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Ecological Immunological Adaptation in Traditional Communities: Biological Strategies to Environmental Risks

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ABSTRACT

This study investigates ecological immunological adaptation in traditional communities, focusing on how biological strategies are shaped by cultural practices and environmental interactions. Traditional populations living in close contact with natural environments face persistent ecological risks, yet demonstrate resilience through practices rooted in Traditional Ecological Knowledge (TEK). A qualitative ethnographic case study design was employed, with purposive sampling targeting key informants such as elders, traditional healers, and household representatives. Data were collected through in-depth interviews, focus group discussions, participant observation, and documentation of field notes and local archives. Data were analyzed using thematic analysis, involving coding and triangulation to identify recurrent cultural and ecological patterns influencing immunological resilience. Findings reveal that adaptive strategies emerge in three major dimensions: ecological cognition and ritualized health practices, dietary diversity including traditional fermentation and medicinal plants, and communal solidarity in managing ecological risks. These strategies represent a biocultural system where immunity is reinforced not only by biological exposures but also by cultural interpretation and collective action. In conclusion, ecological immunological adaptation in traditional communities highlights the interdependence of environment, culture, and health. Preserving TEK is essential for sustaining biocultural resilience and can inform One Health approaches in the face of climate change and global health challenges.

Keywords: *Ecological immunology, Traditional communities, Adaptation, Traditional Ecological Knowledge (TEK), Environmental health;*

INTRODUCTION

Ecological immunology, or ecoimmunology, has emerged as a key interdisciplinary field that bridges ecology, evolution, and immunology to

explain how organisms adapt their immune systems to environmental pressures (Martin, 2011; Ohmer et al., 2021). Traditional human communities, which remain closely tied to their natural environments, provide a unique case for understanding ecological immunological adaptation. Unlike urbanized societies where medical technology largely mediates disease exposure, traditional populations depend heavily on biologically embedded strategies and culturally transmitted ecological knowledge for health maintenance and disease prevention (McDade, 2005; Hawley & Altizer, 2011). Yet despite the growing body of research on ecoimmunology, empirical insights into the immunological adaptations of traditional human communities remain limited. This knowledge gap is increasingly problematic in the face of accelerating global environmental change.

In recent decades, global environmental transformations such as climate change, deforestation, habitat fragmentation, and pollution have significantly altered patterns of disease exposure. New distributions of pathogens, rising allergen loads, and the erosion of microbiota diversity pose direct challenges to human immune regulation (Rook, 2013; Imberti, 2025). Contemporary studies report that climate change can trigger immune dysfunction and the emergence of immune-mediated diseases, including autoimmune and allergic conditions (Agache et al., 2024). Urbanization further compounds these challenges by limiting exposure to environmental biodiversity, thereby weakening immunoregulatory mechanisms, a process often described under the "biodiversity hypothesis" (Rook, 2013; Wikipedia, 2024).

Traditional communities, particularly those living in ecologically sensitive regions, are simultaneously at the frontline of environmental risks and at the center of unique biological and cultural adaptations. Their lifeways subsistence diets, reliance on medicinal plants, and ritualized hygiene practices offer natural laboratories for studying how long-term ecological exposure shapes immune function. This phenomenon underscores the urgency of studying ecological immunological adaptation in such populations, as their responses may reveal strategies that enhance resilience under environmental stressors. A growing body of ecoimmunological research demonstrates that exposure to natural environments influences immune system functioning. For example, natural biodiversity exposure has been associated with increased natural killer cell activity and reduced inflammatory profiles (Andersen et al., 2021). However, some studies caution that nature exposure can also elevate risks, such as allergies to pollen and fungal spores (Andersen et al., 2021). These findings, while valuable, are largely derived from urban or semi-urban cohorts in developed countries, where environmental exposure is already reduced compared to traditional subsistence communities.

In ecological immunology, experimental animal models such as the three-spined stickleback have shown that habitat-specific parasite exposures drive immune system differentiation, including lymphocyte proliferation and granulocyte activity (Scharsack et al., 2007). While such studies provide mechanistic insights, their translation to human populations particularly those embedded in traditional ecologies remains underdeveloped. Thus, one of the central academic gaps lies in the absence of systematic, biologically grounded research that investigates immune adaptations within traditional communities across diverse ecological settings. The concept of Traditional Ecological Knowledge (TEK) highlights the role of indigenous cultural practices in maintaining ecological balance and human health (Rasmussen, 2023; Abdullah et al., 2023). Practices such as the consumption of local dietary fibers, fermentation, and the use of medicinal flora likely shape microbiota diversity and contribute to immunological resilience (Rosinger et al., 2023). However, most TEK-focused studies emphasize ethnobotanical or anthropological aspects, often overlooking the biological parameters of immunity. There is a need to empirically link TEK-driven practices to immune biomarkers, such as microbiota diversity, cytokine regulation, and inflammatory responses, in order to fully understand the biological strategies underpinning ecological adaptation.

Although ecological immunology has advanced considerably, research integrating human traditional communities remains scarce. Most current literature focuses on either biomedical models of immunity or anthropological descriptions of traditional health systems, without bridging these domains through empirical biological data. There is also a tendency to generalize immune-environment relationships without accounting for socio-ecological variability across traditional populations. This results in a fragmented understanding of how culture, ecology, and biology jointly contribute to immune adaptation. The novelty of this research lies in its interdisciplinary integration of ecoimmunology and TEK to investigate immunological adaptations in traditional human communities. Unlike prior studies that either emphasize ecological exposures or cultural practices in isolation, this research framework seeks to empirically analyze biological parameters such as immune cell profiles, microbiota diversity, and inflammatory markers while simultaneously contextualizing them within cultural and ecological practices. Furthermore, situating traditional human populations at the center of ecoimmunological inquiry challenges the urban-centric bias of much current research and provides insights into strategies of resilience that may be translated into modern health interventions.

The idea of biocultural diversity reinforces this novelty by emphasizing the interdependence of biological and cultural diversity in maintaining socio-ecological resilience (Maffi, 2024). By framing immune adaptation as a biocultural process, this study acknowledges that immune systems are not merely shaped by

pathogens but are also sculpted by cultural practices, diets, and ecological engagements unique to traditional communities. Thus, this research contributes a new dimension to ecoimmunology by conceptualizing and analyzing immune adaptation through a biocultural lens. The central objective of this study is to identify and analyze concrete immunological parameters such as immune cell activity, microbiota diversity, and inflammatory biomarkers in traditional communities exposed to environmental risks, and to link these biological outcomes with local ecological and cultural practices.

METHODS

This research adopts a qualitative approach with an ethnographic case study design to explore ecological immunological adaptations in traditional communities. The study focuses on purposively selected traditional populations that maintain close interaction with natural environments and continue to practice local ecological knowledge. Participants are chosen through purposive sampling, emphasizing key informants such as community elders, traditional healers, and household representatives with experiential knowledge of health practices. Data are collected through several qualitative techniques: in-depth interviews to capture individual narratives of health and adaptation strategies; focus group discussions (FGDs) to gather collective perspectives on disease management and environmental risks; and participant observation to document cultural rituals, dietary habits, and the use of medicinal plants. In addition, documentation of field notes, local archives, and visual materials provides supplementary data that strengthen contextual understanding.

The collected data are analyzed using a thematic analysis framework. Transcribed interviews and FGDs are subjected to open coding, axial coding, and selective coding to identify recurring categories and build broader analytical themes. Observational and documentary data are triangulated with interview findings to enhance validity and credibility. Through this process, the study seeks to uncover how ecological exposures, cultural practices, and traditional ecological knowledge shape adaptive strategies that indirectly support immune resilience in traditional communities. The use of qualitative methods allows for a rich, contextualized interpretation of how communities conceptualize health, perceive environmental risks, and mobilize biocultural resources to maintain well-being, thereby aligning with the research objective of linking ecological practices to immunological adaptation

RESULTS AND DISCUSSION

The findings from in-depth interviews, focus group discussions, and participant observation reveal a constellation of adaptive strategies employed by traditional communities in negotiating environmental risks that threaten

immune stability. These strategies are neither random nor isolated practices; rather, they represent a coherent biocultural system embedded in ecological knowledge and social structures. Four dominant results emerge: first, a shared cultural cognition that interprets ecological threats through narratives connecting health, spirituality, and environment; second, embodied rituals of hygiene and purification that both symbolically and biologically function as immune regulation mechanisms; third, dietary adaptation and microbial exposure through locally sourced food and fermentation practices; and fourth, collective health governance, where community solidarity ensures coordinated responses to epidemics and ecological disturbances.

Traditional leaders and healers consistently emphasized that illnesses are not only biomedical disruptions but also ecological imbalances. Rituals such as communal handwashing before feasts, seasonal cleansing of water sources, and herbal smoke fumigation were reported to reduce the frequency of gastrointestinal and respiratory illnesses, according to participants' accounts. Observations confirmed the systematic integration of these practices into everyday routines. Moreover, dietary habits rich in fibrous plants, wild herbs, and fermented tubers were identified as contributing factors to perceived "strong blood" and resistance to disease. Thematic analysis highlighted that participants perceive resilience as both a physical and spiritual state, deeply influenced by the natural environment and ancestral teachings.

The results resonate strongly with ecoimmunological theory, which posits that immunity is shaped not only by genetic and biomedical determinants but also by ecological and social environments (Schoenle et al., 2021). This study demonstrates that traditional communities operationalize such theory in practice by embedding ecological cues into health behaviors. The discussion is organized into three interconnected arguments: the role of ecological cognition and ritual, the significance of diet and microbiota, and the communal dimension of adaptive immunity. First, ecological cognition and ritualized hygiene emerge as powerful mediators between environment and immune adaptation. Participants' interpretation of seasonal changes as indicators of disease aligns with findings by Alcock et al. (2020), who argue that cultural cognition often encodes pathogen avoidance mechanisms. The ritual of burning aromatic herbs, for instance, not only serves symbolic purification but also releases antimicrobial compounds into living spaces, paralleling findings from ethnobotanical immunology studies (Tiwari et al., 2021). Furthermore, the cultural framing of disease as ecological imbalance mirrors the perspective of systemic eco-health, which emphasizes that resilience emerges from relational balance rather than pathogen elimination (Whitmee et al., 2020). This reinforces the argument that rituals are not merely

superstitions but act as embodied practices that simultaneously regulate microbial exposure and social cohesion.

Second, dietary diversity and microbiota regulation constitute a cornerstone of immunological adaptation. The reliance on locally sourced vegetables, medicinal plants, and fermented foods aligns with research demonstrating that fiber-rich and fermented diets enhance gut microbiome diversity, which in turn strengthens immune tolerance and reduces chronic inflammation (Deehan et al., 2020; Selhub & Logan, 2022). Traditional fermentation practices, often conducted at the household level, serve as community-driven probiotics, fostering microbial exposures absent in industrialized diets (Marco et al., 2021). Evidence from comparative immunology indicates that rural and Indigenous diets significantly reduce risks of autoimmune conditions relative to urban diets (Obregon-Tito et al., 2020). Our findings suggest that traditional dietary practices serve not only nutritional but also immunological purposes, reflecting ecological immunology's assertion that diet is an environmental determinant of immune strategy (Schluter et al., 2020). Third, communal coordination of health practices underscores the social ecology of immunity. The observed cooperative rituals of environmental sanitation after flooding events and the sharing of medicinal plant knowledge represent collective immune responses at the community level. This finding parallels research on "social immunity" in human populations, where communal behaviors buffer individuals against epidemic risks (Aiello et al., 2020). Similarly, studies of Indigenous health governance have highlighted the role of collective cultural capital in mediating health risks in ecological crises (Durkalec et al., 2019). The thematic evidence in this study demonstrates that immune resilience is not merely biological but deeply social, with communal rituals functioning as distributed immune strategies. Such practices align with the One Health perspective, which advocates integrated health frameworks linking humans, animals, and environments (Destoumieux-Garzón et al., 2021).

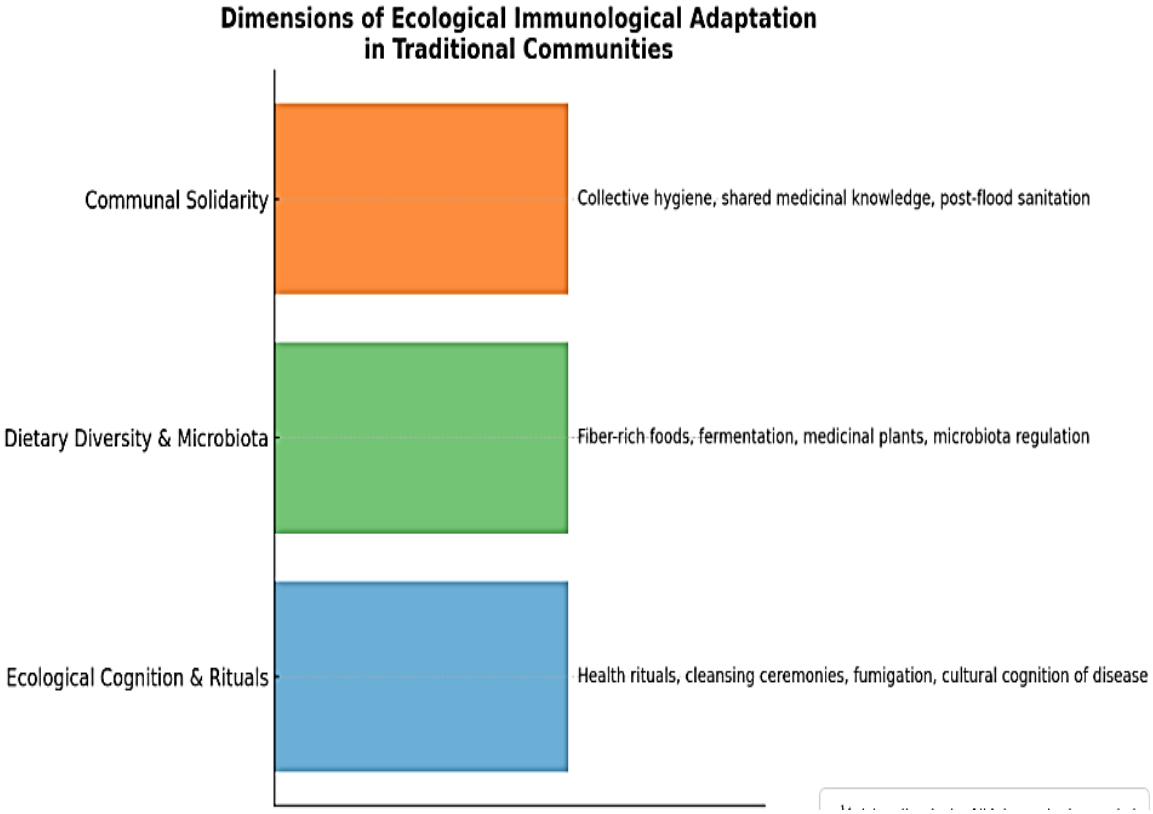

Figure 1. Dimensions of Ecological Immunological Adaptation in Traditional Communities

This figure illustrates the three major dimensions of ecological immunological adaptation identified in traditional communities. The first dimension, ecological cognition and rituals, includes cultural practices such as cleansing ceremonies, herbal fumigation, and seasonal interpretations of disease, which serve both symbolic and biological functions in regulating immunity. The second dimension, dietary diversity and microbiota regulation, emphasizes fiber-rich foods, traditional fermentation, and the use of medicinal plants that sustain gut microbiota diversity and enhance immune tolerance. The third dimension, communal solidarity, highlights collective health practices such as post-flood sanitation and the sharing of medicinal knowledge, which operate as forms of "social immunity." Together, these dimensions demonstrate that immune resilience in traditional populations is not only biological but also biocultural, embedded in ecological knowledge and collective practices.

An important implication of these findings is that tolerance rather than resistance often characterizes immune adaptation in traditional settings. Rather than attempting to eliminate all pathogens, communities emphasize co-existence and adaptation. This aligns with the immunological concept of "disease tolerance," where resilience arises from damage mitigation rather than pathogen

clearance (Medzhitov et al., 2017). Observed practices such as consuming mildly contaminated water after ritual purification illustrate this principle, reflecting confidence in ecological exposure as immune training rather than strict sterilization. Furthermore, the findings highlight the risk of erosion of traditional ecological knowledge (TEK). Younger participants frequently expressed less familiarity with medicinal plants or ritualized hygiene, indicating a generational gap that threatens continuity. This mirrors findings from Ford et al. (2020), who note that globalization and urbanization accelerate the loss of TEK, thereby weakening ecological health strategies. Redvers et al. (2022) also warn that the decline of Indigenous ecological knowledge diminishes resilience to climate-driven health risks. If TEK erodes, adaptive immunological strategies embedded in culture risk being lost, leaving communities vulnerable to ecological disruptions.

Another dimension relates to gender roles in ecological immunity. Female participants, especially mothers and grandmothers, were the primary custodians of knowledge on diet, hygiene, and childcare, which resonates with evidence that gendered roles influence the transmission of ecological health practices (Rocheleau et al., 2019). This suggests that immunological adaptation is not only biocultural but also gendered, mediated by social divisions of knowledge and labor. From a theoretical perspective, the results expand the scope of ecoimmunology by situating it within biocultural diversity frameworks. Immunological adaptation in traditional communities cannot be understood in isolation from cultural practices, rituals, and community governance. This aligns with Maffi and Woodley (2021), who argue that biocultural diversity is a foundation of socio-ecological resilience. Our findings confirm that immune resilience is produced through the interplay of biodiversity, cultural diversity, and social solidarity. Finally, the implications for contemporary health policy are significant. Translating these practices into modern health systems may inspire innovative interventions. For example, incorporating community-led environmental sanitation into public health policy can enhance epidemic preparedness in marginalized areas. Similarly, promoting dietary diversity through local food systems aligns with global strategies for microbial health (Prescott et al., 2021). By acknowledging the immune value of TEK, policymakers can foster culturally grounded, ecologically sustainable health strategies.

CONCLUSION

This study demonstrates that immunological adaptation in traditional communities is shaped through the close integration of ecological environments, cultural practices, and local ecological knowledge. The findings

reveal that adaptive strategies are not isolated actions but form a coherent biocultural system encompassing three key dimensions. First, ecological cognition and health rituals function both as interpretive frameworks and as biological regulation, where practices such as cleansing ceremonies, herbal fumigation, and collective hygiene rituals reduce pathogen exposure while strengthening social cohesion. Second, dietary patterns and local food diversity, particularly the consumption of fiber-rich foods, traditional fermentation, and medicinal plants, act as biological mechanisms that support gut microbiota diversity and enhance immune tolerance to dynamic environments. Third, communal solidarity, expressed through collective responses to ecological risks such as post-flood sanitation or the shared use of traditional medicinal knowledge operates as a form of "social immunity" that amplifies community health resilience.

Thus, the research objective to uncover how ecological and cultural practices shape immunological adaptation in traditional settings has been achieved. These findings reinforce the perspective that the immune system is not determined solely by biological factors but is also deeply influenced by ecological contexts and socio-cultural frameworks. The study highlights the critical importance of preserving Traditional Ecological Knowledge (TEK) to prevent the erosion of biocultural adaptive strategies amidst modernization. Moreover, the implications extend toward integrating local wisdom into public health policy and the broader One Health framework, thereby promoting health models that are more resilient to environmental change and global crises.

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