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# Ethnophysics-Based Heat Transfer Analysis of Lemang Plaho for Contextual Physics Learning

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***ABSTRACT***
*Ethnophysics research on traditional foods has frequently focused on identifying science concepts, while the thermal mechanisms and empirical indicators of doneness embedded in cultural practices remain less systematically explained. This study analyzes the production of* Lemang Palho *in Siulak Mukai District, Kerinci Regency, as a bamboo-based traditional thermal system and examines its contribution to contextual physics learning through indigenous science integration. A descriptive qualitative design with an ethnophysics perspective was employed. Data were collected through direct observation, semi-structured interviews with six informants, and documentation, then analyzed using thematic coding involving data condensation, data display, verification, and interpretation. The findings show that* Lemang Palho *production involves radiation from fire and embers, conduction through the bamboo wall, and convection of water and steam inside a semi-closed bamboo chamber sealed with a banana-leaf stopper. Doneness is influenced by a bamboo diameter of approximately 3–5 cm, inclined bamboo positioning, periodic rotation, stable embers, a burning duration of approximately 2–4 hours, and retained steam moisture. These findings demonstrate that the traditional process of making* Lemang Palho *can serve as a culturally grounded learning context for explaining temperature, heat transfer, phase change, and food texture transformation. The study further supports the development of physics teaching materials that connect local wisdom with scientific concepts, thereby strengthening culturally responsive science learning and the integration of indigenous knowledge into the physics curriculum.*

## INTRODUCTION

Studies on ethnophysics and ethnoscience education have increasingly shown that local cultural practices can function as meaningful contexts for science learning. Local culture-based science learning has been reported to help students connect scientific concepts with familiar phenomena, increase learning engagement, and support scientific literacy because students are encouraged to interpret everyday events through observation, evidence, explanation, and culturally relevant experiences (Atmojo et al., 2019; Gde et al., 2023; Sari & Wilujeng, 2023; Sotero et al., 2020). In physics education, ethnophysics has also been used to identify and reconstruct physics concepts embedded in traditional games, vernacular houses, arts, crafts, local food, and regional traditions (Festiyed et al., 2024; Habibi et al., 2023; Sihombing et al., 2025; Virijai & Liliawati, 2024). These studies indicate that ethnophysics is not only relevant for documenting local wisdom, but also for developing contextual physics learning that connects formal scientific concepts with students' cultural and community-based experiences.

This perspective is closely related to indigenous STEM education, place-based science education, and culturally responsive pedagogy. Indigenous STEM education emphasizes that local knowledge, culture, language, and place are foundational resources for STEM learning, rather than supplementary examples outside formal science (Chinn & Nelson-Barber, 2023; Snively & Williams, 2016). Place-based science education similarly argues that science learning becomes more meaningful when it is grounded in local environments, community practices, and culturally significant places (Gruenewald, 2003; Semken & Freeman, 2008; Smith & Sobel, 2010). Meanwhile, culturally responsive pedagogy positions students' cultural knowledge and lived experiences as intellectual resources that can support participation, conceptual understanding, and identity formation in learning. Therefore, the study of Lemang Plaho is pedagogically relevant because this cultural practice provides a concrete context for explaining heat transfer, phase change, moisture transformation, and empirical reasoning in physics learning.

However, the existing literature still leaves an important gap. What is already known is that local cultural practices can be used as contextual resources for science learning, and previous ethnophysics studies have identified many physics concepts in cultural objects and community traditions. Studies on traditional food and lemang have also shown that heat, temperature, energy transfer, and material change can be introduced through food-processing practices (Jufrida et al., 2021; Sagita et al., 2021; Wahyudi et al., 2017). In addition, food-science studies have explained that rice-based food processing involves water absorption, starch swelling, gelatinization, moisture migration, and texture formation (Khwanchai et al., 2024; Liang et al., 2025; Xu et al., 2024; Yin et al., 2023; Zhu et al., 2021). What remains insufficiently known is how the specific practice of making Lemang Plaho in Siulak Mukai operates as an integrated bamboo-based thermal system, particularly in relation to radiation from fire and embers, conduction through bamboo, convection of steam and hot fluid inside the bamboo chamber, moisture retention, starch transformation, and community-based indicators of doneness.

This gap matters for both scientific and pedagogical reasons. Scientifically, without a detailed explanation of the thermal mechanisms involved, Lemang Plaho may be understood only as a cultural product, rather than as a community-based physical system shaped by empirical observation and experience-based thermal control. Pedagogically, without a clear reconstruction of indigenous knowledge into physics concepts, the practice may only be used as an illustrative example and may not fully support scientific literacy, contextual reasoning, or culturally responsive physics learning. In fact, the ways local practitioners regulate fire intensity, bamboo position, cooking duration, steam, aroma, texture, and doneness show that indigenous knowledge contains empirical logic that can be interpreted through scientific concepts.

To address this gap, the present study analyzes the heat transfer mechanisms involved in the making of Lemang Plaho in Siulak Mukai District. Specifically, this study identifies the indigenous indicators used by local practitioners to determine doneness and interprets these indicators through physics concepts, including radiation, conduction, convection, phase change, and heat-related material transformation. By doing so, this study connects cultural practice, indigenous empirical knowledge, and scientific explanation within a contextual physics learning framework. This approach is expected to strengthen the contribution of ethnophysics to scientific literacy, indigenous science integration, place-based science education, and culturally responsive pedagogy.

The novelty of this study lies in three aspects. First, this study positions Lemang Plaho not merely as a traditional food or cultural symbol, but as a cultural-thermal system that can be analyzed through heat transfer theory. Second, it documents community-based doneness indicators, including bamboo condition, ember stability, aroma, steam, cooking duration, moisture, and final texture, as forms of indigenous empirical knowledge. Third, it connects these indicators with formal physics concepts to support contextual physics learning. Thus, this study contributes to ethnophysics education by showing how a local food tradition can become a scientifically meaningful and culturally responsive learning context for understanding heat transfer.

## METHOD

### Research Type and Approach

This study employed a descriptive qualitative approach with an ethnophysics perspective (Creswell & Creswell, 2018). This approach was selected because the purpose of the study was not to test a hypothesis, but to describe the practice of making *Lemang Plaho*, interpret the local knowledge of the community, and reconstruct it into physics concepts. The research focused on the stages of production, forms of heat transfer, doneness factors, and empirical indicators used by the community to assess the cooking result.

The ethnophysics perspective was used to interpret cultural practices as sources of scientific knowledge. In this approach, community knowledge is not positioned as less scientific than formal knowledge, but as empirical knowledge that can be explained through physics concepts. Therefore, field data were analyzed while maintaining the cultural context and relating it to the concepts of temperature, heat, radiation, conduction, convection, phase change, and starch gelatinization.

### Researcher Positionality and Reflexivity

To increase the transparency of the qualitative interpretation, this study also considered the researcher's relationship with the community and potential interpretive biases. The researcher was not a maker of *Lemang Plaho* and did not act as a customary actor in the *Plaho* tradition. The researcher's role was limited to observing the production process, conducting interviews, documenting field data, and interpreting the practice through an ethnophysics framework.

The researcher entered the field through communication with local informants who were familiar with the *Plaho* tradition. This relationship helped the researcher obtain access to the production site and relevant informants, but it also required careful reflexivity because cultural explanations might be interpreted too quickly through formal physics categories. To minimize this bias, the researcher did not directly replace local explanations with scientific terms. Instead, local terms, empirical indicators, and informants' explanations were first recorded as field data, then compared with observation results before being interpreted through physics concepts. Field notes, interview transcripts, coding notes, and documentation were reviewed repeatedly to ensure that the interpretation remained grounded in community knowledge.

### Research Location and Time

The study was conducted from February to April 2026 in Siulak Mukai District, Kerinci Regency, Jambi Province, with the main sites located in Serujung Village and Mukai Pintu Village. These locations were selected because the local community still recognizes and practices the *Plaho* tradition, including the serving of *Lemang Plaho*. The site selection also considered the availability of informants who understood the production process, burning technique, and cultural meaning of *Lemang Plaho*.

Field observation was conducted in 3 observation sessions, with each session lasting approximately 24 hours. The total observation duration was approximately 8 hours. The observation covered the preparation of materials, bamboo preparation, filling process, positioning of bamboo near the fire, ember control, bamboo rotation, steam release, aroma, cooking duration, and final texture.

**Research Participants**

This study involved six participants who were selected purposively based on their direct involvement, practical experience, and cultural knowledge related to the *Plaho* tradition and the process of making *Lemang Plaho*. The selection followed the principle of information-rich informants in qualitative research, in which participants are chosen because they can provide detailed and relevant information about the phenomenon being studied.

The six participants consisted of three categories. The first category was one community or customary figure who understood the cultural meaning of *Lemang Plaho* in the *Plaho* tradition (I1). The second category consisted of four local residents and *Lemang Plaho* makers who had direct experience in material selection, bamboo preparation, fire control, cooking process, bamboo rotation, and doneness determination (I2–I5). The third category was one organizer of *Plaho Saleh* who understood the social and cultural context of the tradition (I6). Informant codes were used to protect personal identities while allowing the data to be analyzed systematically.

Semi-structured interviews were conducted in 3 interview sessions. Each informant participated in one interview, with an average interview duration of approximately 120 minutes. Follow-up confirmation was conducted with I2, I3, and I6 to clarify key information related to bamboo selection, fire regulation, cooking duration, steam, aroma, and texture as indicators of doneness.

Although the number of participants was relatively limited, it was considered sufficient for this descriptive qualitative study because the data reached thematic saturation. Thematic saturation was indicated by the recurrence of similar information across interviews and observations, particularly regarding the selection of bamboo, the use of banana leaves as a stopper, the regulation of fire and embers, bamboo rotation, cooking duration, steam and aroma as signs of heating, and texture as an indicator of doneness. After interviews with the main *Lemang Plaho* makers and confirmation with the community figure and event organizer, no substantially new themes emerged.

**Data Collection Techniques**

Data were collected through direct observation, semi-structured interviews, and documentation. Observation was conducted in a limited non-participatory manner. The researcher was present at the *Lemang Plaho* production site to observe the stages of activity, tools and materials, bamboo position relative to the heat source, fire intensity, bamboo rotation, burning duration, steam release, aroma, and signs of doneness, without becoming the main maker. Observation notes were compiled as field notes and supported by visual documentation.

Semi-structured interviews were conducted to explore the reasons for material selection, bamboo size, burning technique, function of the banana-leaf stopper, fire regulation, cooking duration, and doneness indicators used by the community. The interview guide contained core questions, but the researcher allowed informants to explain their experiences, local terms, and practical reasoning in their own words. Documentation was carried out through photographs, field notes, and interview recordings with informants' consent.

**Research Instruments**

The main instrument in this study was the researcher, while supporting instruments included observation guidelines, interview guidelines, documentation sheets, writing tools, a mobile phone or recording device, and a camera. The observation guideline covered aspects such as production stages, types of materials, bamboo size, bamboo position, heat source, rotation, fire and ember stability, steam release, aroma, and signs of doneness. The interview guideline included questions about the meaning of *Lemang Plaho*, experience in making lemang, technical reasons for production practices, and how the community assesses doneness.

### Data Analysis Technique

Data were analyzed using the interactive model of Miles, Huberman, and Saldaña (2014), which includes data condensation, data display, and conclusion drawing and verification. To clarify the analysis process, this study applied thematic coding by referring to thematic-analysis procedures and criteria for qualitative-analysis traceability (Braun & Clarke, 2006; Nowell et al., 2017).

The first stage was open coding, which involved assigning initial codes to data such as bamboo selection, banana-leaf stopper, inclined bamboo position, bamboo rotation, stable embers, steam release, aroma, color, cooking duration, and texture. The second stage was axial coding, which grouped the codes into major themes such as heat-transfer mechanisms, doneness factors, empirical indicators, and cultural meaning. The third stage was selective coding, which established relationships among themes to explain *Lemang Plaho* as a traditional thermal system. In this stage, local empirical indicators were interpreted through relevant physics concepts, including radiation, conduction, convection, phase change, moisture transformation, and starch gelatinization.

### Data Validity, Triangulation, Member Checking, and Research Ethics

Data validity was ensured through source triangulation, technique triangulation, member checking, and an audit trail. Source triangulation was conducted by comparing information from the customary figure, *Lemang Plaho* makers, and the tradition organizer. For example, information from the makers regarding the need to rotate the bamboo was compared with the explanation of the community figure and the organizer's description of the traditional cooking process. The consistency of these explanations supported the interpretation that bamboo rotation functions to distribute heat more evenly and prevent one side of the bamboo from burning excessively.

Technique triangulation was conducted by comparing interview data, direct observation, and documentation. For instance, informants explained that stable embers, steam release, aroma, and texture were important signs of doneness. This explanation was compared with observation notes showing that the bamboo was kept near stable embers, rotated periodically, and assessed through steam, smell, and texture before being removed from the fire. Visual documentation was also used to confirm bamboo position, heat source, and the absence of banana-leaf lining inside the bamboo.

Member checking was conducted by reconfirming important findings with selected informants. For example, the interpretation that the banana leaf functioned as a stopper to retain steam and moisture was confirmed with I4. The interpretation that aroma and texture were used as empirical indicators of doneness was also checked with I5. The informants confirmed that these interpretations were consistent with their practical experience in making *Lemang Plaho*. No major correction was given by the informants, but several clarifications were added, particularly regarding cooking duration, bamboo size, and ember stability.

An audit trail was maintained by storing field notes, interview recordings, photographs, coding notes, and data-reduction tables. This documentation allowed the analytical pathway from raw field data to ethnophysics interpretation to be traced systematically.

Research ethics were addressed by obtaining informants' consent before interviews and documentation were conducted. Informants were informed about the research objectives, data use, and their right not to answer certain questions. Informants' identities were anonymized using codes, while visual documentation was used only for academic purposes and to explain the research findings.

## RESULTS AND DISCUSSION

This section presents the findings and discussion in an analytical structure. The results are organized into three connected levels: field findings obtained from observation, interviews, and documentation; interpretation of local knowledge; and physics reconstruction that connects the practice of making *Lemang Plaho* with heat transfer concepts. This structure is used to clearly distinguish between what was observed in the field, what was explained by the informants, and how the findings were interpreted through an ethnophysics perspective.

**Cultural Context and Distinctive Characteristics of Lemang Plaho**

The observation and interview data indicate that *Lemang Plaho* is embedded in the *Plaho* tradition of the Siulak Mukai community. It is not treated merely as a food product, but as part of a social and cultural practice transmitted across generations. In several forms of *Plaho*, including *Plaho Nganta Iman* and *Plaho Saleh*, *Lemang Plaho* appears as a cultural object with ritual, social, and symbolic functions.

One community figure explained:

*"Lemang Plaho is not merely ordinary food, but part of the Plaho tradition. Its preparation and serving inside bamboo are important because they show the identity of the tradition" (I1, community figure, translated from the local language).*

Observational evidence also showed that *Lemang Plaho* was prepared and served differently from common lemang. The lemang was cooked in small *manyan* bamboo, was not lined with banana leaves inside the bamboo, used water rather than coconut milk as the liquid medium, and was served while remaining inside the bamboo. These observed characteristics suggest that the cultural distinctiveness of *Lemang Plaho* is also related to its cooking technique.

From the perspective of local knowledge, these procedures are not merely inherited habits. They function as practical controls over the cooking process. The choice of bamboo, the absence of an inner banana-leaf lining, the use of water, and the use of a banana-leaf stopper appear to influence moisture retention, heating pattern, and final texture. However, this study does not claim that these effects were directly measured through thermal instruments. Rather, the interpretation is based on field observation, informant explanation, and reconstruction through heat transfer theory.

From a physics perspective, *Lemang Plaho* can be interpreted as a bamboo-based thermal system. Bamboo functions as a container, a heat-transfer boundary, and a serving medium. The absence of banana leaves inside the bamboo may reduce the additional barrier between the bamboo wall and the rice mixture. The use of water supports steam formation and moist heating, while the banana-leaf stopper helps retain vapor while still allowing limited steam release. These features distinguish *Lemang Plaho* from common lemang and provide the basis for its ethnophysics interpretation.

Table 1. Differences Between Lemang Plaho and Lemang in General

| Aspect | *Lemang Plaho* | Lemang in General |
|---|---|---|
| Cultural context | Used in the *Plaho* tradition of the Siulak Mukai community. | Generally consumed as traditional food or served during certain events. |
| Liquid ingredient | Uses plain water as the cooking medium. | Commonly uses coconut milk as a source of flavor and fat. |
| Inner lining | Does not use banana leaves as an inner lining inside the bamboo. | Often uses banana leaves as an inner lining inside the bamboo. |
| Bamboo type and size | Uses young *manyan* bamboo with an estimated diameter of about 3–5 cm. | Bamboo size is more varied according to local practice and consumption needs. |
| Stopper | The top is sealed with rolled banana leaves. | Does not always use a specific stopper. |
| Serving method | Served whole together with the bamboo after the charred outer layer is peeled. | Usually removed from the bamboo and cut into pieces before serving. |
| Doneness indicators | Determined through aroma, bamboo color, steam, remaining liquid, texture, and maker experience. | Commonly determined through texture, aroma, or family/community cooking habits. |

**Production Process of Lemang Plaho**

The production process observed in the field consisted of five main stages: preparing tools and materials, filling the bamboo, burning, determining doneness, and serving. The first stage involved preparing young *manyan* bamboo, glutinous rice, grated coconut, water, salt, banana leaves, firewood, and burning equipment. The selected bamboo was generally small, with an estimated diameter of about 3–5 cm and a length locally referred to as *situ nggam* or *situ lpeh*. The diameter reported here should be understood as an approximate field estimate rather than a precise laboratory measurement.

One informant explained the reason for selecting *manyan* bamboo:

*"In Lemang Plaho, bambu manyan is used, whereas ordinary coconut milk-based lemang usually uses bambu telang. Bambu manyan is chosen because it has a thicker outer layer and a smaller diameter. The thicker surface makes it easier to scrape off the blackened layer after burning when the lemang is served in the Plaho ceremony" (I2, Bulian/ritual leader, translated from the local language).*

This statement was supported by observation. During the serving stage, the charred outer part of the bamboo was peeled while the lemang remained inside the bamboo. This was different from common coconut milk-based lemang, which is usually split open and removed from the bamboo before being served. This evidence suggests that the use of *manyan* bamboo is related not only to availability or tradition, but also to the technical need to preserve the bamboo as part of the serving form.

The second stage was filling the bamboo. The glutinous rice was cleaned, mixed with grated coconut and salt, inserted into the bamboo, and then combined with water. The top of the bamboo was sealed with rolled banana leaves. Field observation showed that the stopper was not completely airtight. It retained part of the steam but still allowed limited vapor release.

The third stage was burning. The filled bamboo was placed near the fire and embers in an inclined position, as shown in Figure 1. This inclined position allowed the makers to regulate heat exposure more effectively, while periodic rotation of the bamboo helped reduce uneven burning. The fourth stage was determining doneness. The makers did not use a thermometer or formal timer. Instead, they relied on bamboo color, steam, aroma, texture, and the presence or absence of remaining liquid.

Fig.1. Burning process of *Lemang Plaho* using *manyan* bamboo

These stages (Figure 1) demonstrate that the production process incorporates empirical control over heat, moisture, and material transformation. Although these observations were not supported by direct measurements of temperature or moisture content, they indicate practical knowledge developed through repeated experience. The internal appearance of the cooked *Lemang Plaho* is presented in Figure 2. The cooked glutinous rice appears dense and cohesive, indicating visible moisture absorption and texture transformation after the heating process.

Fig.2. Internal appearance of cooked *Lemang Plaho*

The fifth stage was serving. Field observations showed that the charred outer layer of the bamboo was peeled away while the cooked *Lemang Plaho* remained inside the bamboo. This serving method differs from ordinary coconut milk-based lemang, which is commonly removed from the bamboo and cut into pieces before serving. The comparison is presented in Figure 3.


(a) (b)

Fig. 3. Comparison of serving forms; a) *Lemang Plaho* served inside the peeled bamboo, b) Ordinary coconut milk-based lemang served after being removed from the bamboo

This distinctive serving practice suggests that the use of *manvan* bamboo is associated not only with material availability or cultural tradition but also with the practical function of preserving the bamboo as part of the final presentation. As shown in Figure 3a, *Lemang Plaho* is served while remaining inside the peeled bamboo, whereas ordinary coconut milk-based lemang is typically removed from the bamboo before serving (Figure 3b).

**Analytical Synthesis of Findings, Interpretation, and Physics Reconstruction**

Table 2 presents the analytical reconstruction of the findings. The first column records field findings obtained from observation and interviews. The second column presents the interpretation of local practice based on community knowledge. The third column reconstructs the same practice through physics concepts. The fourth column explains its ethnophysics meaning. This separation is important because the study does not claim that all physics concepts were explicitly stated by the community. Rather, the physics explanation is an analytical reconstruction based on observed practice and informant explanations.

Table 2. Analytical Matrix of Lemang Plaho Ethnophysics

| Empirical findings | Interpretation of local practice | Physics reconstruction | Ethnophysics meaning |
|---|---|---|---|
| Young *manyan* bamboo with an estimated diameter of about 3–5 cm is selected. | Small bamboo is preferred because experience shows that it cooks more evenly and reduces the risk of a hard center. | A smaller diameter may shorten the heat-transfer distance from the bamboo wall to the center of the filling. | Local size selection reflects empirical knowledge of heat distribution. |
| No banana-leaf lining is placed inside the bamboo. | This is a distinctive feature of *Lemang Plaho* compared with many forms of ordinary lemang. | The absence of an inner lining may reduce additional thermal resistance between the bamboo wall and the rice-water mixture. | Cultural distinctiveness creates a different heat-transfer pathway. |
| Water is used as the liquid medium instead of coconut milk. | Water supports cooking and texture formation while maintaining the local character of the product. | Water absorbs heat, produces steam, supports convection, and contributes to starch gelatinization. | Local ingredient choice functions as a thermal and phase-change medium. |
| The top of the bamboo is sealed with rolled banana leaves. | The stopper helps keep the lemang moist without sealing the bamboo completely. | The stopper creates a semi-closed chamber that retains vapor while still allowing limited steam release. | Local practice demonstrates practical control of a moist-heating system. |
| Bamboo is placed in an inclined position and rotated periodically. | Inclination and rotation are used to prevent one side from burning and to obtain more even doneness. | Inclination regulates exposure to radiation and supports water/steam movement, while rotation distributes heat around the bamboo wall. | Cooking technique functions as community-based heat equalization. |
| Stable embers are preferred over large flames. | Large flames are considered risky because they can char the bamboo before the filling is cooked. | Stable embers may provide a more gradual and stable heat flux. | Fire control reflects empirical regulation of heating rate. |
| Aroma, bamboo color, steam, remaining liquid, and texture are used as doneness indicators. | Doneness is assessed through sensory and experiential signs. | These signs may correspond to moisture movement, steam release, starch swelling, gelatinization, and texture formation. | Indigenous indicators function as an empirical evaluation system. |

**Semi-Closed Thermal System in Lemang Plaho**

In this study, the term semi-closed thermal system refers operationally to the bamboo cooking chamber of *Lemang Plaho*. One end of the chamber is closed by the bamboo node, while the other end is partially sealed with a rolled banana-leaf stopper. Field observation showed that the stopper retained some steam but did not completely prevent vapor release. Therefore, the system was not fully open, but it was also not fully closed.

Thermodynamically, *Lemang Plaho* may be interpreted as a transient, non-isothermal, semi-closed moist-heating system. Energy enters the system through radiation from fire and embers, convection from hot air, and conduction through the bamboo wall. Inside the bamboo, water absorbs heat, produces steam, and transfers thermal energy to the glutinous rice. Some vapor remains inside the bamboo chamber, while some escapes through gaps in the stopper.

This interpretation should not be read as a direct thermodynamic measurement. The study did not measure heat flux, vapor pressure, or internal temperature. The term semi-closed system is used as a conceptual reconstruction to explain how the observed cooking arrangement allows energy exchange and limited mass exchange.


Fig.4. Ethnophysics reconstruction of heat transfer in *Lemang Plaho*

Figure 4 show radiation from fire and embers, conduction through the bamboo wall, convection of water and steam inside the bamboo chamber, limited vapor release through the banana-leaf stopper, and texture transformation of glutinous rice during heating.

### Heat-Transfer Mechanisms and Doneness Factors

The main analytical finding is that *Lemang Plaho* involves a combination of radiation, conduction, convection, and phase change. Heat from wood combustion reaches the bamboo surface through radiation from fire and embers, as well as through hot air around the burning area. Heat then moves through the bamboo wall by conduction. Inside the bamboo, water and steam transfer heat to the rice mixture. This process contributes to changes in temperature, moisture, and texture.

This interpretation is consistent with food-processing principles stating that cooking involves external heat transfer from the heat source to the food surface and internal heat transfer toward the center of the material. In roasting or burning systems, radiation and convection affect the outer surface, while conduction contributes to internal heating (Sakin et al., 2009; Incropera et al., 2011; Singh & Heldman, 2014). However, *Lemang Plaho* differs from ordinary roasting because the food is enclosed in bamboo with water and a semi-permeable stopper. Therefore, the process combines dry external burning and internal moist heating.

### Bamboo diameter and heat distribution

The selection of small *manyan* bamboo is one of the main observed features of *Lemang Plaho*. Informants explained that small bamboo is preferred because it helps the lemang cook more evenly. From a physics perspective, this practice can be interpreted as a way to reduce the distance that heat must travel from the bamboo wall to the center of the rice mixture. If the diameter is too large, the portion near the wall may cook earlier, while the center may require more time to soften.

This interpretation is related to the surface-area-to-volume ratio. As bamboo diameter increases, the volume of filling increases faster than the heat-receiving surface area. Consequently, the center may require longer time to reach the expected texture. The community does not express this principle in mathematical terms, but the practice suggests empirical understanding of heat distribution.

### Absence of inner banana-leaf lining and direct conduction

Unlike many types of lemang, *Lemang Plaho* does not use banana leaves as an inner lining inside the bamboo. This observed characteristic is analytically important because it may affect the heat-transfer pathway. In ordinary lemang, the inner banana-leaf lining can act as a separation layer between the bamboo wall and the food. In *Lemang Plaho*, the absence of this layer allows more direct thermal contact between the bamboo wall and the rice-water mixture.

This feature represents one of the specific contributions of the study. Previous lemang studies have generally discussed lemang as a traditional food containing science concepts. The present study shows that a specific local variant, *Lemang Plaho*, has a distinct thermal structure because of its material arrangement: water-based filling, small *manyan* bamboo, no inner banana-leaf lining, a banana-leaf stopper, and serving inside the bamboo.

### Inclination, rotation, and heat equalization

The inclined position and periodic rotation of the bamboo form another important mechanism. Observation showed that the bamboo pieces were placed at an angle near fire and embers, not directly above a large flame. The position allowed the maker to adjust distance from the heat source. Periodic rotation was used to prevent one side of the bamboo from being excessively burned.

Two informants explained:

*"During the roasting process, the bamboo must be rotated so that all sides receive heat evenly. The bamboo is turned several times. When one side begins to blacken, it is rotated so that another side faces the heat. The embers must be kept stable; the fire should not be too large or too small. This prevents the lemang from burning and keeps the outer bamboo layer easy to peel" (I4 and I5, lemang makers, translated from the local language).*

This statement was consistent with field observation. The researcher observed that the bamboo was not left in one fixed position. It was turned periodically, especially when the side facing the heat source became darker. This supports the interpretation that rotation functions as a local strategy for heat equalization.

Scientifically, rotation distributes heat exposure around the bamboo circumference. Inclination may also affect the movement of water and steam inside the bamboo. When water is heated, hotter fluid and vapor tend to move upward while cooler portions remain lower. This movement may help distribute heat and moisture within the rice mixture. In water-based food processing, heat and mass transfer affect starch swelling, texture, and doneness level (Briffaz, Bohuon, Meot, Dornier, et al., 2014; Briffaz, Bohuon, Meot, Pons, et al., 2014).

### Stable embers as heat-flux control

The preference for stable embers rather than continuous large flames indicates practical control over heating intensity. Informants stated that large flames can char the bamboo before the filling is fully cooked. Observation also showed that the makers tended to maintain the bamboo near embers rather than expose it continuously to high flames.

From a physics perspective, stable embers may provide a more gradual and consistent heat supply. This condition can reduce rapid surface overheating and allow heat to move through the bamboo wall more steadily. This interpretation remains qualitative because the study did not measure heat flux or temperature. Nevertheless, the practice shows that local makers distinguish between excessive heat and useful heat for cooking.

### Banana-leaf stopper and moisture regulation

The banana-leaf stopper at the top of the bamboo functions as a partial boundary. Observation showed that the stopper was rolled and inserted at the bamboo opening, but it was not completely airtight. This design retained part of the steam while still allowing vapor release.

From the perspective of local knowledge, the stopper helps maintain moisture and prevent the lemang from drying too quickly. From a physics perspective, it can be interpreted as a simple mechanism for controlling vapor retention, moisture movement, and internal heating. It is not identical to a modern pressure cooker because mass exchange still occurs. However, it follows a comparable principle of retaining steam long enough to support moist heating and starch gelatinization.

**Starch gelatinization and indigenous doneness indicators**

The doneness of *Lemang Plaho* is indicated by the transformation of glutinous rice into a soft, dense, and cohesive texture. This change may be explained through starch gelatinization. When glutinous rice absorbs water and receives sufficient heat, starch granules swell and the texture becomes softer and more cohesive. Previous studies on rice starch show that temperature, water content, and heating duration affect gelatinization properties and final texture (Briffaz, Bohuon, Meot, Dornier, et al., 2014).

The community determines doneness through aroma, bamboo color, steam release, remaining liquid, and texture.

*"The doneness of lemang is indicated by the distinctive aroma of glutinous rice and by the bamboo turning evenly black. To ensure that the rice inside has cooked, the banana-leaf plug is opened to observe the texture. The bamboo is also inverted to see whether any liquid remains. If liquid still comes out, the lemang is not yet evenly cooked. If no liquid comes out, the lemang is considered cooked" (I3, community member involved in Plaho Saleh, translated from the local language).*

This interview evidence was supported by observation. The maker checked the lemang not by using a thermometer, but by observing bamboo color, aroma, steam, and the condition of the filling. The bamboo was also handled and examined before being removed from the heat. These signs function as empirical indicators of doneness.

The physics reconstruction suggests that these indicators are related to physical and chemical changes during heating. Aroma may indicate volatile compounds released during cooking, steam indicates water boiling and moisture movement, bamboo color reflects external heat exposure, and texture reflects water absorption and starch transformation. Therefore, indigenous doneness indicators can be interpreted as a local empirical evaluation system.

**Contribution to Ethnophysics and Previous Lemang Studies**

The findings of this study are consistent with ethnoscience studies showing that local knowledge can be reconstructed as a contextual science-learning resource (Atmojo et al., 2019; Gde et al., 2023; Sari & Wilujeng, 2023). They also align with previous studies on lemang, which showed that bamboo-based cooking can be connected to science concepts such as measurement, temperature, and heat (Jufrida et al., 2021; Sagita et al., 2021; Wahyudi et al., 2017).

However, the unique contribution of the present study lies in its more specific object and more detailed thermal reconstruction. Previous lemang studies have generally positioned lemang as a cultural object or as an example for identifying physics concepts. This study focuses specifically on *Lemang Plaho* in Siulak Mukai and explains it as a cultural-thermal system. The analysis does not stop at identifying heat concepts, but explains how bamboo type and size, the absence of inner lining, water-based filling, banana-leaf stopper, bamboo inclination, rotation, stable embers, steam, aroma, and texture work together in the cooking process.

Compared with studies that examine *Plaho* mainly as oral tradition or cultural heritage (Oktania et al., 2022), this study expands the discussion toward ethnophysics without removing the cultural context. It shows that the practice of making *Lemang Plaho* contains empirical knowledge that can be interpreted through physics concepts. Thus, the contribution of this study is not simply that local culture contains science, but that a specific traditional food practice can be reconstructed as a systematic model of heat transfer, moisture regulation, and indigenous evaluation of doneness.

**Classroom Implementation Strategies**

The findings of this study can be applied in physics learning, especially in topics related to temperature, heat, heat transfer, phase change, and energy. The implementation can be designed as a contextual and culturally responsive learning activity that connects students' cultural environment with formal physics concepts.

A possible classroom strategy consists of four stages. First, the teacher introduces *Lemang Plaho* through photographs, short videos, field stories, or local narratives. At this stage, students are asked to identify what they see in the process, such as bamboo, fire, embers, steam, water, banana-leaf stopper, and texture change. Second, students classify the observed phenomena into physics concepts. For example, radiation is linked to heat from fire and embers, conduction is linked to heat movement through the bamboo wall, convection is linked to the movement of water and steam, and phase change is linked to water becoming steam. Third, students analyze why local makers rotate the bamboo, use small bamboo, maintain stable embers, and check aroma, steam, and texture. Fourth, students present their explanation by connecting local knowledge with scientific reasoning.

The activity can be implemented through worksheets or group discussion. Example worksheet questions include: Why does bamboo need to be rotated during cooking? How does bamboo diameter affect the time needed for heat to reach the center? Why should the banana-leaf stopper not be completely airtight? What physics concepts are shown by steam release? How can aroma and texture become indicators of doneness? These questions encourage students to use evidence, observation, and explanation, which are important elements of scientific literacy.

Teachers may also design a simple inquiry activity without directly burning lemang in the classroom. For example, students can use diagrams, photographs, or a simulation of heat transfer in a cylinder. They can compare small and large cylinders to discuss heat-transfer distance, or compare open and partially closed containers to discuss evaporation and steam retention. In this way, *Lemang Plaho* can be used safely and practically as a local context for physics learning.

The expected learning outcomes include students' ability to identify heat transfer mechanisms in a cultural practice, explain the relationship between local empirical indicators and scientific concepts, and appreciate indigenous knowledge as part of science learning. Assessment can be conducted through concept maps, explanation essays, group presentations, or problem-based questions related to heat transfer in *Lemang Plaho*. Therefore, the classroom contribution of this study is not limited to providing an example, but also offers an implementable learning strategy for contextual physics education.

### Analytical Limitation and Future Research

This study reconstructs heat-transfer mechanisms based on qualitative observation, interviews, documentation, and theoretical interpretation. Therefore, the explanation emphasizes ethnophysics interpretation rather than direct thermal measurement. The study did not measure bamboo surface temperature, internal temperature, heat flux, vapor pressure, moisture content, or texture profile.

Future studies can strengthen these findings by combining ethnographic observation with quantitative measurement. For example, researchers may measure bamboo surface temperature, internal filling temperature, cooking duration, moisture content, and texture profile during the cooking process. Such measurements would allow the qualitative reconstruction of local knowledge to be compared with quantitative thermal data. However, future research should still maintain the cultural context of *Lemang Plaho* so that the practice is not reduced merely to a laboratory cooking experiment.

## CONCLUSION AND SUGGESTION

This study concludes that the making of *Lemang Plaho* in Siulak Mukai can be understood as a cultural-thermal system in which indigenous knowledge and heat-transfer principles operate together. The community's practical decisions in selecting bamboo, arranging the cooking position, controlling fire and embers, regulating steam, and determining doneness show that traditional food processing contains empirical knowledge that can be interpreted through physics concepts. Thus, *Lemang Plaho* is not only a cultural object or traditional food, but also a concrete context for understanding radiation, conduction, convection, phase change, moisture retention, and texture transformation.

The main contribution of this study lies in its reconstruction of local cooking knowledge into an ethnophysics explanation. The findings show that community-based indicators such as aroma, steam, bamboo condition, cooking experience, remaining liquid, and final texture function as traditional evaluation tools for determining doneness. These indicators demonstrate that local knowledge has a systematic empirical basis, although it is not expressed through formal scientific terminology. In this sense, the study expands ethnophysics research by showing how cultural practice, indigenous empirical reasoning, and formal physics concepts can be connected without separating the practice from its social and cultural meaning.

The findings have important implications for science education. *Lemang Plaho* can be used as a culturally relevant learning resource to help students understand heat-transfer concepts through phenomena that are close to community life. In physics learning, this practice can support scientific literacy by encouraging students to observe local phenomena, identify evidence, explain causal relationships, and connect everyday cultural experiences with scientific concepts. Learning activities may be developed through observation-based tasks, student worksheets, simple projects, problem-based discussions, or classroom analysis of local cooking processes.

In terms of curriculum development, this study suggests that local cultural practices can be integrated into physics teaching materials, especially in topics related to temperature, heat, energy transfer, phase change, and material transformation. Curriculum designers and teachers may use *Lemang Plaho* as a place-based and culturally responsive learning context that links indigenous science with formal physics content. Such integration can make science learning more contextual, meaningful, and relevant to students' cultural environment while also preserving local knowledge as part of science education.

Future studies may strengthen this ethnophysics reconstruction through quantitative measurements, such as bamboo surface temperature, internal temperature, moisture content, cooking duration, and texture analysis. These measurements would provide additional empirical evidence for explaining the thermal mechanisms of *Lemang Plaho* while maintaining its cultural meaning as part of the *Plaho* tradition.

## CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

## AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, D.P. and B.H.; methodology, D.P., B.H., and P.M.; investigation, D.P.; formal analysis, D.P.; data curation, D.P.; validation, B.H. and P.M.; ethnoscience framework development, B.H., P.M., and M.N.; interpretation of ethnophysics concepts, D.P. and M.N.; writing—original draft preparation, D.P.; writing—review and editing, B.H., P.M., and M.N.; visualization, D.P.; supervision, B.H., P.M., and M.N.; project administration, D.P. All authors have read and agreed to the published version of the manuscript.

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## DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the author(s) used ChatGPT for language improvement and grammar checking. The author(s) used NotebookLM to develop the physics-concept info graphic presented in Figure 4. All generated content was carefully reviewed, revised, and verified by the author(s), who take full responsibility for the final content of the manuscript.

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