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Traditional Ecological Knowledge and Climate Resilience in Sustainable Agriculture

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Abstract

Climate change is intensifying rainfall variability, drought, flooding and pest pressure across smallholder farming systems, exposing the limits of input-intensive adaptation pathways. Traditional ecological knowledge (TEK), the intergenerational knowledge, practices and beliefs that communities hold about their environments, is increasingly recognised as a resource for climate resilience, yet the evidence remains fragmented across regions, disciplines and knowledge systems. This article synthesises how TEK contributes to climate resilience in sustainable agriculture and identifies the conditions under which those contributions hold. A systematic literature review following an adapted PRISMA 2020 protocol was conducted on 25 peer-reviewed publications (2021–2026) with active DOIs and analysed through qualitative thematic synthesis. The findings identify five interlocking TEK domains: climate observation and forecasting, agrobiodiversity and crop management, soil and water stewardship, ecological pest and waste management, and social-institutional arrangements, which together strengthen the absorptive, adaptive and transformative capacities of farming communities. Evidence from Asia, Africa and Latin America shows that TEK is most effective when it is hybridised with scientific knowledge, supported by institutions and actively transmitted across generations. Where it erodes or is marginalised, traditional practice can instead become a source of vulnerability. The study proposes a conditional, multi-capacity framework for integrating TEK into agricultural adaptation policy and extension.

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INTRODUCTION

Agriculture is at once one of the sectors most exposed to climate change and one of the sectors most capable of shaping how societies adapt to it. Shifting rainfall onset, prolonged dry spells, intense floods, rising temperatures and the spread of pests are already reshaping cropping calendars and yields in many farming regions. The burden of these changes falls disproportionately on smallholders, Indigenous Peoples and local communities whose livelihoods depend directly on rainfall, soil fertility and local biodiversity, and who often have limited access to irrigation, insurance, credit and formal extension services (Apraku et al., 2021; Schlingmann et al., 2021). For these communities, climate resilience is not an abstract policy goal but a daily practical problem of securing food, income and well-being under uncertainty.

Dominant responses to agricultural climate risk have long emphasised technological solutions such as improved varieties, synthetic inputs, mechanisation and centralised climate services. These measures have value, but they are frequently costly, poorly suited to heterogeneous micro-environments and dependent on supply chains that smallholders cannot always reach. They can also erode the ecological foundations of farming, including soil organic matter, agrobiodiversity and natural pest regulation, on which long-term resilience depends (Barman et al., 2024; Kamakaula, 2026). This has prompted growing interest in sustainable agriculture approaches that combine productivity with ecological integrity and social equity, and within that agenda, in the knowledge systems that farming communities have developed over generations of living with environmental variability.

Traditional ecological knowledge (TEK) refers to the cumulative body of knowledge, practices and beliefs about the relationships among living beings and their environment that evolves through adaptive processes and is transmitted across generations. Related terms such as indigenous knowledge (IK), indigenous technical knowledge (ITK), Indigenous and local knowledge (ILK) and ethnoecology emphasise different facets of the same broad phenomenon: locally grounded, experience-based and often holistic understandings of land, water, plants, animals and climate (Jakes, 2024; Kamakaula, 2024; Santos & Villanueva, 2026). In agriculture, TEK is expressed in seed selection and landrace conservation, intercropping and agroforestry, soil and water conservation structures, botanical pest control, seasonal calendars and biological weather indicators, as well as in the norms, rituals and institutions that regulate resource use and mutual support (Karn, 2024; Mugambiwa, 2026).

Over the past five years, the literature linking TEK and climate resilience has expanded rapidly. Systematic reviews show that Indigenous Peoples and local communities worldwide deploy a broad portfolio of responses to climate impacts, and that these responses are shaped more by livelihood systems than by the climate zone in which communities live (Schlingmann et al., 2021). Dorji et al. (2024) conclude that IK contributes to adaptation and resilience through multiple pathways and is most effective when used alongside scientific knowledge. Regional syntheses document TEK-based agricultural adaptation in High Mountain Asia (Witharana et al., 2025), Mesoamerica (Márdero et al., 2023) and the Sahel (Zougmoré et al., 2023).

Empirical studies from Chile, China, Nepal, the Philippines, Kenya, South Africa, Uganda and Zimbabwe add place-based evidence on how specific communities use their knowledge to buffer climate shocks (Apraku et al., 2021; Caviedes et al., 2024; Chaudhary et al., 2022; Li & Han, 2022; Mugabirwe & Turyamureeba, 2025; Salindo et al., 2025).

Despite this growth, three problems limit the usefulness of the evidence for policy and practice. First, the literature is fragmented. Studies use different terms (TEK, IK, ITK, ILK, ethnoecology), different units of analysis (practices, households, communities, landscapes) and different definitions of resilience, which makes it hard to compare findings or identify general patterns. Second, much of the literature remains descriptive. It inventories practices but rarely specifies which dimension of resilience a practice strengthens: the capacity to absorb a shock, to adjust in response to it, or to transform the system that produces vulnerability. Third, a celebratory tone sometimes obscures the limits of TEK. Recent work cautions that traditional practices deformed by external stressors can become aggravators of climate risk rather than buffers (Witharana et al., 2025), that ILK-based adaptation responses are not automatically sustainable (Galappaththi & Schlingmann, 2023), and that local and scientific understandings of climate change do not always align (Zougmoré et al., 2023).

These gaps matter because governments are under growing pressure to integrate Indigenous and local knowledge into national adaptation plans, agricultural extension and climate services. Policy-oriented studies argue that such integration can strengthen resilience and sustainability (Sakapaji, 2022) and can, for example, reinforce national climate action plans through TEK-based agricultural waste management (Das et al., 2024). Integration without a clear understanding of when and how TEK works, however, risks either tokenistic inclusion or the uncritical transfer of practices across contexts in which they may not function. Researchers and policymakers therefore need a synthesis that goes beyond listing practices to explain the mechanisms and conditions through which TEK supports resilience in agricultural systems.

Evidence from agroecology reinforces this need. A review of 77 cases of agroecological treatments in low- and middle-income countries found that such practices frequently improved indicators of adaptive capacity without compromising yields, and that positive outcomes were more likely where practices were locally adapted, including through local or indigenous knowledge (Dittmer et al., 2023). At the household level, Caviedes et al. (2024) found that Indigenous and local knowledge of social-ecological change is positively associated with livelihood resilience in a Globally Important Agricultural Heritage System. In the Philippines, Salindo et al. (2025) show that traditional knowledge mediates the relationship between climate awareness and agricultural resilience by turning awareness into concrete practices such as crop diversification, rainwater harvesting and mutual aid. Taken together, these findings suggest that TEK functions less as a static repository of techniques than as a dynamic capacity that links perception, action and social organisation.

Conceptually, resilience in social-ecological systems is commonly understood as the capacity of a system to absorb disturbances, adapt to changing conditions and, where necessary, transform into a new configuration that reduces underlying

vulnerability. TEK is relevant to all three capacities because it combines practical techniques with ways of observing environmental change and with social institutions that coordinate collective action (Li & Han, 2022; Santos & Villanueva, 2026). Importantly, TEK is not a fixed inheritance. It is continuously updated as communities experiment, learn from neighbours and selectively incorporate external knowledge, a process described as hybridisation (Chaudhary et al., 2022). Recognising TEK as a dynamic system rather than a museum of practices is essential for assessing its contribution to resilience under climatic conditions that may exceed historical experience.

Against this background, this article asks two questions. (1) Through which domains and mechanisms does TEK contribute to climate resilience in sustainable agriculture? (2) Under what enabling and constraining conditions do these contributions hold, weaken or reverse? To answer them, the study systematically reviews and thematically synthesises 25 peer-reviewed publications from 2021–2026 covering Asia, Africa, Latin America and global syntheses.

The novelty of this article lies in four contributions. First, it brings together the most recent evidence, including studies published in 2025 and 2026, which earlier reviews could not cover, and combines regional reviews with community-level empirical studies. Second, rather than producing another inventory of practices, it organises TEK contributions according to the absorptive, adaptive and transformative capacities of resilience, clarifying what each domain of knowledge does for farming systems facing climate stress. Third, it treats conditionality as a central analytical object by systematically identifying the enabling conditions (such as hybridisation with science, institutional support and intergenerational transmission) and the constraining conditions (such as knowledge erosion, external pressures and policy marginalisation) that determine whether TEK strengthens or undermines resilience. Fourth, it translates these findings into a conditional, multi-capacity framework that can guide the integration of TEK into agricultural adaptation policy, extension and research, particularly in countries with rich Indigenous agricultural heritage and high climate exposure such as Indonesia. In doing so, the article seeks to move the debate from whether TEK matters to how, when and for whom it builds climate resilience.

METHODS

2.1 Research design

This study used a systematic literature review (SLR) design combined with qualitative thematic synthesis. An SLR was chosen because the research questions concern patterns, mechanisms and conditions across a heterogeneous body of evidence rather than the effect size of a single intervention. Because the included studies varied widely in design, from household surveys and ethnographic case studies to regional and global reviews, statistical meta-analysis was not appropriate. Instead, the evidence was integrated through interpretive synthesis. The review procedure was adapted from the PRISMA 2020 reporting guideline and comprised four stages: identification, screening and eligibility, supplementary search, and inclusion and synthesis (Figure 1).

2.2 Data sources and search strategy

Records were identified on 13 November 2026 through the Consensus academic search engine, which indexes peer-reviewed literature from major scholarly databases. Two parallel queries were run using the article's core concept in Indonesian ("Pengetahuan Ekologis Tradisional dan Ketahanan Iklim dalam Pertanian Berkelanjutan") and in English ("Traditional Ecological Knowledge and Climate Resilience in Sustainable Agriculture"). This bilingual strategy was used to capture literature that is semantically relevant across language framings. The results of both queries were exported in RIS format, yielding 16 and 17 records respectively, for a total of 33 records.

2.3 Eligibility criteria and screening

Records were imported into a reference manager and de-duplicated by matching DOI and title, which removed 11 duplicate records and left 22 unique records. Each unique record was screened against five inclusion criteria: (a) peer-reviewed journal article; (b) published between 2021 and 2026, in line with the five-year recency requirement; (c) an active, resolvable DOI; (d) a substantive focus on traditional, indigenous or local ecological knowledge; and (e) explicit engagement with climate change adaptation, resilience or sustainability in agricultural or food systems. Exclusion criteria were grey literature without DOIs, studies outside the agricultural or food domain, and publications before 2021. All 22 unique records met the criteria and were retained.

2.4 Supplementary search

To strengthen the evidence base with high-impact syntheses and quantitative evidence that the Consensus exports did not capture, a targeted supplementary search was conducted using Google Scholar–indexed sources and backward and forward citation tracking from the included reviews. Three additional publications that met all inclusion criteria and whose DOIs were verified as active were added: a global systematic review of adaptation by Indigenous Peoples and local communities (Schlingmann et al., 2021), a review of agroecological practices and adaptation outcomes in smallholder systems (Dittmer et al., 2023) and a review of indigenous knowledge for adaptation in the Sahel (Zougmoré et al., 2023). The final corpus therefore comprised 25 publications.

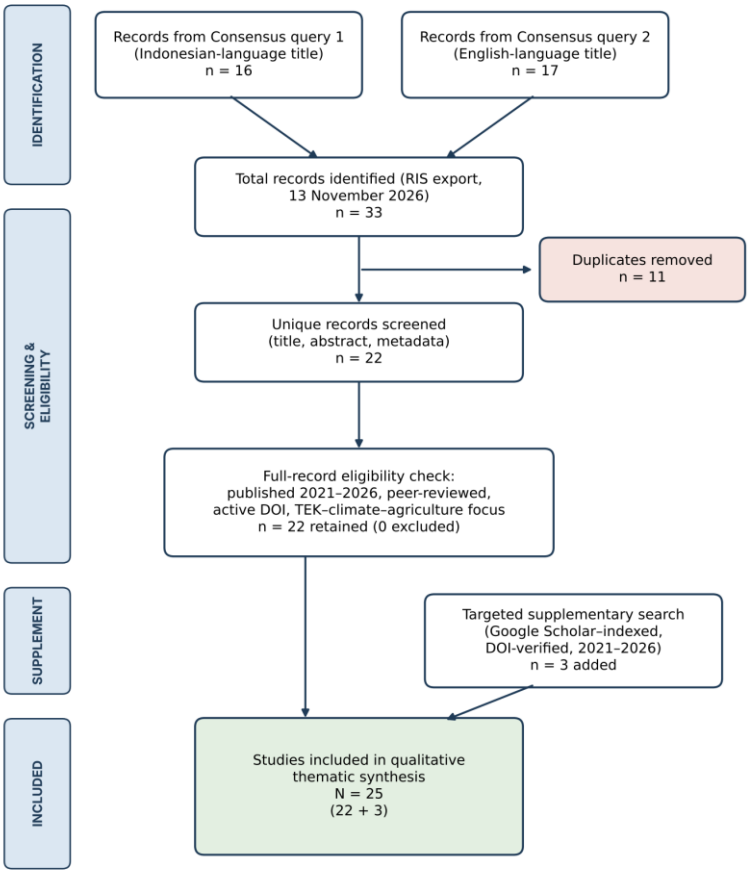

Image 1. Flow diagram of the literature identification, screening and inclusion process (adapted from PRISMA 2020). Source: Author's elaboration (2026).

2.5 Data extraction and synthesis

A structured extraction matrix was used to record, for each publication, the authors and year, geographical context, study design, TEK practices described, climate hazards addressed, reported resilience outcomes, and mechanisms or barriers relevant to integrating TEK with scientific knowledge and policy. Synthesis proceeded in three steps. First, descriptive coding of practices and outcomes was carried out inductively. Second, codes were clustered into higher-order TEK domains. Third, each domain was mapped deductively onto the three resilience capacities widely used in climate adaptation research: absorptive capacity (buffering and recovering from shocks), adaptive capacity (adjusting practices and livelihoods to changing conditions) and transformative capacity (altering the social-ecological structures that generate vulnerability). Enabling and constraining conditions were coded separately to address the second research question.

2.6 Quality considerations and limitations

The corpus combines publications from high-impact international journals with articles from regional and emerging journals. Rather than excluding the latter, which often provide the only available documentation of particular communities' practices, the synthesis gave greater interpretive weight to findings that were corroborated across several sources or supported by systematic or quantitative evidence. Findings from single descriptive studies were treated as illustrative. The

main limitations are the reliance on one primary search engine, the modest corpus size and the possibility that relevant non-English or non-indexed literature was missed. These limitations are mitigated, but not eliminated, by the bilingual search strategy and the supplementary citation tracking.

RESULTS AND DISCUSSION

3.1 Characteristics of the included studies

The 25 included publications span 2021–2026. The literature has grown steadily: two publications appeared in 2021, three in 2022, four in 2023, seven in 2024, four in 2025 and five in 2026, showing that the field is still accelerating. Geographically, eight publications focus on Asia (India, Nepal, China, the Philippines and High Mountain Asia), five on Africa (Kenya, South Africa, Uganda, Zimbabwe and the Sahel), two on Latin America (Chile and Mesoamerica), and ten adopt a global or multi-context perspective. By design, seven are empirical field studies (surveys, case studies and ethnographies), while eighteen are systematic, narrative, conceptual or policy reviews. This balance means the synthesis draws both on community-level detail and on broader patterns established by earlier reviews. Terminology across the corpus is also diverse. Publications variously use TEK, indigenous knowledge (IK), indigenous technical or technological knowledge (ITK), Indigenous and local knowledge (ILK), indigenous ecological knowledge (IEK), traditional knowledge and ethnoecology. Because these terms overlap substantially in the agricultural context, the synthesis treats them as members of one family of place-based knowledge systems while noting differences in emphasis where relevant. Table 1 summarises the corpus.

Table 1. Characteristics of the 25 included studies (ordered by year)

No	Author(s) (Year)	Region / context	Design	Main focus
1	Apraku et al. (2021)	Kenya & South Africa	Empirical field study	Role of IK in small-scale agricultural adaptation
2	Schlingmann et al. (2021)	Global	Systematic review	Global patterns of IPLC adaptation responses
3	Chaudhary et al. (2022)	Western Tarai, Nepal	Qualitative case study	Hybrid knowledge in Tharu climate-resilient farming
4	Li & Han (2022)	Yunnan-Guizhou karst, China	Qualitative case study	Ethics and flexible actions as TEK properties
5	Sakapaji (2022)	Global / policy	Policy review	Integrating IEK into adaptation policy
6	Dittmer et al. (2023)	LMICs	Evidence review	Agroecology, adaptation outcomes and yield
7	Galappaththi & Schlingmann (2023)	Global	Review / assessment	Sustainability of ILK-based adaptation in food systems
8	Márdero et al. (2023)	Mesoamerica	Systematic review	Traditional knowledge for adaptation
9	Zougmoré et al. (2023)	Sahel	Review	Indigenous knowledge for effective adaptation
10	Barman et al. (2024)	India	Review	ITK for climate-resilient agriculture
11	Caviedes et al. (2024)	Chiloé GIAHS, Chile	Quantitative household study	ILK and livelihood resilience
12	Das et al. (2024)	India	Review / policy	TEK in agricultural waste management and NAPCC
13	Dorji et al. (2024)	Global	Systematic review	How IK contributes to adaptation and resilience

No	Author(s) (Year)	Region / context	Design	Main focus
14	Jakes (2024)	Global	Conceptual review	Traditional knowledge in sustainable development
15	Kamakaula (2024)	Multi-context	Conceptual review	Ethnoecology and agricultural adaptation
16	Karn (2024)	South Asia (tribal communities)	Conceptual / descriptive	Tribal cognizance of climate change
17	Harnessing ITK … Assam (2025)	Assam, India	Review	ITK as a pathway to climate resilience
18	Mugabirwe & Turyamureeba (2025)	Ankole, Uganda	Empirical field study	IK for adaptation in rural communities
19	Salindo et al. (2025)	Northern Negros, Philippines	Quantitative survey (n = 394)	TK as mediator of awareness and resilience
20	Witharana et al. (2025)	High Mountain Asia	Review	TEK-based agriculture and adaptation priorities
21	Kamakaula (2026)	Multi-context	Conceptual review	Ethnoecology-based traditional agricultural systems
22	Kamakaula & Soares (2026)	Multi-context	Qualitative / conceptual	Indigenous systems and socio-ecological resilience
23	Mugambiwa (2026)	Rural Zimbabwe	Qualitative case study	Indigenous farming knowledge of smallholders
24	Nkwenkwe & Matiso (2026)	Smallholder systems, Southern Africa	Conceptual framework	Co-produced indigenous–scientific soil knowledge
25	Santos & Villanueva (2026)	Multi-context	Review	TEK and adaptation in indigenous communities

Source: Author's synthesis of the included studies (2026).

3.2 Domains through which TEK builds climate resilience

Thematic synthesis identified five interlocking domains through which TEK contributes to climate resilience in agriculture (Table 2). These domains are analytically distinct but rarely separate in practice. A single farming system typically combines several of them, and their resilience value often lies in this combination.

Climate observation and forecasting. Many communities read environmental indicators such as the behaviour of insects and birds, the flowering and fruiting of particular trees, wind patterns and celestial signs to anticipate rainfall onset, drought or flooding and to time planting and harvesting. In Kenya and South Africa, smallholders draw on such indicators to guide agricultural decisions where formal forecasts are inaccessible or distrusted (Apraku et al., 2021). In the Sahel, farmers' perceptions of local climate change are largely consistent with meteorological records, although precipitation trends are perceived more heterogeneously (Zougmoré et al., 2023). Evidence from Uganda and the Philippines shows that personal experience and family remain the main sources of this knowledge (Mugabirwe & Turyamureeba, 2025; Salindo et al., 2025). Forecasting knowledge mainly strengthens absorptive and anticipatory capacity, allowing farmers to prepare before a shock occurs.

Agrobiodiversity and crop management. Conserving landraces, intercropping, polycultures, agroforestry and crop diversification are the TEK practices most frequently linked to resilience across the corpus. In High Mountain Asia, the largest contribution of documented TEK-based agriculture is to adaptation priorities such as developing water- and nutrient-efficient crops, and diversified traditional agroecosystems buffer farmers against multiple hazards (Witharana et

al., 2025). In Mesoamerica, systems such as the milpa and home gardens combine food security with risk spreading (Márdero et al., 2023), while studies from India and Assam document flood- and drought-tolerant traditional varieties and diversified cropping as low-cost adaptation options (Barman et al., 2024; "Harnessing Indigenous Technical Knowledge," 2025). This domain mainly strengthens adaptive capacity because diversity widens the set of options available when conditions change.

Soil and water stewardship. Terracing, mulching, water harvesting, indigenous irrigation and local soil classification help sustain productivity under rainfall variability. In rural Zimbabwe, IKS-based water management and irrigation are central adaptive strategies among smallholders (Mugambiwa, 2026). In the fragile karst landscape of Baojiatun, China, flexible land- and water-use practices embedded in TEK help the community cope with climate impacts (Li & Han, 2022). Nkwenkwe and Matiso (2026) show that indigenous soil indicators such as soil colour, plant composition and biotic activity correspond to scientific indicators such as soil organic carbon and nutrient status, providing a basis for co-produced soil management frameworks.

Ecological pest, nutrient and waste management. Botanical pesticides, biological control, crop-residue recycling, composting and integrated crop–livestock systems reduce dependence on external inputs while maintaining soil fertility. Das et al. (2024) argue that TEK-based agricultural waste management can reduce emissions and strengthen India's National Action Plan on Climate Change, while reviews of indigenous technological knowledge and ethnoecology document low-cost, location-specific practices that support both mitigation and adaptation (Barman et al., 2024; Kamakaula, 2026). Because climate change shifts pest distributions, the ecological flexibility of these practices is an important complement to chemical control.

Social-institutional and ethical arrangements. TEK is also embodied in norms, taboos, rituals, customary rules, collective labour and mutual-aid networks. Li and Han (2022) identify "strong ethics and flexible actions" as defining properties of TEK that sustain socioecological resilience: stable ethical commitments regulate resource use, while flexible practices allow adjustment. Mutual aid and social networks for sharing seeds, labour and ideas appear repeatedly as mechanisms that convert individual knowledge into collective resilience (Mugambiwa, 2026; Salindo et al., 2025). Studies of indigenous agricultural systems further show that ecological and social resilience reinforce one another (Kamakaula & Soares, 2026; Santos & Villanueva, 2026). This domain is the main source of transformative capacity, because it shapes who has access to resources, how decisions are made and whether communities can renegotiate their relationships with markets and the state.

Table 2. TEK domains, practices and the resilience capacities they strengthen

TEK domain	Representative practices	Climate hazards addressed	Main resilience capacity	Key sources
Climate observation & forecasting	Biological and astronomical indicators; seasonal calendars; elders' forecasts	Erratic rainfall onset, drought, floods	Absorptive / anticipatory	Apraku et al. (2021); Zougmoré et al. (2023); Mugabirwe & Turyamureeba (2025); Salindo et al. (2025)
Agrobiodiversity & crop management	Landraces, intercropping, polycultures, milpa, agroforestry, diversification	Drought, flood, heat, crop failure	Adaptive	Márdero et al. (2023); Barman et al. (2024); Witharana et al. (2025); "Harnessing ITK" (2025)
Soil & water stewardship	Terracing, mulching, water harvesting, IKS-based irrigation, local soil indicators	Water scarcity, erosion, soil degradation	Adaptive / absorptive	Li & Han (2022); Mugambiwa (2026); Nkwenkwe & Matiso (2026)
Ecological pest, nutrient & waste management	Botanical pesticides, biological control, composting, residue recycling	Shifting pest pressure, input dependence, emissions	Adaptive (with mitigation co-benefits)	Dittmer et al. (2023); Barman et al. (2024); Das et al. (2024); Kamakaula (2026)
Social-institutional & ethical arrangements	Customary rules, taboos, rituals, mutual aid, collective labour, knowledge networks	Compound shocks, livelihood loss	Transformative	Li & Han (2022); Salindo et al. (2025); Kamakaula & Soares (2026); Mugambiwa (2026); Santos & Villanueva (2026)

Source: Author's synthesis of the included studies (2026).

3.3 Evidence on resilience outcomes

Several studies move beyond description to test associations between TEK and resilience outcomes. At the household level, Caviedes et al. (2024) found that Indigenous and local knowledge of social-ecological change is positively associated with livelihood resilience in the Chiloé Globally Important Agricultural Heritage System in Chile. In Northern Negros, the Philippines, a survey of 394 respondents showed that traditional knowledge acts as a mediator that translates climate awareness into resilience-building practice (Salindo et al., 2025). At a broader scale, Dittmer et al. (2023) reported that among cases reporting yields, agroecological treatments produced higher yields in 63% of cases, and indicators of adaptive capacity (crop and income diversity, net income, nutrient regulation and reduced pest infestation) were associated with positive outcomes in 70% or more of cases. These outcomes were more likely where practices were locally adapted. Global syntheses confirm that local adaptation is diverse and livelihood-driven (Schlingmann et al., 2021) and that IK contributes to resilience across agriculture, natural resource management and disaster risk reduction (Dorji et al., 2024).

The evidence also points to limits. Galappaththi and Schlingmann (2023) show that ILK-based adaptation responses in agricultural and aquatic food systems vary in their sustainability across ecological, social and economic dimensions and can involve trade-offs. Witharana et al. (2025) note that when traditional practices are

deformed by multiple external stressors, they can become aggravators of climate risk rather than buffers. These findings caution against treating TEK as inherently resilient and support a conditional reading of its contribution.

3.4 Enabling and constraining conditions

The second research question concerned the conditions under which TEK contributions hold. Four sets of conditions emerged consistently (Table 3). The first is knowledge integration. The Tharu of Nepal's western Tarai illustrate "hybrid knowledge", in which traditional practices are combined selectively with introduced techniques to produce climate-resilient farming (Chaudhary et al., 2022). Co-produced frameworks that map indigenous indicators onto scientific measures make such hybridisation systematic and verifiable (Nkwenkwe & Matiso, 2026). The second is institutional and policy support. Without formal recognition in adaptation policy, extension and climate services, TEK remains marginal and under-resourced (Das et al., 2024; Sakapaji, 2022). The third is intergenerational transmission. Because TEK is largely transmitted through practice, family and community, out-migration, formal schooling that ignores local knowledge and changing livelihoods all weaken transmission (Jakes, 2024; Karn, 2024; Mugabirwe & Turyamureeba, 2025). The fourth is ecological and socio-economic integrity. Land dispossession, market pressure and the degradation of the ecosystems on which practices depend can undermine TEK even where knowledge is still held (Witharana et al., 2025; Kamakaula, 2024).

Table 3. Enabling and constraining conditions for TEK-based climate resilience

Condition	Enabling factors	Constraining factors	Key sources
Knowledge integration	Hybrid knowledge; co-produced indicators; joint indigenous–scientific forecasting	One-way "validation"; dismissal of TEK as backward; mismatch between local and scientific signals	Chaudhary et al. (2022); Zougmoré et al. (2023); Dorji et al. (2024); Nkwenkwe & Matiso (2026)
Institutional & policy support	Recognition in adaptation plans; extension programmes that document local practices	Policy marginalisation; top-down, input-centred programmes	Sakapaji (2022); Das et al. (2024); Jakes (2024)
Intergenerational transmission	Learning through practice, family and elders; community networks	Youth out-migration; schooling detached from local knowledge; livelihood change	Karn (2024); Mugabirwe & Turyamureeba (2025); Salindo et al. (2025)
Ecological & socio-economic integrity	Intact agroecosystems; secure land and resource rights; heritage system status	Land and ecosystem degradation; market pressure; practices deformed by external stressors	Caviedes et al. (2024); Galappaththi & Schlingmann (2023); Witharana et al. (2025)

Source: Author's synthesis of the included studies (2026).

3.5 Discussion: Toward a conditional, multi-capacity framework

The synthesis supports three interpretive claims. First, TEK contributes to climate resilience not as a single technique but as a layered system: observation and forecasting support anticipation, agrobiodiversity and soil–water stewardship sustain adaptation, ecological input management lowers costs and emissions, and social-institutional arrangements enable collective and transformative responses. Interventions that extract a single practice, such as a botanical pesticide or a

traditional variety, from this system may therefore capture only part of its resilience value.

Second, the resilience value of TEK is conditional. It is strongest where knowledge is hybridised with science, recognised by institutions, actively transmitted and anchored in functioning ecosystems and secure land rights. It weakens, and may even reverse, where these conditions erode. This conditional reading reconciles the strongly positive associations reported in empirical studies (Caviedes et al., 2024; Salindo et al., 2025) with the cautionary findings of sustainability assessments (Galappaththi & Schlingmann, 2023; Witharana et al., 2025). It also explains why the same practice can succeed in one context and fail in another: transferability depends less on the practice than on the conditions surrounding it.

Third, integration should be understood as co-production rather than validation. Many studies call for TEK to be "scientifically validated", but the evidence from Nepal, South Africa and the Sahel suggests that the most productive integration occurs when both knowledge systems inform one another. Local indicators enrich data-sparse monitoring, and scientific tools help communities interpret unprecedented changes (Chaudhary et al., 2022; Nkwenkwe & Matiso, 2026; Zougmoré et al., 2023). This has practical implications for countries such as Indonesia, where diverse ethnoecological farming systems coexist with high climate exposure and where ethnoecology-based approaches are increasingly proposed as strategies for sustainable agricultural development (Kamakaula, 2024, 2026). Agricultural extension could incorporate participatory documentation of local indicators and practices; climate services could combine scientific and indigenous forecasts; and national adaptation plans could formally recognise customary institutions as partners in resilience building. Overall, the findings suggest that strengthening TEK requires investing in the people, institutions and ecosystems that hold it, rather than only cataloguing practices.

The synthesis also reveals important gaps for future research. Most outcome evidence relies on farmers' perceptions or cross-sectional associations, and few studies follow communities over time to observe how TEK-based responses perform across successive climate shocks. Mitigation co-benefits such as carbon sequestration and reduced emissions are rarely measured, a limitation also noted in agroecological evidence reviews (Dittmer et al., 2023). Gender and generational differences in who holds and benefits from knowledge receive limited attention, even though they shape both transmission and access to resources. Finally, Southeast Asia beyond the Philippines and Indonesia's many agrarian Indigenous communities remain under-represented in the international literature, despite their rich agricultural heritage and high exposure to climate hazards. Addressing these gaps would strengthen both the scientific basis and the policy relevance of TEK-based adaptation.

CONCLUSIONS

This review of 25 peer-reviewed publications from 2021–2026 shows that traditional ecological knowledge makes a substantial and multidimensional contribution to climate resilience in sustainable agriculture. Five interlocking domains (climate observation and forecasting, agrobiodiversity and crop

management, soil and water stewardship, ecological pest and waste management, and social-institutional arrangements) together strengthen the absorptive, adaptive and transformative capacities of farming communities. Empirical and review evidence from Asia, Africa and Latin America consistently links TEK to more diverse, lower-cost and locally adapted farming systems and to stronger livelihood resilience.

These contributions, however, are conditional. TEK builds resilience most reliably when it is hybridised with scientific knowledge, supported by institutions and policy, transmitted across generations and grounded in functioning ecosystems and secure access to land. Where these conditions erode, traditional practices may lose effectiveness or even aggravate climate risk. The proposed conditional, multi-capacity framework therefore shifts attention from whether TEK matters to how, when and for whom it works.

Three recommendations follow. Policymakers should formally recognise TEK and customary institutions in national adaptation plans and agricultural policies, with safeguards for community consent and benefit-sharing. Extension and climate-service agencies should adopt co-production approaches that combine indigenous indicators and practices with scientific monitoring. Researchers should conduct more longitudinal and comparative studies that measure resilience outcomes, examine trade-offs and include under-represented regions, including Indonesia and other parts of Southeast Asia, where ethnoecological farming systems remain rich but under-documented.

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