



Ethnochemical Reconstruction of Dayak Tomun Tuak Fermentation for Contextual Chemistry Learning: an Applied Ethnography with AI-Augmented Qualitative Analysis

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ABSTRACT

This study integrates AI-augmented qualitative analysis into an applied-ethnographic reconstruction of Dayak Tomun tuak fermentation to address the lack of curriculum-ready, place-based chemistry materials. Fieldwork in Arut Selatan, Central Kalimantan (August 2024–January 2025) engaged two participants (one brewer, one customary leader) through structured observation, semi-structured narrative interviews, and audiovisual documentation under inclusion criteria of ≥ 10 years' practice and consistent use of traditional methods. Within Google Colab, ChatGPT assisted transcript segmentation and first-pass open-axial-selective coding; researchers verified all outputs line by line and iteratively refined a codebook with an audit trail. Findings clarify a two-stage process: glutinous-rice *tapai* for approximately 2–3 days followed by fermentation of a cooled sugar-and-spice infusion for approximately 4–5 days. Three controls consistently mattered: cooling to hand-warm (≤ 35 °C) before inoculation, tightly sealed vessels for defined durations, and spice infusion (clove, cinnamon, nutmeg, long pepper, black pepper) for flavor and perceived "cleanliness." Sensory shift from sweet to bitter aligned with community assessments of progress; sociocultural boundaries (acid exclusion, restricted access, optional kapur sirih markings) co-occurred with empirical controls. We provide four curriculum-aligned exemplars for Grades 10–11: stoichiometry and reaction progress with simulated sucrose musts; anaerobiosis and gas balance via sealed-jar CO₂ capture; phenolic antioxidant assays (DPPH) using culinary spices with safety notes; and pH-shift demonstrations framed by the acid-exclusion hypothesis. Limitations include no instrumental ABV, pH, or microbiome data; pathway figures are interpretive. Future work should prioritize spot pH/Brix and hydrometer ABV, along with microbiome–metabolome mapping to strengthen the scientific and educational bridge.

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1. INTRODUCTION

Indonesia's cultural richness is embedded in traditional fermentation practices, including *tuak*, *terasi*, *tempoyak*, *dadih*, and *tape singkong*, which display biochemical complexity and microbial diversity with documented nutritional and health-promoting potential (Hutajulu et al., 2021; Kurnianto, 2025; Rovik, 2025). Two concrete gaps persist. First, research on *tuak* and related fermentations continues to prioritize microbial parameters and alcohol content rather than mapping process knowledge to curricular constructs that teachers can implement. Second, classroom-ready resources that translate these practices into chemistry lesson plans, activities, and rubrics remain scarce in both the literature and schools (Hayati et al., 2022; Sumarni et al., 2021). Without structured documentation and educational translation, indigenous knowledge risks being underused. Deliberate designs grounded in ethnoscience and ethno-STEM can bridge cultural knowledge and academic content and enhance relevance, engagement, and learning outcomes in chemistry (Sumarni et al., 2021; Suyanta, 2020).

As a focal context, the Dayak Tomun *tuak* process exhibits empirically controlled steps that are teachable. Distinctive features include a two-stage workflow in which glutinous-rice *tapai* production precedes

alcoholic fermentation, household starter preparation, and specific spice profiles such as clove, nutmeg, cinnamon, long pepper, and black pepper. Process controls include boiling and cooling of the spice-sugar solution, tightly sealed vessels for several days, and taboos that restrict acidic contamination or premature opening. This workflow highlights substrate preparation, conversion, and control of variables and maps cleanly to secondary-level constructs such as fermentation reactions and regulation of reaction conditions (Sius et al., 2022). Spice additions introduce biochemical interactions that shape aroma and flavor and may contribute antimicrobial protection, which opens discussions that connect molecular structure, bioactivity, and food safety in a single context (Putri & Mustakim, 2025; Silaban et al., 2025).

A broader curricular disconnect is evident when chemistry emphasizes abstraction without local grounding. Within Kurikulum Merdeka (Phase E, Grades 10–11), topics such as generic redox, pH, and stoichiometry can be concretized through fermentation, yet explicit links to culturally grounded practice remain rare (Ambarsari et al., 2022; Oktavia et al., 2024). Analyses of Indonesian classrooms indicate opportunities to align abstract ideas with tangible local methods so that chemical principles become relatable and testable in everyday contexts, including *tuak* production (Sutrisno et al., 2020). Ethnochemistry provides a pragmatic framework for constructing teaching resources that integrate indigenous knowledge with scientific content and thereby bridge culture and chemistry (Wardani et al., 2023). The underlying mechanism is straightforward. Cultural relevance promotes student engagement and supports improved learning outcomes, consistent with culturally responsive pedagogy and aligned with Indonesian ethnoscience initiatives in design and practice (Creswell & Creswell, 2018; Prastowo et al., 2025). Studies further report that using community practices, including food fermentation, can strengthen scientific literacy, improve attitudes toward learning, and increase motivation and participation in chemistry when tasks are framed as inquiries drawn from students' own communities (Alamanda et al., 2023; Januarita et al., 2023).

At the biochemical level, *tuak* fermentation commonly involves yeasts such as *Saccharomyces cerevisiae* and the stoichiometric conversion $C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2$. These organismic attributions are typical in the fermentation literature and were not measured directly in this study; direct measurements for specific *tuak* productions also remain limited (Cirne et al., 2012; Salma et al., 2020). Recent studies on traditional fermentation, including *tuak* in Dayak settings, show that yeast type, environmental conditions, and ingredients such as sap-derived sugars and spices shape both the chemistry of fermentation and sensory outcomes (Gunam et al., 2022; Pahlawan et al., 2022). Spices such as clove and nutmeg can modulate microbial activity and contribute antimicrobial and antioxidant effects, providing natural entry points for linking redox to structure–function relationships in a context that is empirically accessible for students (Gahamat et al., 2023; Zhao et al., 2024). Socioculturally, *tuak* serves as more than an alcoholic beverage. It anchors social interaction and ritual, with norms that include tight vessel sealing to maintain anaerobiosis, avoidance of acidic inputs to limit contamination, and participation taboos (Marta et al., 2021). These norms constrain process variables such as oxygen exposure, contamination risk, and pH in measurable ways and provide a bridge between anthropology and chemistry in lesson design (Sius et al., 2021; Wijaya & Rinayanthi, 2024). Despite the value of this integrated view, explicit classroom applications of Dayak fermentation within ethnoscience and ethnochemistry remain limited and need development to reach scale and to align with standards (Rahayu & Setiadi, 2023; Rinto et al., 2023).

A translation gap therefore remains. Few studies explicitly connect fermentation kinetics, stoichiometric conversions, pH shifts, and sensory analysis to lesson design, assessment, and classroom enactment, and even fewer provide ready-to-use artefacts that teachers can adopt with minimal adaptation (Ardyansyah, 2024; Rahmawati et al., 2023; Setiawan et al., 2023). Effective materials should bridge fermentation science and lesson design so that students gain tangible experiences that deepen conceptual understanding, yet examples that trace a full line from field reconstruction to lesson plans, tasks, and rubrics remain rare (Zowada et al., 2020). A scoping search for 2019–2025 using the terms *tuak/Dayak/chemistry education/lesson plan/rubric* identified domain studies and pedagogy papers but no integrated lesson-plan package that links field reconstruction to chemistry instruction with *tuak* specifically (Gunam et al., 2022). The continuing lack of structured curriculum materials that connect fermentation with stoichiometry and pH dynamics limits opportunities for experiential learning; without clear resources, teachers must navigate the complexities of integrating indigenous practices while meeting curricular standards. There is a need for lesson plans and assessments that make these connections explicit and provide practical scaffolding for classroom use (Rodenbough & Manyilizu, 2019). Complementary reports indicate that culturally responsive implementations can boost engagement and inquiry in science, which

supports efforts to frame *tuak* as a gateway to core chemical ideas in local schools (Langmann, 2025).

This study uses AI assisted qualitative analysis to enhance the reliability, efficiency, and transparency of interpreting diverse interview data while linking local fermentation practices to chemical mechanisms through a verifiable coding process. By combining open, axial, and selective coding cycles supported by AI, the approach produces traceable codebooks that connect Dayak Tomun *tuak* practices with key chemistry concepts such as stoichiometry, pH dynamics, enzymatic catalysis, and redox. Consistent with the view that generative and analytic AI can deepen qualitative insights, foster consensus, and strengthen methodological transparency while still requiring human oversight for validity and ethics (Wilder & Calderone, 2025), the study reconstructs essential process variables such as yeast concentration, time, temperature, and pH (Gunam et al., 2022; Samadov et al., 2019). These findings are translated into instructional materials that include lesson activities, practice to concept mappings, and analytic rubrics addressing common misconceptions. The AI assisted coding framework ensures that the connection between indigenous practice and chemical understanding is auditable, adaptable, and culturally responsive (Fransiska, 2023).

Positioned against earlier Indonesian ethnoscience and ethnochemistry projects that connected culture to classroom without thorough field-level reconstruction or that relied on manual coding without a documented, auditable pipeline, this study aims to provide a coherent pathway from raw narratives to teachable constructs and to identify actionable entry points for curriculum development related to Dayak Tomun *tuak* fermentation (Sutrisno et al., 2020). The overall contribution is a set of evidence-based, classroom-ready materials and a transparent methodological scaffold that together help close the gap between indigenous practice and school chemistry.

2. MATERIAL AND METHOD

Research Design

We used a qualitative descriptive approach with an applied ethnographic design to explore Dayak Tomun *tuak* fermentation and to reconstruct chemistry aspects that can be taught at the secondary level. Fieldwork was carried out in South Arut Subdistrict, West Kotawaringin Regency, Central Kalimantan, from August 2024 to January 2025. Sites were selected using verifiable criteria: (i) continuing household-level *tuak* practice, confirmed by the Demang (head of customary authority) and the Chair of the Institute for the Preservation and Enforcement of Dayak Tomun Customary Law through village records; (ii) routine ceremonial use, with Dayak Tomun weddings occurring about 1–2 times per month in West Kotawaringin Regency; and (iii) the presence of recognized knowledge holders. Administrative descriptors at the hamlet level are provided in Supplement S1; the approximate centroid coordinates of the study area are 2°42'24.84050"S 111°38'51.38884"E / 2.7069001389°S 111.6476080111°E / -2.7069001389, 111.6476080111. Seasonal variation across the dry–rain transition (August to January) was also noted because it may influence ambient temperature and humidity, thereby affecting fermentation conditions.

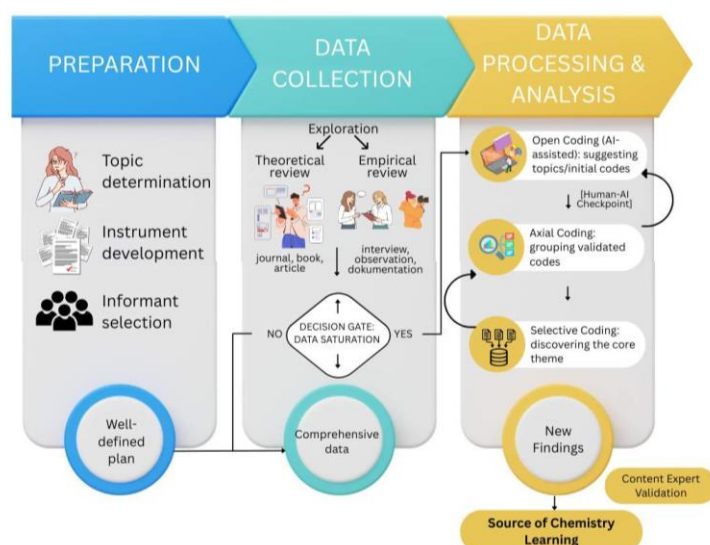


Figure 1. Research Design and Flowchart

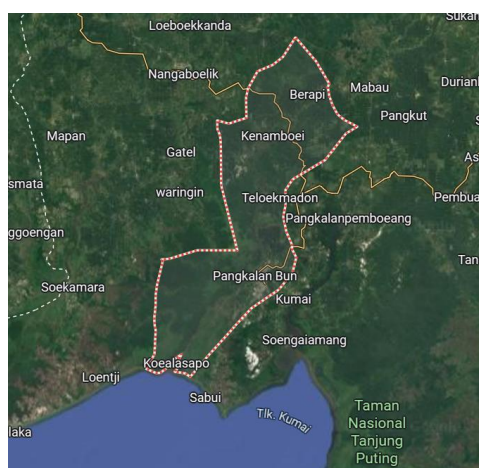


Figure 2. Location of South Arut, West Kotawaringin, Central Kalimantan, Indonesia

Participants

The study deliberately focused on two key informants: (N1) a Traditional Tuak Maker and (N2) a customary leader serving as the Chair of the Institute for the Preservation and Enforcement of Dayak Tomun Customary Law (locally referred to as the Demang). Informants were recruited via purposive sampling using culturally appropriate introductions. Inclusion criteria required: (i) ≥ 10 years of continuous involvement in rice-based *tuak* practice or governance; (ii) consistent adherence to traditional methods; and (iii) observance of relevant customary taboos and rituals throughout the process.

To ensure transparency, “traditional methods” were operationalized via an auditable checklist verified through observation and interview: locally prepared yeast; two-stage workflow (glutinous-rice *tapai* followed by alcoholic fermentation); spice–sugar decoction; vessel sealing during fermentation; avoidance of locally identified acidic inputs; and ritual markings around vessels. The target and achieved sample were identical by design (two informants). Age range and gender are reported as ranges or withheld to avoid deductive disclosure in a small community. Refusals/non-response: none recorded. Data collection proceeded until saturation, that is, until additional engagement yielded no substantively new information relevant to the codebook.

Table 1. Profile of Participants and Context

Code	Role	Experience (Years)	Highest Level of Education	Residence Location	Place of Origin	Characteristic of Practice
N1	Traditional Tuak Maker	20	Junior High School	West Kotawaringin, Central Kalimantan	Lamandau, Central Kalimantan	Uses homemade yeast and a complete blend of traditional spices
N2	Ketua Lembaga Adat	22	Equivalent to Senior High School	West Kotawaringin, Central Kalimantan	Lamandau, Central Kalimantan	Prepares yeast from rice flour and nutmeg through hereditary methods

Ethical procedures were rigorously upheld throughout the study. Informed consent was obtained both verbally and in writing after clear explanation of the aims, procedures, potential risks and benefits, the voluntary nature of participation, and the right to withdraw at any time. Confidentiality was protected through pseudonyms and de-identification, and explicit permission was sought for all photographic and video documentation. Formal authorization from local customary authorities was secured to conduct fieldwork and to respect indigenous protocols of the Dayak Tomun community. In line with local norms and by mutual agreement, no cash honoraria were provided; instead, the research team covered customary visit arrangements and essential materials required for field activities without disclosing amounts. All research data were stored on encrypted drives with role-based access controls and are scheduled for five-year retention prior to secure deletion.

Data Collection and Procedures

Data were collected through structured observation, semi-structured narrative interviews, and field documentation in the form of photographs and short video clips. Observations followed the two-stage *tuak* workflow, beginning with raw-material handling and starter preparation, proceeding through the glutinous-rice *tapai* fermentation to alcoholic fermentation, continuing with the spice–sugar decoction, vessel preparation and sealing, and concluding with filtration and storage. During observation, the researcher recorded sensory cues (aroma, foaming, the shift in taste from sweeter to drier), the sealing technique and the time of first opening, and environmental conditions such as ambient temperature and humidity; fieldnotes were time-stamped and cross-referenced to the supporting photo or video assets. Observations were repeated at the same production site to capture process variation and to confirm practice consistency. Where available, pH or Brix readings were noted.

Semi-structured narrative interviews were used to elicit tacit knowledge, step rationales, and practical considerations from practitioners. The interview guide was condensed to core themes to remain flexible and responsive to the informants' narratives. The principal themes included profile and practice history (trajectory, sources of know-how, production setting, reasons for choosing *tuak*), equipment and materials (types, construction, reasons for selection, sourcing, packaging), process parameters (sequence, mixing technique, duration of each stage, the intent of "overnighting," ingredient ratios and the consequences of deviation, effects of season and temperature, use of boiled water, yeast type and pre-treatment, rice type), quality, failure, and process engineering (shelf life, sensory changes, failure factors, optimization techniques), spices, taste, and preferences (use of spices or other natural ingredients and the desired flavor profile), and socio-cultural dimensions and uses (daily versus ceremonial use, beliefs and cultural meanings). Market availability was explored descriptively without discussing prices. Sensitive topics such as household-level taboos or prohibition of acidic inputs were framed respectfully, and participants could decline to answer; findings were then classified as shared norms or household-specific practices. Brief end-of-session member clarification was used when local terms or procedures required sharpening of meaning.

Field documentation was employed to capture technical details that are difficult to convey verbally and to record cultural expressions that accompany the process. Each visual asset was time-stamped and linked to fieldnotes to enable traceability during analysis. Recording occurred only after explicit permission from informants, and use of the materials was limited to analysis unless separate consent for dissemination was granted. All interviews were transcribed with AI assistance using a combination of ChatGPT and a Google Colab pipeline, then manually checked line by line to ensure the accuracy of local terminology, fidelity of meaning, and consistency with observation notes. This procedure accelerated transcription without compromising scholarly rigor and provided a sufficient audit trail for back-tracing during coding and triangulation.

Data Analysis Procedure

This research integrated Miles and Huberman's interactive cycle (data reduction, data display, conclusion drawing) with Strauss and Corbin's open–axial–selective sequence to maintain coherence from raw materials to interpretive claims (Miles et al., 2014). In practice, data reduction was operationalized as open coding that segmented transcripts, fieldnotes, and media-linked annotations into first-order codes. Data displays (source × time × theme matrices and practice to concept maps) then supported axial coding by making relationships among codes visible and grouping them into higher-order categories. Conclusion drawing and verification coincided with selective coding, which synthesized categories into a core storyline that links Dayak Tomun *tuak* practices to teachable chemical mechanisms. The analysis focused on three interconnected thematic areas. The first concerned biochemical transformations, reflected in changes to substrates, observable yeast activity, gas evolution, and acidity cues such as foaming and the transition from a sweeter to a drier taste, with illustrative excerpts provided in Supplement S2. The second centered on sensory perceptions, including aroma, mouthfeel, visual clarity, and spice related notes expressed through locally meaningful descriptors. The third addressed cultural and spiritual dimensions, which included permissions, taboos, ritual markings, and ceremonial timing, with a clear distinction between norms that are shared across the community and practices that are specific to individual households. Throughout the analytic process, memoing in the form of decision, reflexive, and integration memos and diagramming through process flowcharts and evolving practice to concept maps documented coding decisions, tracked rival explanations, and recorded how data displays informed category refinement.

A codebook captured each code's definition, inclusion and exclusion rules, anchors, and excerpt IDs, and it was revised iteratively until no new first-order codes appeared and category boundaries stabilized. For transcription and early coding support we used ChatGPT within a Google Colab workflow to generate tentative labels and candidate synonyms and to accelerate verbatim transcription; all outputs were treated strictly as suggestions and were accepted, modified, or rejected by the researchers. Credibility and validity were strengthened through methodological triangulation across sources and time using a structured matrix, member checking with both informants on provisional themes and the process map, and peer debriefing with experts in ethnopedagogy and chemistry education to assess conceptual coherence and curricular alignment. An audit trail (dated memos, versioned codebooks, decision logs, and scripts), together with encrypted role-based data storage and a five-year retention schedule, supports transparency and replicability.

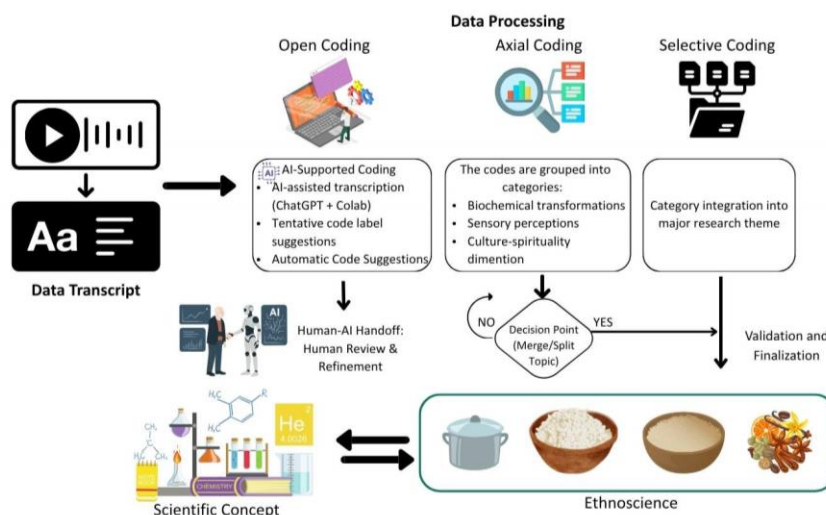


Figure 3. Data Analysis Process

3. RESULTS

Triangulating structured observations, semi-structured narrative interviews, and field documentation produced a coherent reconstruction of Dayak Tomun *tuak* making and three headline findings that directly inform chemistry teaching are thermal control (cooling thresholds to protect yeast viability), anaerobiosis (strict vessel sealing and delayed first opening), and spice-derived effects (phenolic-linked aroma and perceived antimicrobial protection). Observations anchored the process chronology and handling cues; interviews supplied rationales, taboos, and household heuristics; audiovisual notes preserved hand movements, sealing techniques, and spatial layout, allowing later cross-checks during coding.



Figure 4. One of the Respondents from Tuak Producers

Stages of Tuak Production and Local Practices

Two-phase workflow. Production proceeds in two phases inherited intergenerationally: Phase I *tapai*

fermentation and Phase II alcoholic fermentation of *tuak*. Across our two informants (N1, N2), both reported the same sequence with minor household variation in spice set and optional roasting of rice.

Phase I: *Tapai* fermentation. Glutinous rice is rinsed, drained, optionally dry-roasted to intensify roast notes (community rationale: flavor development and “drier” finish), steamed, spread thin, and cooled to ambient. The yeast starter (*ragi tape*) is sun-dried one to two days or briefly pan-roasted to reduce moisture. Once the rice is fully cool to the touch (community threshold), yeast is sprinkled evenly and the mass sealed for ~2–3 nights. Observable success proxies during observations included the rise of fine bubbles along container walls, a sweet–alcoholic aroma (lexicon taught by makers as “wangi, tidak asem”), and slight warmth within the pile. A typical maker statement was: “We leave it for two to three nights until it smells pleasant—neither sour nor strange. Once the aroma is right, it is ready” (N1). N2 independently corroborated this cue. The product, *tapai ketan*, becomes the substrate for Phase II.

Phase II: alcoholic fermentation of *tuak*. *Tapai* is mixed with a sugar solution infused with local spices (modal set reported by both informants: clove, cinnamon, nutmeg; long pepper and black pepper present in one household). The sugar–spice solution is boiled and cooled completely before mixing; makers emphasize a “not warm at all” threshold to avoid harming yeast. The mixture is then sealed and left undisturbed for roughly 4–5 days. Taboos and rules act as boundary protocols: keep the vessel tightly covered and secluded; keep acidic materials (e.g., tamarind, citrus, *langsats*) out of the processing area; avoid approaching or opening the vessel before time. As one maker put it, “The container must be covered tightly and should not be opened before its time. Even children are not allowed nearby” (N2). Afterward, the liquid is filtered, yielding a cloudy, pale beverage with characteristic aroma. Batch size and exact mass ratios were described qualitatively (handful-based measures); we record these household heuristics in Supplement S1 rather than imposing invented gram values.

Frequency across participants. Optional dry-roasting of glutinous rice was reported by 1/2 informants; sun-drying or pan-roasting yeast by 2/2; strict cloth sealing and delayed first opening by 2/2; exclusion of acidic items from the work area by 2/2.

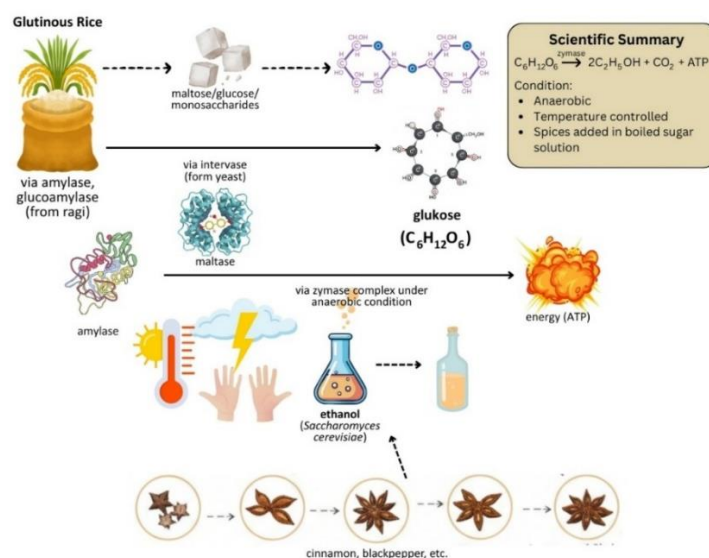


Figure 5. Interpretive Model of the Alcoholic Fermentation Pathway and Enzymatic Roles in Traditional *Tuak* Processing

Sensory Characteristics and Local Preferences

The preferred profile is sweet–bitter, pungent, and warming (*sengar*), locally interpreted as “stronger.” The often-quoted “about 35%” alcohol is a community perception, not an instrumental measurement in this study. We therefore treat it as a sensory proxy for strength rather than a verified ABV. Makers also state that sweetness declines and bitterness and aroma intensity rise with longer sealed storage, consistent with continued biochemical transformation under anaerobic conditions. We stop short of claiming indefinite ABV increase and instead note that stability depends on hygiene, anaerobiosis, and residual sugars; risks include oxidation and acetic souring if headspace or exposure increases.

Coding-Derived Evidence Map (Key Excerpts)**Table 2.** Mapping Local Practices to Ethnochemical Concepts in Dayak Tomun Tuak Fermentation

Quote (ID)	Open code	Axial theme (cause, context, strategy, consequence)	Selective proposition (EC-Px; If/Then/Because)	Ethnochemical concept	Local practice (EN)	Factor type
"Air rebusan tidak benar-benar dingin." (N1)	Mixing-temperature error	Cause: high temperature suppresses/inactivates yeast; Context: day-3 mixing; Strategy: ensure solution cools fully; Consequence: optimal fermentation	EC-P2 — If the sugar solution is truly cool at mixing, then fermentation proceeds as expected, because yeast is not heat-inactivated.	Thermal control; yeast growth kinetics	Ensure sugar solution is fully cool before combining	Environmental/Natural
"Cuci ketan; sangrai... tanak... dinginkan; sangrai lagi; tabur lagi merata; tutup 3–4 hari...." (N1; corroborated N2)	Initial <i>tapai</i> procedure	Cause: proper substrate and inoculum preparation; Context: pre- <i>tuak</i> stage (<i>tapai</i>); Strategy: follow order and timing; Consequence: stable <i>tapai</i> for <i>tuak</i>	EC-P3; EC-P4 — If substrate and yeast are prepared correctly with early inoculation, then the next fermentation stage is stable and yields are consistent, because substrate–inoculum balance aligns early growth curves.	Saccharification & early fermentation; yeast population dynamics	Roast → steam → cool glutinous rice; sprinkle yeast; seal 2–3 days (<i>tapai</i>)	Empirical/Sensory
"Hari ke-8: masih manis & hangat; lama-lama makin pahit & 'keras'; aroma lagi kuat." (N2)	Sensory dynamics and perceived alcohol increase	Cause: continued fermentation during storage; Context: post-filtration storage; Strategy: time consumption; Consequence: preference for bitter/ <i>sengar</i>	EC-P6 — If stored longer, then perceived alcohol and bitterness increase, because chemical and microbial transformations continue.	Alcohol–bitterness –aroma correlation	Over time: Empirical/Sensory stronger aroma; "keras" increases	
"Tidak boleh dekat bahan asam (asam jawa, jeruk, pepaya, langsung...)." (N1; N2)	Acid taboo as pH control	Cause: pH control and acidification risk; Context: kitchen/work area; Strategy: segregate acidic items; Consequence: prevent sour/failure; stabilize environment	EC-P8; EC-P5. If production is kept away from acidic inputs and taboos are observed, then pH remains more stable and quality is more consistent, because acid exposure and competing microbes are minimized through social–process control.	Environmental pH; microbial dominance	Keep away from acidic materials	Cultural/Spiritual
"Di sekeliling ember diberi tanda silang/tambah dengan kapur sirih ..." (N1)	Symbolic protection with <i>kapur sirih</i>	Cause: protection from non-material disturbances; Context: after pouring sugar solution; Strategy: mark crosses/plus; Consequence: believed to prevent failures and support acceptance	EC-P5. If protective symbols and taboos are observed, then process consistency and social acceptance increase, because norms and symbols reinforce handling discipline.	Symbols as hygiene/boundary protocol	Mark the jar with lime crosses/plus	Cultural/Spiritual
"Membuat tuak saat sakit/haid → asam." (N2)	Producer condition affects outcome (community belief)	Cause: hygiene/ritual norm; Context: production period; Strategy: defer production; Consequence: avoid "sour" batches	EC-P5. If social boundaries are respected, then product quality is more consistent, because process and the social environment are jointly controlled.	Human contamination and process stability	People who are sick/menstruating should not make <i>tuak</i>	Cultural/Spiritual
"Tuak disajikan pada adat tiwah, pernikahan, penyelesaian perkara ..." (N1; N2)	Ritual function and scheduling	Cause: customary norms and sacred status; Context: Dayak Tomun community; Strategy: prepare stock ahead of ceremonies; Consequence: continuity and legitimacy of rites	EC-P5 (social value). If ritual needs guide production, then supply is ensured and sacred status maintained, because production is bound to customary norms and timings.	Contextualizing science within ritual practice	<i>Tuak</i> as sacred requirement in ceremonies	Cultural/Spiritual

Open–axial–selective coding yielded proposition-level statements that connect practice to chemistry constructs. First, cooling threshold and yeast viability: the open code was “mixing-temperature error,” the axial link was that high temperature suppresses or inactivates yeast, and the selective proposition is that if the sugar solution is fully cool at mixing, then fermentation proceeds as expected because yeast is not heat-inactivated; the associated ethnochemical concept is thermal control and yeast growth kinetics. Second, acid exclusion and pH stability: the open code was “acid taboo,” the axial link concerned pH and contamination control, and the selective proposition is that if acidic inputs and vapors are excluded, then pH drift and souring risk decrease because acid exposure and competing microbes are minimized; the concept is environmental pH and microbial dominance. Third, sealing, delayed opening, and anaerobiosis: the open code was “tight sealing,” the axial link addressed headspace management, and the selective proposition is that if the vessel remains sealed until the stated time, then anaerobiosis is maintained and volatile loss is limited, enabling consistent outcomes; the concept is gas balance and the redox environment. Fourth, spice additions and structure–function: the open code was “clove/nutmeg set,” the axial link focused on aroma and protection rationales, and the selective proposition is that if phenolic-rich spices are infused, then characteristic aroma emerges and makers perceive fewer failures, which creates entry points to discuss redox-active compounds and antimicrobial hypotheses in class. Counts by node and representative quotations with source IDs are reported in Table 2, which uses bilingual column headers, standardized EC-Px codes, and one fully sourced quote for each axial theme.

Environmental and Cultural Regulators Observed in Practice

Producers associate rainy or transitional seasons with greater process variability. To manage risk, they ensure hot liquids are fully cooled before inoculation, maintain tight sealing and seclusion, and keep acids away from the processing area. Sociocultural boundaries, such as deferring production when ill or menstruating and marking vessels with *kapur sirih* crosses or plus signs, are respected as community protocols to safeguard the process and maintain social acceptance. We frame these as norms that co-occur with empirical controls rather than as causal biochemical claims. With a small sample (two households), both reported acid exclusion and strict sealing, and *kapur sirih* marking was present in one of the two households.

4. DISCUSSION

Synthesis of findings

Across two households, *tuak* production followed two linked stages, *tapai* of glutinous rice followed by sugar–spice fermentation where three controls consistently mattered. First, thermal control and anaerobiosis were enacted through cooling the sugar solution before inoculation and maintaining tightly sealed vessels for defined durations. Second, spice infusion (clove, cinnamon, nutmeg, long pepper, black pepper) served both flavor aims and a community rationale for product “cleanliness.” Third, sociocultural boundaries (acid exclusion, restricted access, optional vessel marking with *kapur sirih*) operated as shared norms that co-occurred with empirical controls. Observations and audiovisual records documented the cooling step and sealed containers; interviews explained why these rules are followed and when exceptions are avoided.

Mechanisms and interpretation

Biochemically, the process is consistent with yeast-mediated alcoholic fermentation in which *Saccharomyces cerevisiae* converts glucose to ethanol and carbon dioxide ($C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2$). In our data this mechanism is inferred from practice and literature rather than from microbiological identification or enzyme assays (Gunam et al., 2022). Enzyme labels such as invertase, maltase, and zymase are used here as functional shorthand to support teaching, not as measured pathway components. Makers use a hand-cool rule for inoculation; for classroom translation we note $\leq 35^\circ C$ as a community threshold to protect yeast viability rather than a measured limit. Sensory indicators anchor assessment: “sweet,” “sour,” “bitter,” and the warming–pungent *sengar* are locally intelligible cues of progress. Where possible in future classroom enactments, these terms can be paired with simple proxies (spot pH or Brix) to reduce circular reasoning.

Spice roles should be separated into what the community believes versus what is plausible from literature. Constituents such as eugenol and cinnamaldehyde are frequently linked to antioxidant or antimicrobial effects (Batiha et al., 2020; Zhao et al., 2024), which provides a structure–function bridge for lessons. Whether spices “accelerate alcohol” was not measured here and should be treated as a hypothesis; high spice loads may also inhibit yeast and would require controlled trials.



Figure 6. Traditional Process of Tuak Production among the Dayak Tomun Community

Environment and culture as controls

Makers associated rainy and transitional weeks with slower gas formation or a higher chance of souring. The relationship among environmental factors, cultural rules, and perceived tuak quality is summarized in [Figure 7](#). In response to these seasonal conditions, both households explained that they always cooled hot liquids completely before inoculation, sealed vessels tightly in a secluded area, and kept any acidic materials away from the processing space. These practices function collectively as hygiene and process controls, as environmental stabilizers, and as sociocultural boundaries that guide proper handling. Hygiene and process controls include actions such as cooling ingredients to a hand warm temperature, ensuring firm sealing, and postponing any opening of the vessel until the appropriate time. Environmental stabilizers involve choosing a quiet and protected location and maintaining steady ambient conditions. Sociocultural boundaries include keeping acidic items away from the workspace, avoiding production during illness or menstruation, and in some households marking the vessel with kapur sirih. In our sample, acid exclusion and strict sealing were practiced in both households, while kapur sirih marking was reported by one household. We interpret these elements as norms that accompany empirically grounded controls rather than as direct biochemical causes. Each of these practices can be linked to a testable instructional pathway, because seclusion can reduce airborne inoculum, firm covering can help maintain anaerobiosis, and acid avoidance aligns with managing early pH shifts and reducing contamination risk ([Pradnyandari et al., 2017](#); [Wang et al., 2018](#)).

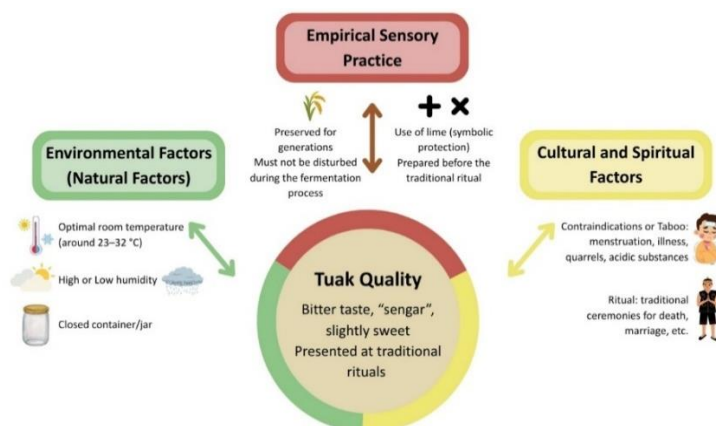


Figure 7. Map of the Relationship between Natural Factors, Culture, and the Quality of Traditional Dayak Tomun Palm Wine

Perceived strength increased over time as sweetness declined and bitterness and aroma intensity rose, which aligns with literature linking higher ethanol to lower sweetness and stronger aromatic profiles (Dupa et al., 2022; Wahyuningsih et al., 2023). Community statements such as “about 35%” should be interpreted as perceptions because no instrumental ABV was collected here; undistilled ferments do not increase indefinitely. Storage stability depends on hygiene, anaerobiosis, and sugar depletion, and there are risks of oxidation or acetic spoilage. A simple stability frame for teaching is “container × headspace × time,” with safe-use cautions.

Educational Mapping and Safety

These findings translate directly into practice → concept → activity artifacts for Grades 10–11. A consolidated mapping from observed practices to reconstructed chemical concepts and example activities is provided in Table 3. Cooling and sealing anchor lessons on yeast viability, gas balance, and anaerobiosis; spice infusion anchors phenolic structure–function and redox; time-linked sensory shifts support stoichiometry and reaction progress. Where ethanol handling is restricted, teachers can use simulated sucrose musts, non-ingestive aroma kits, or virtual datasets rather than live alcohol. Simple antioxidant labs with culinary spices (e.g., DPPH quenching) should include a negative control, a brief disposal note, and light shielding expectations (Bobo et al., 2015). Any optional sensory exploration must follow school policy; when inappropriate, replace with odor-only kits and visual proxies. The bilingual evidence map in Table 2, with standardized EC-Px codes and one fully sourced quote per axial theme, provides clear alignment points for curriculum-ready activities.

Table 3. Mapping of Tuak Fermentation Practices to Chemical Concepts and Learning Activities

Local Practice	Informant Quotation	Reconstructed Chemical Concept	Potential Contextual Learning Activity
Yeast and Sugar Fermentation	<i>“To make tuak, the ingredients are glutinous rice, tapai yeast, and sugar. It's cooked, cooled, and then yeast is added. Wait two nights, then add the sugar water.” (N2)</i>	Alcoholic fermentation reaction ($C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$), stoichiometry, reaction thermodynamics, anaerobic fermentation	Glucose fermentation simulation; calculating reaction yields and pH changes during fermentation
Bitter Taste as Indicator of High Alcohol	<i>“Good tuak tastes bitter and ‘sengar’. If it’s still sweet, it’s not ready. If it’s bitter, the alcohol is high.” (N1)</i>	Alcohol functional group, relationship between molecular structure and taste, alcohol content indicators	Sensory testing and simulated alcohol content measurement; exploring correlations between compound structure and perceived flavour
Addition of Spices	<i>“We add clove, nutmeg, cinnamon, black pepper, and long pepper to make it taste warm, bitter, and aromatic. It makes the tuak better and lasts longer.” (N1–N2)</i>	Interaction of phenolic compounds (eugenol, cinnamaldehyde), antibacterial and antioxidant properties	Natural antioxidant testing from spices (DPPH assay); discussion on bioactive compounds in traditional spices
Cultural Taboos	<i>“We’re not allowed to make tuak during menstruation, illness, or when handling sour things like papaya or citrus. It can fail or turn sour.” (N1)</i>	Microbial contamination, pH change due to acidic compounds, environmental catalysis in spontaneous fermentation	Interdisciplinary discussion linking science and culture; experimental testing of pH/acid impact on fermentation outcomes

Limitations

The sample is small (two households), and we did not instrument ABV, pH, or Brix. Microbial identities and enzyme activities were not assayed, so the biochemical pathway in Figure 5 is an interpretive model rather than a confirmed mechanism. Environmental logs were qualitative, based on observation and recall. These constraints limit generalizability and motivate cautious phrasing around mechanism and outcomes.

Future Work

Priority next steps include light-touch environmental logging (ambient temperature and relative humidity), spot pH/Brix during both stages, simple ABV checks with a hydrometer on permitted matrices, controlled spice trials at graduated loads to probe facilitation versus inhibition, and stability observations that vary container, headspace, and time. These additions would let classrooms compare perceived intensity scales to measured curves and refine the interpretive model.

Closing Takeaways

Ethnochemical analysis shows that household rules around cooling, sealing, spice infusion, and sociocultural boundaries map cleanly to control points in fermentation science. The resulting curriculum-ready artifacts flow summaries with durations and containers, a bilingual evidence map tied to open–axial–selective coding, and an interpretive pathway figure labeled as such equip teachers to implement culturally grounded chemistry lessons immediately while respecting community norms.

5. CONCLUSION

This study reveals that Dayak Tomun tuak fermentation follows a culturally structured two stage process consisting of glutinous rice tapai fermentation and sugar spice fermentation. The process is guided by essential controls such as cooling before inoculation, sealing vessels tightly, and keeping acidic materials separate. These practices align with chemical concepts including enzymatic fermentation by *Saccharomyces cerevisiae*, stoichiometry, and pH regulation, while sociocultural norms such as restricted access and lime markings help maintain stability without direct biochemical functions. An AI assisted qualitative approach using ChatGPT in Google Colab combined with the Miles and Huberman analytical cycle established clear links between field narratives and chemical principles, translating community knowledge into teachable materials.

Educationally, the reconstructed model supports integration into Phase E of the Merdeka Curriculum by connecting traditional fermentation practices with chemistry topics such as anaerobiosis, redox, and reaction progress through safe and simulation based activities. Although limited by small sampling and absence of instrumental data, this research provides a foundation for future analytical and educational studies involving community collaboration. Overall, it bridges indigenous knowledge and formal chemistry education while advancing SDG 4 on quality education and SDG 12 on responsible consumption and production.

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