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Integration of Toraja Local Wisdom into Contextual Chemistry Learning

Marwa Indah[1], Farah Erika[2*)], and Usman[3]

Mulawarman University, Samarinda, Indonesia

[*)] E-mail: farah.erika@fkip.unmul.ac.id

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ABSTRACT

This study explores traditional chemical practices within the Toraja community, an area of knowledge that remains underdocumented in existing scholarship. The research aims to: (1) describe chemical practices involved in the Rambu Solo' funeral ceremony; (2) examine techniques for processing natural materials; and (3) discuss their pedagogical implications for chemistry education rooted in local wisdom. Using a qualitative ethnographic approach, the study was conducted in Tana Toraja and involved two purposively selected key informants: a teacher and a local cultural leader. Data were collected through in-depth interviews, direct observations, and documentation, then analyzed thematically. The analysis revealed two main themes. First, the use of pine leaves (*Pinus merkusii*) and tille wood in Rambu Solo' functions as natural antiseptics and preservatives, a finding supported by literature on the bioactivity of terpenoids and phenolic compounds. Second, the fermentation of ballo' and the production of natural dyes demonstrate biochemical processes and principles of green chemistry utilizing renewable natural resources. These findings show that Torajan traditional practices provide authentic and meaningful contexts for chemistry education. Incorporating such indigenous knowledge into the curriculum can make learning more relevant while helping preserve culture. Overall, this research offers an initial empirical basis for developing ethnoscience-based learning modules and suggests further studies involving quantitative chemical analyses and the development of innovative instructional materials. This approach can improve students' scientific literacy and promote education for sustainable development.

INTRODUCTION

The integration of local wisdom into science education particularly chemistry constitutes a strategic approach for fostering contextualized, meaningful, and sustainable learning. This approach is grounded in the framework of ethnoscience, which encompasses knowledge derived from culturally embedded practices that possess scientific value, even when such knowledge is not explicitly articulated within the conventions of modern science (Yuliani et al., 2020; Zidny et al., 2020). Within an educational context, ethnoscience serves as a bridge connecting academic science with sociocultural realities, thereby enhancing scientific literacy while simultaneously strengthening students' cultural identity (Rahmawati & Ridwan, 2019; Susanti et al., 2022).

Indonesia's Kurikulum Merdeka emphasizes the importance of linking scientific concepts to lived experience and cultivating the traits outlined in the Profil Pelajar Pancasila, which include creativity, moral integrity, and sustainability-oriented thinking (Kemendikbudristek, 2022). This aligns with UNESCO's Education for Sustainable Development (ESD) framework, which advocates for integrating scientific knowledge, cultural heritage, and environmental stewardship within educational systems (Lee & Buxton, 2022; UNESCO, 2020). Consequently,

embedding local wisdom into chemistry instruction functions not only as a pedagogical innovation but also as a contribution to broader sustainability efforts (Hiwasaki et al., 2014; Wahyuni et al., 2021).

Local wisdom encompasses more than technical knowledge; it also includes value systems, belief structures, and intergenerational modes of oral knowledge transmission. This understanding is consistent with insights from an interviewed teacher (Apriani, 2025), who emphasized that traditional knowledge of natural materials has historically been passed down directly through community practice, yet is increasingly threatened by the influence of modern culture and declining interest among younger generations. Similar concerns were noted by (Sumarni et al., 2021), who reported that traditional knowledge faces a significant risk of disappearing if it is not properly documented and integrated into formal education.

Although ethnoscience research in Indonesia has expanded considerably, the literature still reflects a strong geographical bias. Much of the research concentrates on major cultural groups such as Javanese, Balinese, and Sundanese communities (Suardana et al., 2018; Zidny & Eilks, 2020). This imbalance creates a substantial gap in understanding the diversity of traditional chemical knowledge across the Indonesian archipelago. In this regard, the traditional practices of the Toraja community represent a critical but understudied case. The complexity of ritual activities such as Rambu Solo', which involve the intelligent use of natural materials such as pine leaves (*Pinus merkusii*) and tille stems for body preservation has not yet been examined through the lens of modern chemistry. Likewise, the fermentation of ballo' and the production of natural dyes for Toraja textiles embody concrete applications of green chemistry principles that remain largely unexplored in scientific research.

Thus, the research gap is both geographical and substantive, involving the absence of systematic analyses of the chemical dimensions embedded in Toraja cultural practices. Addressing this gap is urgent for two reasons. From a cultural preservation standpoint, traditional chemical knowledge in Toraja is increasingly endangered due to modernization, globalization, and generational shifts (Elvianasti, Lufri, & Asrizal, 2023; Mungmachon, 2018). number of knowledge bearers such as cultural leaders and educators who understand Toraja traditions is steadily declining alongside reduced interest among youth. From a science education perspective, delays in documenting and analyzing these practices risk forfeiting valuable opportunities to develop chemistry learning resources that are contextual, relevant, and culturally grounded, particularly for learners in Sulawesi and Indonesia more broadly.

Accordingly, this study is not only essential for addressing academic gaps but also represents a timely effort to safeguard an increasingly rare body of indigenous knowledge and to enrich chemistry education in alignment with the principles of Kurikulum Merdeka and student-centered learning approaches. This research constitutes the first systematic investigation into the chemical dimensions of Toraja cultural practices and their implications for developing contextualized and sustainable chemistry education. Based on this background, the aims of the study are as follows: to describe traditional chemical practices embedded in the *Rambu Solo'* ceremony;to explore natural-material processing techniques within the Toraja community that are relevant to chemical concepts; and to delineate the implications of these practices for the development of sustainability-oriented chemistry instruction grounded in local wisdom.

METHODS

Research Design

This study employs a qualitative approach with an ethnographic and exploratory design to identify and interpret traditional chemical practices within the Toraja community (Creswell & Poth, 2018; Flick, 2018). This methodological design was selected because it enables a holistic understanding of the meanings, symbolic dimensions, and sociocultural contexts that shape

these traditional chemical practices. The researcher served as the primary instrument, engaging directly with participants in their natural setting to ensure contextual depth and maintain cultural sensitivity throughout the research process.

Research Target

The research focused on the traditional chemical practices within the Toraja community, particularly those embedded in the Rambu Solo' ceremony and the processing of natural materials such as bamboo sap fermentation and natural dye production. The study involved two key informants, selected purposefully to represent both educational and cultural perspectives:

1. Mrs. Apriani, a teacher who provided pedagogical and scientific insights related to the integration of local wisdom into chemistry learning.
2. Mr. Jon Batara, a resident and cultural resource person with deep knowledge of Toraja traditional practices.

The limited number of informants reflects the ethnographic emphasis on data richness rather than sample size (Palinkas et al., 2019). In this study, participants were selected purposively because both individuals serve as primary knowledge holders: a teacher who understands the scientific dimensions of local practices and a Toraja cultural leader with direct experiential knowledge of traditional practices. Within ethnographic research, sampling is not determined statistically but is guided by the depth, relevance, and contextual insight that informants can provide (Moleong, 2019; Sugiyono, 2019).

This approach aligns with the concept of information power, which posits that a smaller number of participants is sufficient when the study's focus is specific and participants possess strong expertise (Malterud et al., 2016). Supporting this idea, (Guest et al., 2006) demonstrated that data saturation in qualitative studies can often be reached with a limited number of interviews, particularly when informants exhibit substantial knowledge of the research topic.

In this study, data saturation was confirmed as the in-depth interviews conducted on 7 April and 27 July 2025 consistently produced recurring core themes such as the use of pine leaves, *tille* stems, *ballo'* fermentation, and natural dye extraction without the emergence of new substantive information. The credibility of these findings was further strengthened through methodological triangulation involving interviews, observations, and documentation, in accordance with established principles of qualitative validity (Nowell et al., 2017). Thus, the use of two key informants in this research is not only methodologically justified but also meets the criteria of depth, authenticity, and contextual richness that characterize high-quality ethnographic inquiry.

Research Data

The primary data consisted of empirical narratives, observations, and documentation collected from the participants. These data focused on:

1. The use of natural materials such as *Pinus merkusii* and *tille* stems in traditional preservation practices.
2. Fermentation processes and the production of local dyes that align with principles of green chemistry.
3. The cultural meanings and symbolic interpretations underlying these practices.

Supporting secondary data were gathered from relevant literature, field notes, and photographic records, providing additional contextual and theoretical reinforcement.

Research Instruments

The instruments employed in this study consisted of the following components:

1. A semi-structured interview guide, developed to explore participants' experiences, local terminologies, and interpretations of traditional practices.

2. An observation sheet, designed to document ritual sequences, material usage, and observable reactions while maintaining cultural sensitivity through non-participant observation (O'Reilly, 2019).
3. A documentation protocol, which ensured the systematic collection of photographs, field notes, and supplementary materials.

Data Analysis

The data were analyzed using the interactive model proposed by (Miles et al., 2018), which comprises three concurrent activities:

1. Data reduction, involving the summarization and coding of interview transcripts, observational field notes, and documents into thematic categories.
2. Data display, which organized the findings into descriptive matrices and visual representations to illustrate the relationships between traditional practices and relevant chemical concepts.
3. Conclusion drawing and verification, entailing the interpretation of emerging patterns and the confirmation of meanings through iterative comparison.

The trustworthiness of the findings was ensured through several strategies:

1. Source triangulation, achieved by comparing data obtained from both informants.
2. Methodological triangulation, involving cross-verification across interviews, observations, and documentation.
3. Member checking, in which participants reviewed the interpretations to confirm their accuracy (Nowell et al., 2017; Silverman, 2020).

RESULTS AND DISCUSSION

The analysis followed the interactive model outlined by (Miles et al., 2018). Initially, raw interview transcripts, field notes, and documentation were reduced into codes representing recurring meanings within the data. These codes were then synthesized into thematic categories related to ritual functions, material transformations, and pedagogical relevance. The resulting themes were subsequently organized into descriptive matrices that mapped traditional practices onto scientific concepts, and verified through iterative cross-comparisons among data sources as well as member checking. The following sections present these themes, supported by direct quotations and observational evidence.

The findings were generated through a thematic analysis of the interviews with key informants, guided by the framework of (Braun & Clarke, 2022). The process began with the identification of meaningful units within the transcripts, which were then assigned initial codes such as "pine resin as a natural preservative," "use of tille stems," "bamboo-sap fermentation," and "natural dye extraction." These codes were subsequently grouped into subthemes including "traditional preservation techniques," "biochemical reactions in fermentation," and "oxidation processes in natural dyes," which were later consolidated into the final overarching themes.

The relationship between data, codes, subthemes, and final themes is clearly traceable. For example, the statement from informant Jon Batara Selle' (2025), describing how "Toraja people still perform traditional corpse treatment by applying large amounts of pine leaves to the body, and using tille stems similar to bamboo to inject fluids into the oral and nasal cavities of the deceased," was coded as "corpse management practices."

This study successfully identified several traditional chemical practices within Toraja culture that align with concepts in modern chemistry. The integration of these elements of local wisdom is summarized in Table 1.

Table 1. Integration of Toraja Local Wisdom with Chemical Concepts and Pedagogy.

Aspect of Local Wisdom	Specific Practices & Materials	Related Chemical Concepts	Cultural Values/ Symbolism	Potential for Chemistry Learning	Evidence/ Citation
Rambu Solo' Ceremony	Pine leaves (*Pinus merkusii*) crushed and applied; tille stems used to inject fluids	Antimicrobial Activity of Bioactive Compounds: Extracts from the leaves and resin of *Pinus merkusii* contain terpenoid compounds (α-pinene, β-pinene, limonene) and phenolics that exhibit strong antibacterial and antifungal properties, effectively inhibiting the growth of decomposing microorganisms (Yu et al., 2022; Zhao et al., 2021). Natural Preservation Mechanism: These bioactive constituents particularly terpenoids and phenolic compounds function by disrupting microbial cell membrane integrity and inhibiting key enzymatic processes, thereby delaying decomposition (Gyawali & Ibrahim, 2014; Silva et al., 2021). This mechanism aligns with the principles of green chemistry, which emphasize the use of safer, naturally derived chemical agents, as advocated in the integration of local wisdom into chemistry education in Indonesia (Rahayu & Kita, 2020; Widarti et al., 2017).	Respect for ancestral traditions, notions of purity, spirituality, and a culturally rooted belief in the safety and effectiveness of natural materials inherited from past generations perceived as superior to synthetic substances such as formalin.	Organic Chemistry & Biochemistry: Case-based discussions may be developed to examine the mechanisms of action of natural preservatives in comparison with synthetic ones. Students can also engage in literature-based projects to identify the bioactive compounds present in traditional materials. These activities allow clear connections to Green Chemistry, particularly the principles of waste prevention and the use of safer chemical substances. (Anastas & Warner, 1998).	"The Toraja people continue to practice traditional mortuary rituals, which include thoroughly applying crushed pine leaves to the body of the deceased. In addition, a tille stem similar in form to bamboo is used to inject preservative liquid into the body, particularly through the oral and nasal cavities." (JB, Interview 2)
Natural Material Processing	Bamboo sap (*ballo'*) fermentation;natural dyeing of textiles from leaves and roots	The anaerobic conversion of glucose ($C_6H_{12}O_6$) into ethanol (C_2H_5OH) and CO_2 is facilitated by a consortium of indigenous microorganisms primarily yeasts and bacteria that function as natural enzymatic	The process embodies social bonding, sustainability values, reverence for nature, and the expression of cultural identity through motifs and natural dyes.	The principle of employing safe catalysts such as microbes or enzymes and renewable resources (Zidny & Eilks, 2020).	"One example is the aren tree; the aren tree is used to produce *ballo'* or traditional palm wine, a practice that has been carried out by the Toraja

Aspect of Local Wisdom	Specific Practices & Materials	Related Chemical Concepts	Cultural Values/ Symbolism	Potential for Chemistry Learning	Evidence/ Citation
		catalysts (Tamang et al., 2020). The formation and fixation of color involve the extraction of pigment compounds (such as anthocyanins or tannins), followed by oxidation reactions and the establishment of complexes with textile fibers or mordants, which serve as applied examples of redox processes (Armstrong et al., 2019).			people since the time of their ancestors." (JB, Interview 2)

The findings from Toraja provide a distinctive perspective that enriches the body of ethnoscience research in Indonesia. In comparison, studies conducted in Bali predominantly examine *usada* practices and religious rituals (Suardana et al., 2018), whereas research in Java often highlights traditional batik production in relation to colloid concepts and extraction processes (Zidny & Eilks, 2020). The unique contribution of the Toraja context lies in the complexity of the Rambu Solo' funeral ritual and the fermentation of *ballo'*, both of which offer authentic settings for understanding the biochemistry of preservation and fermentation areas that remain underexplored in other regional studies. Consequently, this research broadens the landscape of Indonesian ethnoscience and reinforces the idea that each cultural tradition contributes its own distinctive scientific knowledge.

Figure 1. Cultural Context of the Rambu Solo' Ceremony as a Medium for Traditional Chemical Practices

The preservation practices observed in the Rambu Solo' funeral ceremony were analyzed using a thematic analysis framework. Drawing from interview data, informant JB explained:

"Among the Toraja people, traditional mortuary practices are still carried out, including applying large amounts of crushed pine leaves to the body of the deceased, as well as using tille stems similar to bamboo to inject a preservative liquid into the corpse, particularly into the mouth and nasal cavities." (JB, Interview 2)

The informant's description of these physical procedures was coded as the initial category "traditional corpse-handling practices." It is important to note that the informant did not articulate chemical mechanisms; rather, the explanation focused on customary procedures transmitted across generations. To interpret the underlying scientific functions, this study referred to current literature. Findings from (Zhao et al., 2021) and (Yu et al., 2022) indicate that the resin of *Pinus merkusii* contains bioactive compounds including α-pinene, β-pinene, and phenolic derivatives that exhibit strong antimicrobial and antifungal activities.

Drawing on literature indicating that *Pinus merkusii* contains antimicrobial bioactive compounds (Yu et al., 2022; Zhao et al., 2021), this practice is interpreted as serving a function of "inhibiting natural decomposition," classified under the category of "natural antiseptic agents," and ultimately forming the theme "traditional chemical practices in the Rambu Solo' ceremony." Likewise, the statement that "*ballo'* develops spontaneously because bamboo contains natural yeast" was coded as "natural fermentative microorganisms," categorized as "biochemical reactions," and used to construct the theme "fermentation as a traditional chemical practice." This approach, which integrates field data with scientific literature, reflects the characteristics of contemporary ethnoscience methodologies (Zidny et al., 2020). The process also demonstrates analytical transparency consistent with the standards of qualitative research (Nowell et al., 2017; Vaismoradi et al., 2016).

The findings indicate that the use of pine leaves (*Pinus merkusii*) and *tille* stems in the Rambu Solo' ceremony carries both functional and symbolic purposes. These traditional chemical processes are depicted in the flow diagram presented in Figure 2.

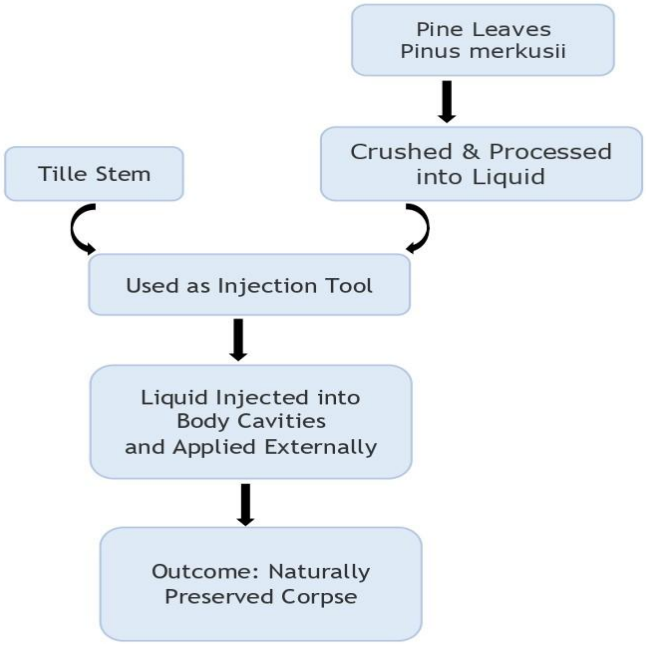

Figure 2. Flowchart of Traditional Preservation Practice

From a functional perspective, this role can be explained by the presence of terpenoid and phenolic compounds in pine resin, which exhibit antimicrobial and antifungal properties (Yu et al., 2022; Zhao et al., 2021). These findings align with (Sholikhah et al., 2020), who reported

that various local plants contain bioactive compounds capable of inhibiting bacterial growth. Scientifically, this indicates that the Toraja community has long applied empirical knowledge that corresponds with modern chemical principles, particularly in the use of natural preservatives. The contemporary chemical interpretation of this mechanism is illustrated in Figure 3.

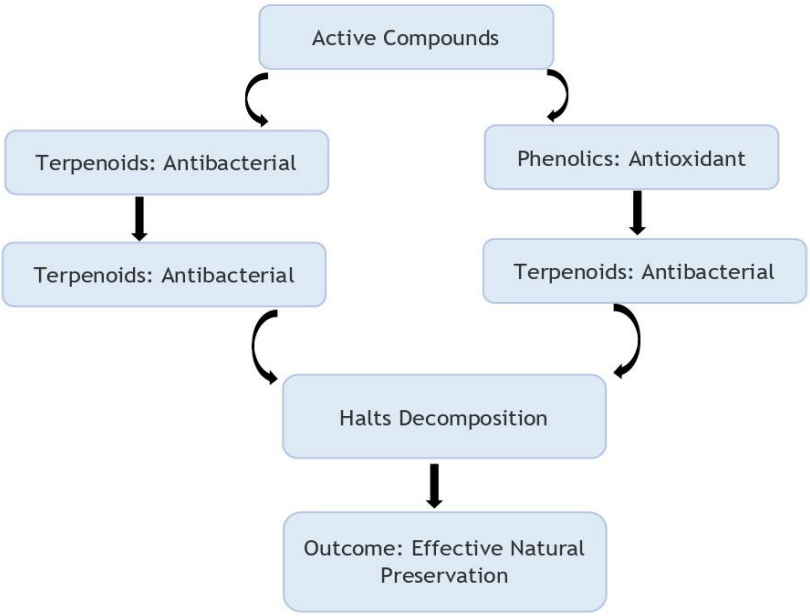

Figure 3. Block Diagram of Modern Chemical Concepts

However, the significance of this practice extends far beyond its functional purpose. The informant emphasized that the use of modern materials, such as formalin, is often considered inappropriate, stating, "*Some say it is not in accordance with customary law if it does not follow the ways of the ancestors*" (JB, Interview 2). This statement reveals a profound symbolic dimension in which preservation practices are closely tied to spirituality, ancestral reverence, and the commitment to sustain inherited traditions (Stevenson, 2019). The interweaving of cultural values with empirical benefits thus creates a rich and authentic learning context.

These findings indicate that the Rambu Solo' ritual can serve as a culturally grounded and sustainability-oriented context for chemistry learning. Integrating Toraja local knowledge with modern chemical principles not only promotes a more holistic understanding but also aligns with the paradigm of green chemistry education, which emphasizes sustainability and responsible use of natural resources (Kummerer, 2020; Zidny & Eilks, 2022). In this sense, the ritual embodies a form of applied "ethnochemistry," where the community's empirical practices resonate intuitively with contemporary scientific principles, offering a valuable model for inclusive and socially relevant science education (Mahaffy et al., 2019).

Processing of Natural Materials as Traditional Chemistry Practices

Another significant finding is the fermentation of bamboo sap into *ballo'*. The informants described this process as occurring naturally and spontaneously, without the involvement of modern additives, relying instead on microorganisms that act as inherent biochemical catalysts. This observation corresponds with studies on traditional fermentation, which highlight the role of indigenous microbial consortia as natural catalysts capable of driving complex biochemical reactions (Tamang et al., 2020). These findings reinforce that Toraja fermentation practices illustrate key concepts in biochemistry, enzymatic catalysis, and sustainability principles aligned with the goals of green chemistry, particularly in the use of renewable resources and safe processing methods (Kummerer, 2020; Zidny & Eilks, 2020).

Similarly, the production of natural dyes for woven textiles involves oxidation and fixation reactions that generate durable and stable colors. The use of leaves and plant roots exemplifies an application of renewable resources while simultaneously reducing reliance on synthetic dyes that may cause environmental harm. This aligns with innovations in the development of environmentally friendly and sustainable colorants (Garcia et al., 2020), as well as their pedagogical value in supporting green chemistry learning through culturally grounded contexts (Armstrong et al., 2019). In this regard, Toraja practices offer not only chemical insights but also concrete models of sustainability that can be meaningfully integrated into classroom learning.

Pedagogical Implications and Challenges

Overall, the findings of this study highlight the pedagogical value embedded in Torajan traditional practices. For chemistry educators, the Rambu Solo' ritual can serve as a culturally grounded entry point for discussing organic compounds and antimicrobial agents, while the fermentation of *ballo'* offers a practical laboratory context for examining biochemical reactions. Additionally, the production of natural dyes provides meaningful opportunities for students to explore redox processes and principles of sustainability through hands-on projects. These insights align with previous studies showing that incorporating ethnoscience into instruction can strengthen students' scientific literacy and cultural identity (Elvianasti, Lufri, & Advinda, 2023; Imaduddin et al., 2020; Suardana et al., 2018).

Nevertheless, several challenges remain. As emphasized by Apriani (2025), *"The difficulties in preserving local wisdom include the influence of modern culture, declining interest among younger generations to study traditional customs, and environmental changes that make certain natural materials increasingly scarce."* Younger generations are demonstrating reduced engagement with traditional practices as a result of modernization and shifting lifestyles. This trend poses a risk of knowledge erosion, a concern also noted in broader contexts by (Mungmachon, 2018). Therefore, integrating local wisdom into chemistry education not only enhances contextual learning but also functions as an important strategy for cultural preservation.

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that the traditional practices of the Torajan community, particularly those found in the Rambu Solo' ritual and the processing of natural materials, possess scientific foundations that align with principles of modern chemistry. The application of pine leaves (*Pinus merkusii*) as a natural preservative is supported by the antimicrobial properties of terpenoids and phenolic compounds. Likewise, the fermentation of *ballo'* and the production of natural dyes illustrate the community's intuitive application of biochemical processes and sustainable principles consistent with green chemistry.

The findings also offer substantial pedagogical implications, particularly for the development of ethnoscience-based learning modules. Practical implementations may include simple laboratory activities such as the extraction of bioactive compounds, fermentation experiments, and the synthesis of natural dyes. Further research is recommended in three key areas: (1) quantitative chemical analysis of active compounds, (2) the design and evaluation of innovative instructional materials, and (3) comparative ethnoscience studies across other Indigenous communities.

Overall, this research contributes not only to the preservation of local wisdom but also to the enrichment of contextual chemistry education in Indonesia by integrating traditional knowledge with contemporary scientific understanding.

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