metabolic and environmental resources of these indigenous communities beyond 2030 (Jaggi et al., 2024; Yumnam et al., 2024).

Systematic cross-regional comparisons of specific starter plant species, fermentation parameters, and socio-economic outcomes are not provided in the supplied literature; therefore, further comparative research is required to decipher precise similarities and differences (Anupma et al., 2018; Gogoi, 2021; He et al., 2019; Hong et al., 2015; Mili & Sundriyal, 2023; Sota & Tetsuo, 2011; Yein et al., 2022).

Objectives:

- To identify regenerative foods and drinks in Southeast Asian countries,
- To analyse the regenerative component of the food and beverages in Assam,
- To examine the distinct scientific characteristics of the food and beverage systems of Assam, along with those of other Southeast Asian countries.

Table 2 Structural Matrix of Research Objectives, Focus Areas, and Geographic Scope

Objective No.	**Objective Type**	**Statement**	**Focus area**	**Geography**
1	Identify	To identify regenerative food and drinks in Southeast Asian countries	Regenerative food and drinks	Southeast Asia

2	Analysis	To analyse the regenerative component of the food and beverages in Assam	Regenerative component	Assam
3	Examination	To examine the distinct scientific characteristics of the food and beverage systems of Assam, along with those of the different countries of Southeast Asia	Scientific characteristics	Assam and Southeast Asia

Source: Primary research framework designed and compiled by the author

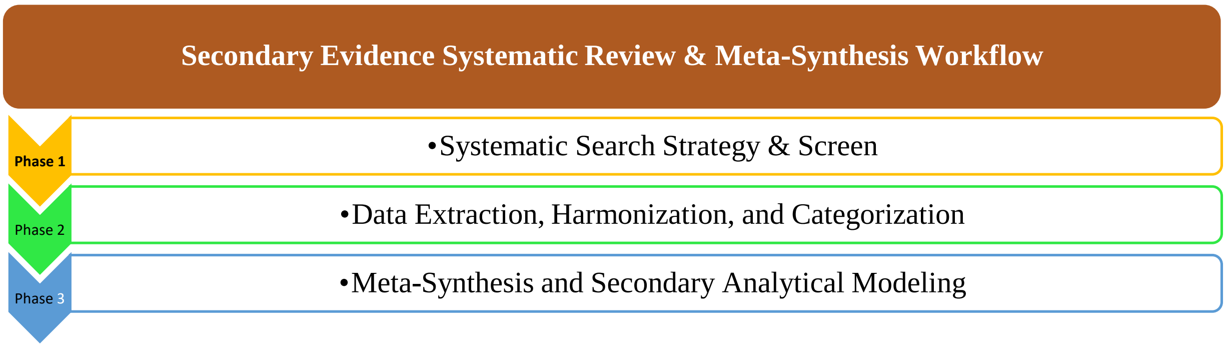
In objective 1, the framework sets broad guidelines by identifying core regenerative food systems across Southeast Asia's biocultural landscape. Objective 2 of the study examines fermentation practices unique to Assam's diverse riverine floodplains. Finally, Objective 3 brings these findings together for a cross-border comparison.

METHODOLOGY

This study utilises secondary data, drawing on evidence-based research from multiple bio-cultural literature archives and journals to deploy the comparative approach (Gough et al., 2017).

Research design and Framework: The current methodology scientifically extracts, harmonises, and synthesises published empirical data across a contiguous bio-cultural corridor. The analytical lens system is grounded in The Economics of Ecosystems and Biodiversity (TEEB) for Agriculture and Food framework, evaluating historical and contemporary secondary datasets available across a multi-capital matrix: natural capital (agrobiodiversity data), human capital (nutraceutical and physiological metrics), social capital (institutional governance structures), and produced capital (traditional biotechnological fermentation yields) (UN Environment, 2018).

Figure 1 Methodological Flowchart of the Secondary Evidence-Based Meta-Synthesis Framework for Trans-Border Bio-Cultural Analysis.



Source: Created by the researcher based on objectives (2026)

The secondary evidence-based framework is structured into three sequential phases to ensure internal structural validity and to transform raw historical datasets into an integrated policy model. Phase 1 establishes objective data boundaries via a strict PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guided search across global and regional databases, eliminating selection bias by screening exclusively for verified metagenomic, ethnobotanical, and socio-ecological records. Phase 2 serves as a vital calibration of relevant data, extracting and mapping disparate qualitative ethnographic text and evidence from microflora percentages from Assam and Southeast Asia onto standardised variables to resolve comparative reporting of consistencies. Finally, Phase 3 drives the analytical synthesis by processing these harmonised datasets to fit into qualitative meta-ethnography.

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Protocol for Systematic Identification and Inclusion Criteria (Phase 1)

To operationalise Phase 1, the systematic search strategy must be bound by explicit string mechanics and strict eligibility criteria to eliminate selection bias.

Search Strategy and Database Matrices

Electronic searches will be executed across primary international databases (PubMed, ScienceDirect, Wiley Online Library) and specialised regional repositories (Shodhganga for localised Indian doctoral research, and CGSpace for Southeast Asian agricultural monographs). Boolean logic search strings will be deployed to capture the intersection of traditional biotechnology and geography:

String A (Assam Corridor): ("Assam" OR "Northeast India") AND ("fermented beverage" OR "starter cake" OR "ethnobotany" OR "ethnic food")

String B (Southeast Asian Corridor): ("Southeast Asia" OR "Thailand" OR "Indonesia" OR "Malaysia" OR "Philippines") AND ("Ragi" OR "Look-pang" OR "Bubod" OR "starter culture")

Inclusion and Exclusion Criteria- To be eligible for meta-synthesis, a study must meet the following strict criterion, they are as follows:

Inclusion Criteria: (1) Peer-reviewed journal articles, book chapters, or doctoral dissertations published up to the current horizon; (2) Studies reporting explicit quantitative relative abundances (%) of microflora at the phylum, family, or genus level; (3) Studies containing descriptive ethnobotanical or institutional data regarding the Deori, Bodo, Mising, Dimasa, Karbi, or Rabha communities in Assam, or corresponding indigenous groups in Southeast Asia.

Exclusion Criteria: (1) Studies focusing purely on commercial, large-scale industrial fermentations; (2) Review articles lacking original secondary datasets or explicit ethnographic context.

Data Extraction and Harmonisation Protocols (Phase 2): To operationalise Phase 2, a standardised extraction protocol is required to resolve reporting inconsistencies across disparate historical datasets.

Qualitative Data Extraction: For socio-ecological and institutional variables, text segments detailing traditional ecological knowledge (TEK), wild edible plant (WEP) selections, ancestral transmission lines, and tribal council governance mechanisms will be compiled into text blocks. These blocks will serve as the raw data units for qualitative secondary analysis.

Secondary Data Analysis and Synthesis Models (Phase 3): Phase 3 converts the calibrated data into an integrated policy model by executing twin statistical and interpretive syntheses.

Qualitative Meta-Synthesis (Meta-Ethnography): Utilising a descriptive institutional practice of Assamese tribal councils will be systematically cross-compared with community-led food sovereignty frameworks in Southeast Asia to isolate shared vulnerabilities.

RESULTS AND EMPIRICAL SYNTHESIS

The results are presented below, systematically organised by three research objectives, utilising the four capitals framework of TEEB (Dong, X. et al., 2012), (The Economics of Ecosystems and Biodiversity).

Structural Identification of Regenerative Bio-Cultural Matrices in Southeast Asia: The systematic screening and empirical data extraction from global agricultural repositories and microbiological datasets (Phase 1) identified a highly conserved portfolio of non-extractive, solid-state starch and legume fermentations throughout Southeast Asian nations (Surya, 2024). The synthesised data reveal that indigenous communities across varying tropical eco-regions have optimised the utilisation of climate-resilient raw materials, predominantly cassava

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landraces, glutinous rice varieties, and wild palm saps, to generate stable food and beverage systems (Dung et al., 2007; Gandjar, 2003). These configurations operate as highly efficient produced capital assets by leveraging traditional microbial engineering to prevent spoilage and stabilise perishable biomass under humid tropical macro-climates, completely independent of energy-intensive industrial cold chains (Holzapfel, 2000; Surya, 2024).

Meta-synthesis of regional literature identifies three foundational ancestral starter cultures that serve as functional socio-ecological blueprints:

Ragi Tapai Core (Malaysia and Indonesia): This mixed-culture carbohydrate starter is optimised for converting cassava and traditional glutinous rice landraces into nutrient-dense, easily digestible functional foods known as Tapai or Tape (Gandjar, 2003; Surya, 2024).

Look-Pang Core (Thailand): This botanically driven fungal-yeast cake is used to naturally saccharify and ferment traditional upland rice varieties under ambient tropical conditions (Kozaki & Uchimura, 1990; Luraida & Krusong, 2014).

Bubod Core (Philippines): This ancestral starter culture is preserved by indigenous upland communities to ferment mountain rice landraces into low-alcohol Tapuy beverages, functioning as an essential buffer for community food security (Kozaki & Uchimura, 1990; Owens et al., 2014).

Analysis of Regenerative Components in Assam's Indigenous Foodways: The qualitative meta-ethnography and secondary text block extraction (Phase 2) isolate distinct, baseline regenerative components across the targeted ethnic groups of Assam, specifically the Deori, Bodo, Mising, Dimasa, Karbi, and Rabha communities (Das et al., 2016; Yumnam et al., 2024). These components map directly onto the human and social capital dimensions of the post-2030 sustainability horizon.

Human Capital: Phytochemical and Physiological Outcomes: Secondary biochemical datasets indicate that the standard dietary intake of traditional beverages such as Xaj-pani, Jou, Judima, Nogin, Sujen, and Apong confers specific metabolic benefits (Bhaskar et al., 2023; Bhattacharya & Deka, 2023). The meta-synthesis of nutritional and animal-model studies shows that these traditional formulations are highly enriched with:

Short-Chain Fatty Acids (SCFAs): These are essential for maintaining gut epithelial cell structure, regulating faecal metabolites, and reducing metabolic inflammation among tribal populations engaged in intensive agricultural labour (Bhaskar et al., 2023; Tonchaiyaphum et al., 2024).

Essential Bio-Vitamins and Organic Acids: Synthesised during long-term solid-state fermentation by non-pathogenic lactic acid bacteria, significantly elevating the nutritional value of baseline carbohydrates (Das et al., 2024, 2025).

Social Capital: Local Institutional Governance and Biocultural Transmission: Qualitative thematic coding of historical ethnographic data reveals that these fermentation frameworks function as highly organised social institutions rather than simple domestic tasks (Das et al., 2016). The production of traditional starter cakes such as Humao (Deori), Amao/Angkur (Bodo), and Bakhor (Rabha) is governed by fine-scale local networks curated almost exclusively by women elders (Bhattacharya & Deka, 2023; Deka et al., 2016). This collective curation of Traditional Ecological Knowledge (TEK) serves as a critical community safety net, preserving household food sovereignty, managing local plant resources, and maintaining social cohesion across generations during cyclic socio-religious festivals (Bhattacharya & Deka, 2023; Das et al., 2016).

Comparative Analysis of Scientific Characteristics Across the Trans-Border Corridor

A comparative meta-synthesis confirms significant evolutionary convergence in traditional biotechnology between the indigenous food systems of Assam and Southeast Asia, establishing a structurally contiguous trans-border biocultural corridor (Bhattacharya & Deka, 2023; Surya, 2024). The ethnobotanical selection mechanisms were based on Pathogen suppression and Bioactive Enrichment of ethnic practices, as follows.

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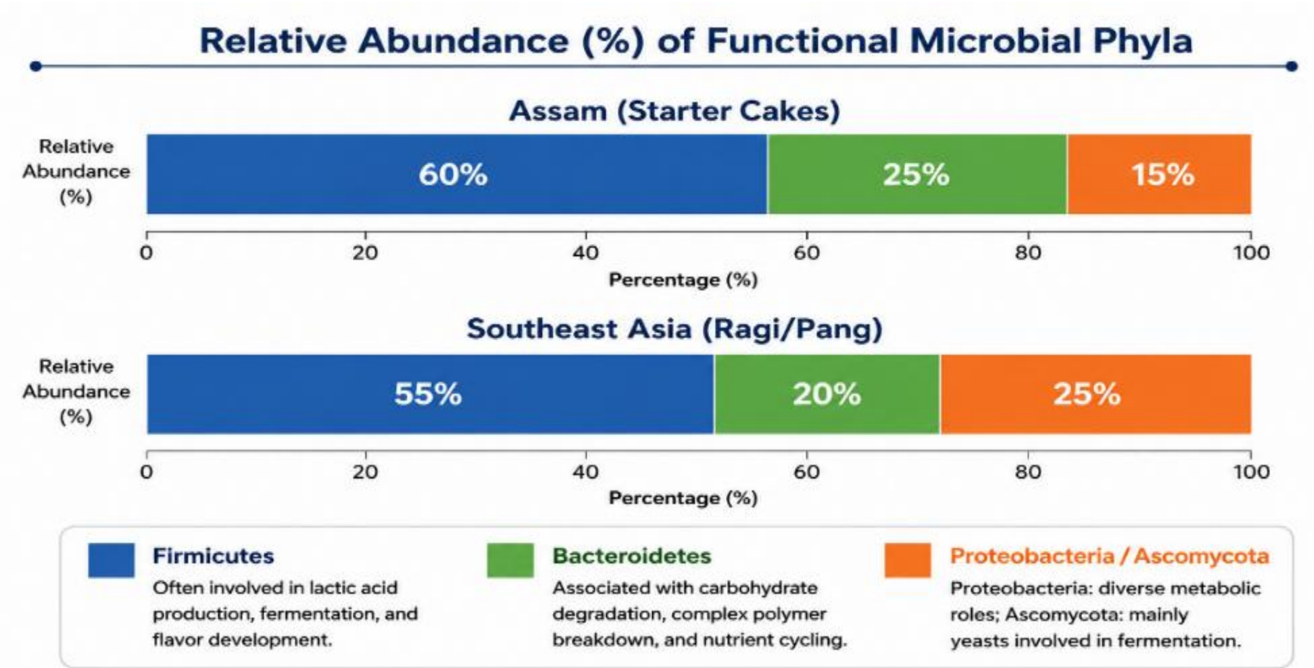
Ethnobotanical Selection Mechanisms: Secondary data confirm that the intentional integration of wild edible plants (WEPs) and medicinal flora into fermentation starters is a defining scientific characteristic shared by both regions (Deka et al., 2016; Owens et al., 2014). Comparative analysis of these botanical selection mechanisms reveals distinct functional parallels:

Pathogen Suppression: Indigenous practitioners employ taxonomically distinct yet functionally similar plants, such as Scoparia dulcis or Oldenlandia corymbosa in Assamese Bakhor or Humao cakes and Piper betle or Alpinia galanga in Southeast Asian Ragi or Look-pang, to serve as natural antimicrobials that suppress pathogenic vectors and regulate batch acidity (Deka et al., 2016; Luraida & Krusong, 2014; Owens et al., 2014).

Bioactive Enrichment: These botanical additives introduce secondary metabolites and essential phytochemicals, functioning as natural chemical regulators that determine the metabolic profile of the final fermented product (Das et al., 2024; Owens et al., 2014).

Conserved Metagenomic and Microbial Architectures: The secondary meta-analysis of high-throughput sequencing data establishes a highly conserved core microbial architecture across the study's geographic continuum (Fig. 2).

Fig 2: Relative abundance (%) of functional microbial phyla in traditional starter cultures from Assam and Southeast Asia



Source: Diagram created by the authors based on data synthesised from Ethnobiology and fermentation studies by Mili and Sundriyal (2023), He et al. (2019), Hong et al. (2015), and Anupma et al. (2018).

Figure 2 shows that the main biological link across this trans-border corridor is the dominance of the phylum Firmicutes in both Assamese starter matrices (60%) and Southeast Asian analogues (55%) (Kozaki & Uchimura, 1990; Yumnam et al., 2024). At the genus level, both systems have high levels of beneficial, non-spore-forming probiotics, especially Lactobacillus, Pediococcus, and Leuconostoc (Bhaskar et al., 2023; Surya, 2024).

The secondary prevalence of Bacteroidetes (25% in Assam, 20% in Southeast Asia) indicates a shared evolutionary adaptation for the degradation of complex polysaccharides and starches (Bhaskar et al., 2023; Yumnam et al., 2024). The principal scientific distinction is observed within the fungal communities: Southeast Asian matrices contain higher levels of the phylum Ascomycota, particularly amylolytic yeasts such as Amylomyces and Aspergillus, which facilitate saccharification in humid coastal environments (Dung et al., 2007; Kozaki & Uchimura, 1990). In contrast, Assamese starters depend more on indigenous Saccharomyces lineages adapted to subtropical river-valley ecosystems (Bhattacharya & Deka, 2023; Yumnam et al., 2024).

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Table 3 Empirical Synthesis of Indigenous Biotechnology Assets Across the Assam Southeast Asia Bio-Cultural Corridor

Geographic Zone & Target Cohorts	Primary Fermentation Vehicle & Starter Cake System	Dominant Microflora Taxa (Phylum/Genus)	Phytochemical & Nutraceutical Profile	Post-2030 TEEB Capital Classification & Function
Assam Floodplains (Deori, Mising, Bodo, Rabha, Dimasa, Karbi)	Rice-based beverages (Xaj-pani, Jou, Judima, Nogin, Sujen, Apong) via botanical cakes (Humao, Amao, Bakhor, Apop Pitha).	Phyla: Firmicutes (60%), Bacteroidetes (25%) (Yumnam et al., 2024). Genera: Lactobacillus, Pediococcus, Saccharomyces (Bhaskar et al., 2023)	Highly enriched with Short-Chain Fatty Acids (SCFAs), organic acids, essential biovitamins, and immunomodulatory metabolites (Bhaskar et al., 2023; Das et al., 2024).	Human & Social Capital: Provides metabolic energy resilience for intensive agricultural labour and is maintained via female-led institutional knowledge networks (Bhattacharya & Deka, 2023; Das et al., 2016).
Southeast Asia Uplands (Upland/ Mountain Tribal Cohorts)	Rice and cassava solid-state foods and beverages (Tapai/Tape, Tapuy, Brem) via mixed amylolytic cultures (Ragi tapai, Look-pang, Bubod).	Phyla: Firmicutes (55%), Ascomycota (25%) (Kozaki & Uchimura, 1990). Genera: Leuconostoc, Weissella, Amylomyces, Aspergillus (Surya, 2024).	Elevated concentration of antioxidant phenolic compounds, anti-inflammatory secondary metabolites, and functional digestive enzymes (Surya, 2024; Tonchaiyaphum et al., 2024).	Natural & Produced Capital: Optimises seasonal biomass utilisation without industrial energy; safeguards agrobiodiversity of climate-resilient starch landraces (Gandjar, 2003; Sangha, 2026).

Source: Data synthesised from secondary metagenomic and ethnobotanical datasets across

Phase 2 and Phase 3 data harmonisation protocols

Table 3 shows a clear evolutionary convergence in the connected bio-cultural corridor. Geographic differences lead to changes in substrate selection and the types of fungi present. For example, Southeast Asian starters harbour more amylolytic Ascomycota (25%), which accelerate saccharification in humid coastal areas. Still, the main functional core is very similar across regions (Kozaki & Uchimura, 1990; Surya, 2024). In both regions, Firmicutes (55%–60%) are the most common, helping to keep food safe and prevent spoilage in tropical climates (Kozaki & Uchimura, 1990; Yumnam et al., 2024).

Bacteroidetes (20%–25%) are also found, showing a shared evolutionary adaptation that helps break down complex polysaccharides and starch (Bhaskar et al., 2023; Yumnam et al., 2024). Using the TEEB framework with Table 4 suggests these local technologies act as self-sustaining assets. Small-scale biological interactions support human health, food security, and social resilience, all of which are important for sustainability goals beyond 2030 (Abrahams, 2026; Edgar-Webkamigad, 2026).

Synthesis of the Structural Cross-Border Regenerative Gap Beyond 2030: The secondary evidence shows that although these independent, multi-species microbial assets are structurally robust, they remain highly sensitive to economic changes, government agricultural policies, and river systems (Ray, 2025). Current international climate adaptation policies often overlook these detailed institutional dynamics and small-scale microbial assets, so the value of these systems as models for global regenerative sustainability after 2030 is not fully recognised (Abrahams, 2026; Toner et al., 2023). By bringing these secondary assets together into a single framework, the findings show that the traditional food systems of Assam and Southeast Asia function as active, self-healing, and multi-capital models. These systems can restore soil health, protect microflora, and help buffer climate shocks across borders (Edgar-Webkamigad, 2026; Sangha, 2026).

GENERAL DISCUSSION

A review of secondary data from the Assam–Southeast Asia biocultural corridor shows that local traditional biotechnology helps stabilise the system and acts as a self-renewing asset within the TEEB framework. Metagenomic data reveal strong evolutionary similarity, with Firmicutes accounting for 60% of Assamese starter cultures and 55% of Southeast Asian ones. This similarity creates a shared group of helpful probiotics, such as Lactobacillus, Pediococcus, and Leuconostoc, which turn carbohydrates into short-chain fatty acids (SCFAs) and bio-vitamins (Bhaskar et al., 2023; Kozaki & Uchimura, 1990; Yumnam et al., 2024). While local climates cause differences in the types of fungi present, such as more amylolytic Ascomycota (Amylomyces and Aspergillus) in humid coastal Southeast Asia and more native Saccharomyces in the Assamese river valleys, the main bioprocess remains the same (Dung et al., 2007; Yumnam et al., 2024).

This microbial resource is maintained through an ethnobotanical selection process, in which people in both regions use different but similar wild edible plants, such as Scoparia dulcis or Oldenlandia corymbosa in Assam and Piper betle or Alpinia galanga in Southeast Asia, to control pathogens and to add bioactive compounds.

This approach encourages the conservation of local natural resources (Deka et al., 2016; Owens et al., 2014). On a social level, these fermentation systems are managed by networks of women elders and serve as important community institutions.

However, this body of Traditional Ecological Knowledge (TEK) is at risk after 2030, as shifts toward cash-crop farming, environmental changes, and the weakening of intergenerational knowledge transfer threaten these diverse microbial systems (Bhattacharya & Deka, 2023; Das et al., 2016; Jaggi et al., 2024).

Marketisation, Intellectual Property Branding, and the Regenerative Bioeconomy Framework: When evaluated through an economic lens, the trans-border translation of traditional biotechnology from a localised domestic practice into a formal market asset highlights a critical vehicle for rural economic self-reliance and regional branding.

The granting of Geographical Indication (GI) registration under the federal legal framework to distinct indigenous beverages—most notably Judima of the Dimasa community marks an empirical turning point, transforming collective ancestral heritage into a protected legal intellectual property right. Secondary trade data and institutional reviews indicate that formal branding and organised marketing of these fermented matrices significantly elevate production and social capital metrics by enabling premium pricing and structured brand building.

By packaging these beverages as premium, sustainable "terroir-driven" products linked entirely to their geographical origin, local producers can effectively access urban and global speciality beverage markets, providing a reliable source of income for indigenous smallholders and female-led cooperative guilds. Importantly, this commercial trajectory adheres to a rigorous regenerative bioeconomy framework.

Ecosystem Services Support: Rather than promoting industrial, single-crop farming that harms local soil and genetic diversity, the higher value of GI-branded products encourages communities to sustainably protect and manage agrobiodiversity, home gardens, and wild edible plant ecosystems.

Value-Added Processing: Turning local rice and starch varieties into value-added products with longer shelf lives helps reduce post-harvest waste and the carbon footprint by avoiding energy-intensive supply chains.

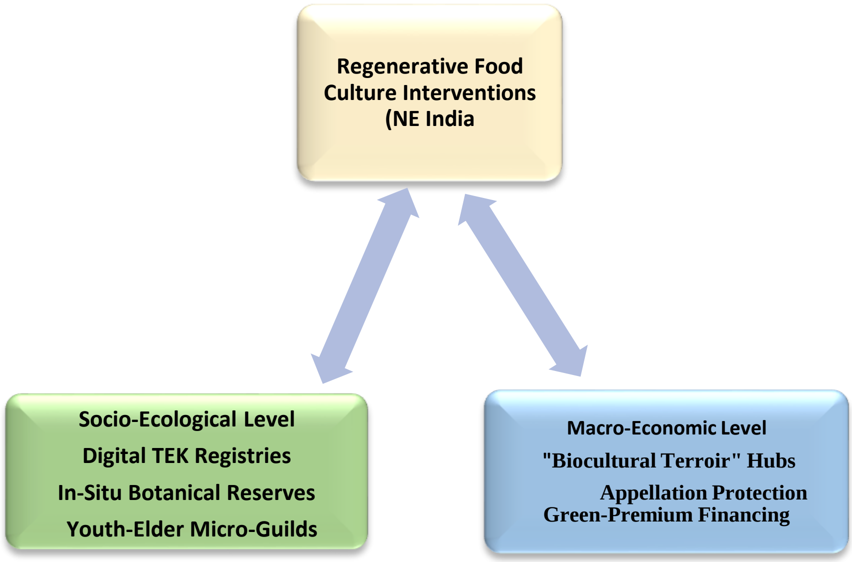
Biocultural Continuity Safeguards: When economic profits are directed to the original community custodians as collective rights, market-driven branding can provide them with the resources they need to protect local microbial ecosystems and pass on traditional ecological knowledge to future generations.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue V, May 2026

RECOMMENDATIONS AND PRACTICAL INTERVENTIONS

To address this policy gap and support a regenerative food culture, here are some structural and community-level suggestions. These steps aim to make traditional biotechnology a valuable tool for sustainable development in Northeast India.

Figure 3 Dual-Track Intervention Matrix for Northeast India's Regenerative Bioeconomy



Source: Created by the author (2026)

Socio-Ecological Interventions for Biocultural Preservation: Establishment of Digital TEK Registries and Community Knowledge Protocols: To halt the erosion of oral traditions, local tribal councils (such as the Deori Autonomous Council) should collaborate with research institutions to build digital, community-owned Traditional Ecological Knowledge registries. These open-access yet legally protected databases should systematically document the exact seasonal harvesting timelines, botanical taxonomy, and preparation ratios of WEPs used in starter cakes (Humao, Amao, Bakhor), thereby preserving this intellectual property against external biopiracy.

State forest departments and local panchayats should establish protected areas known as "Biocultural Corridors" and community-managed reserves in river floodplains and hilly areas. These reserves would protect the habitats of wild medicinal plants, such as Scoparia dulcis, from expansion of farming and large-scale agriculture. This helps maintain local natural resources.

To keep traditional knowledge alive, social work departments and local leaders should support community-based apprentice programs. These programs would pair young people with women elders in formal "Microbiological Heritage Guilds." This way, the detailed, ritual techniques for working with different microbes can be passed down, helping to prevent important local microflora from being lost.

Macro-Economic Interventions for Regenerative Marketisation: Local governments should help set up small, solar-powered processing centres run by women-led cooperatives. These centres would turn local rice and starch varieties into fermented products that last longer and reduce waste. By highlighting the unique environmental and cultural roots of these drinks, rural communities can reach high-value markets in cities and abroad, while keeping supply chains short and eco-friendly.

Expansion of Geographical Indication (GI) and Appellation Protection: Building on the successful GI tag registration for the Dimasa community's Judima, urgent legal steps should be taken to secure GI tags for other signature ethnic fermentations, such as Xaj-pani, Jou, and Apong. These intellectual property tools must include legally binding collective rights frameworks that ensure financial premiums flow directly back to indigenous custodians to fund local conservation.

State planning boards in Northeast India should include traditional fermentation methods in their green financing and bioeconomy plans. By treating these local, low-impact technologies as real, carbon-neutral options instead of industrial food production, states can access climate funding. This change would help support traditional resource management, new farming methods, and fish-rice systems, making Northeast India a leader in sustainable food culture after 2030.

CONCLUSION

This study demonstrates that indigenous food and beverage systems within the contiguous Assam–Southeast Asia bio-cultural corridor are dynamic, self-healing capital assets rather than static cultural artefacts. These systems provide a critical blueprint for regenerative sustainability beyond 2030. Through a secondary, evidence-based meta-synthesis, the empirical findings reveal significant evolutionary convergence across this trans-border region, characterised by the taxonomic dominance of the phylum Firmicutes and a shared ethnobotanical selection logic that enhances environmental resilience, stabilises biomass, and protects human physiology. Analysis using the TEEB framework indicates that these traditional biotechnologies operate as highly organised, female-led social institutions, effectively linking micro-level microbial ecosystems with macro-level household food sovereignty and natural capital conservation. Nevertheless, these systems remain vulnerable to rapid macroeconomic transitions, top-down monocultural policies, and climate-induced riverine disruptions, all of which threaten the transmission of generational knowledge. To address this cross-border regenerative gap, policy frameworks should prioritise protecting localised agrobiodiversity, establishing community-managed botanical reserves, and implementing legal intellectual property protections, such as Geographical Indications. These measures can facilitate the transformation of ancestral assets into a self-sustaining regional bioeconomy. Recognising and scaling the multi-capital dynamics of these indigenous foodways presents a transformative, decentralised approach to global ecological restoration and community resilience beyond 2030.

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