

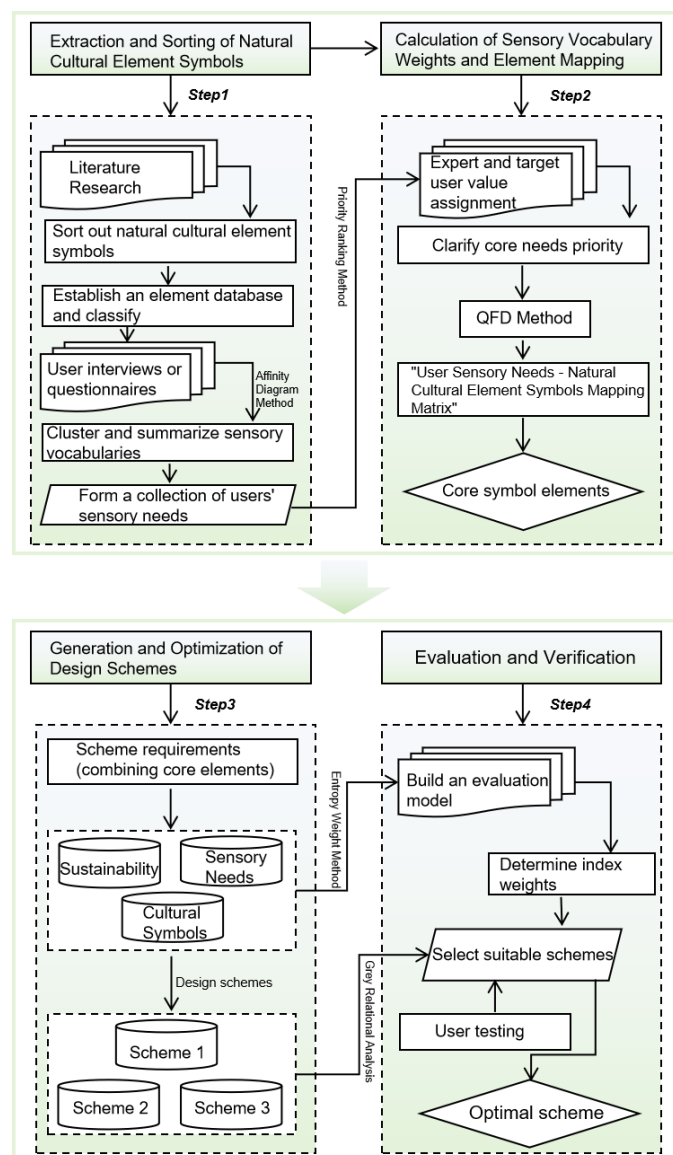
Wooden Jewelry Design Guided by Sustainability Assessment: Integrating Natural and Cultural Elements

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DOI: 10.15376/biores.21.1.439-458

GRAPHICAL ABSTRACT



Wooden Jewelry Design Guided by Sustainability Assessment: Integrating Natural and Cultural Elements

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As consumer preferences increasingly emphasize emotional connection and cultural identity, jewelry design has placed greater focus on cultural symbolism and expressive qualities. This study sought to advance wooden jewelry design within a sustainability assessment framework, using natural and cultural element symbols as the core foundation, and to construct a systematic research process from element extraction to design verification through interdisciplinary approaches. First, natural and cultural element symbols were systematically classified, and users' Kansei vocabulary related to wooden jewelry was collected and structured *via* the Affinity Diagram Method to identify emotional requirements. The Priority Ranking Method was then applied to quantify these requirements, followed by the use of Quality Function Deployment to map Kansei vocabulary to element symbols, enabling the selection of core elements and the development of three design proposals. An evaluation model was subsequently established using the Entropy Weight Method, while Grey Relational Analysis was employed to determine the optimal design, which was further validated through user testing. These findings demonstrate that this framework effectively translates natural and cultural elements into a design language for sustainable wooden jewelry, offering methodological insights into integrating traditional craftsmanship with contemporary design practice.

DOI: 10.15376/biores.21.1.439-458

Keywords: Wooden jewelry; Sustainable assessment; Natural and cultural elements

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INTRODUCTION

In contemporary design, natural elements have become an important source of inspiration because of their distinctive aesthetic qualities and ability to achieve emotional engagement. This trend is especially evident in jewelry design, where evolving consumer expectations have transformed jewelry from simple adornment into a medium for expressing emotional connection and cultural identity (Mei and Ahmad 2023). However, the traditional jewelry industry, which relies heavily on precious metals and gemstones, faces persistent challenges such as resource depletion, environmental degradation, and ethical concerns (d'Anjou 2023). In contrast, wood, which is characterized by renewability, low environmental impact, and unique natural texture, offers a promising pathway for sustainable jewelry design (Freitas *et al.* 2023). Accordingly, sustainability and cultural expression have emerged as key drivers of innovation in contemporary jewelry designs. Moreover, natural-cultural elements, as carriers of regional history and ecological wisdom, not only satisfy consumers' desires for cultural identity but also endow products with narrative value when effectively incorporated into design (Romanenkova *et al.* 2019).

Nevertheless, integrating wooden materials into jewelry design in ways that ensure both market viability and environmental responsibility remains underexplored.

Scholars have investigated sustainable design, Kansei Engineering (KE), and the application of cultural elements (Huang and Cui 2025). In sustainable design, research has promoted material and process innovations through optimized resin techniques (Puspaputra 2017), blockchain-based traceability (Freitas *et al.* 2023), and circular economy models. In KE, approaches such as eye-tracking (Lerma *et al.* 2017) and the Semantic Differential (SD) method quantify users' perceptual needs concerning materials and forms. With respect to cultural expression, rich pathways for symbolic transformation have been identified, ranging from religious motifs of the Renaissance (Romanenkova *et al.* 2019) to contemporary reinterpretations of Dunhuang art (Mei and Ahmad 2023). Yet, gaps remain in systematically integrating natural-cultural elements using sustainable natural materials and in constructing multi-dimensional evaluation frameworks. In the context of wooden jewelry, challenges persist in translating cultural symbols through interdisciplinary approaches and in quantifying sustainability. To address these gaps, this study pursued three objectives: (i) systematically categorizing natural-cultural element symbols and mapping them to user perceptual needs; (ii) screening design elements using Ordinal Relation Analysis (ORA) and Quality Function Deployment (QFD) to guide wooden jewelry design; and (iii) constructing a sustainable evaluation model based on Entropy Weight (EW) method and Grey Relational Analysis (GRA) to assess the comprehensive performance of design proposals.

Accordingly, this study adopted a sustainability assessment-oriented approach that integrated wooden jewelry design with natural-cultural elements. First, a literature review was conducted to systematically organize symbolic resources related to nature and culture. User interviews and open-ended questionnaires were employed to collect perceptual descriptions of wooden jewelry. The Affinity Diagram Method was then applied to cluster and refine these descriptions into 5 to 8 core perceptual categories, thereby constructing a set of user emotional needs. Next, ORA was used to calculate the relative weights of these perceptual words. A QFD -based mapping matrix was subsequently developed to connect perceptual categories with natural-cultural element symbols, leading to the identification of the most compatible core elements. Hand-drawn sketches integrated these elements into wooden jewelry designs, producing three proposals. A sustainability evaluation index system, covering environmental, cultural, and economic dimensions—was constructed. The EW method objectively assigned weights to each dimension, while GRA determined the relative performance of each proposal, thereby selecting the optimal design. Finally, the optimal design was validated through user testing using a five-point Likert scale, and the results were visualized in a radar chart.

LITERATURE REVIEW

Application of Sustainability in Jewelry Design

Sustainability has become a core concept in contemporary jewelry design, encompassing not only material selection and manufacturing processes but also supply chain optimization and the entire product lifecycle. In terms of materials, traditional jewelry reliance on precious metals (*e.g.*, gold, silver) and gems is often associated with environmental and social issues, including resource overuse, water pollution, and labor exploitation (Freitas *et al.* 2023). To reduce dependence on scarce resources, researchers

have proposed alternative materials such as recycled metals, lab grown gems, and renewable options including wood and cork (Tenuta *et al.* 2024). Among these, wood is regarded as a promising material due to its renewability, low environmental impact, and distinctive texture, although its durability and processing techniques require further consideration (Puspaputra 2017).

Regarding the production process, digital technologies provide innovative pathways for sustainability. For example, Computer Numerical Control machining reduces waste of materials such as resin and improves surface quality through precise cutting strategies (Puspaputra 2017). Blockchain technology is applied to trace raw material origins. This can ensure supply chain transparency, particularly in the ethical sourcing of precious metals and gems (Tenuta *et al.* 2024). Moreover, circular economy models highlight repairability and recyclability, such as reusable jewelry packaging (Huang and Chen 2025), thereby further reducing environmental burdens at the end of the product cycle.

Overall, these studies demonstrate the application of sustainability in jewelry design through material innovation (recycled metals, lab grown gems, renewable resources such as wood), process optimization, and assessment frameworks, emphasizing sustainability across the entire lifecycle from material selection to supply chain management. However, research on wooden materials remains fragmented and lacks systematic evaluation models. Therefore, based on the characteristics of wooden jewelry design, this study established an evaluation system focusing on eco-friendly materials and sustainability to provide designers with quantifiable environmental design standards.

Transformation and Expression of Cultural Elements Design

The integration of cultural elements is a central approach for jewelry design to impart meaning and value. Researchers emphasize the systematic exploration of regional culture and traditional art in extracting and reconstructing cultural symbols (Shaw and Nickpour 2024). For example, patterns and gestures from Dunhuang Flying Apsaras art have been transformed into lines and shapes in jewelry design, retaining religious and historical significance while adapting to contemporary aesthetics through modern craftsmanship (Mei and Ahmad 2023). Similarly, jewelry from the Northern Renaissance highlighted religious symbols (*e.g.*, crosses) and mythological motifs (*e.g.*, Cupid), realizing cultural narratives through metal forging and gem setting (Romanenkova *et al.* 2019).

Cross-cultural integration and symbolic innovation have also become research hotspots. For instance, Chinese designers combine traditional embroidery techniques with modern jewelry, achieving cultural interaction through material blending such as silk thread and metal (Li and Zhang 2017). Likewise, Mannerist jewelry incorporated Italian Renaissance styles with local craftsmanship, resulting in elaborate and ornate decorative features (Romanenkova *et al.* 2019). The expression of cultural elements is further shaped by material properties. The malleability of metal supports fluid forms such as the ribbons of Flying Apsaras, while the texture of wood conveys natural and rustic cultural imagery.

Existing research confirms that the transformation of cultural elements requires balancing symbolic extraction with contemporary adaptation. Historical religious symbols are interpreted through traditional craftsmanship, while artistic elements are expressed through modern design language. Moreover, the compatibility between material properties and cultural symbols directly influences expressive outcomes. However, the transformation of natural and cultural elements in wooden jewelry still has been largely

based on experiential approaches, lacking structured methods that extend from symbol extraction to process implementation, which limits the accurate conveyance of cultural meanings.

Therefore, this study systematically categorized natural cultural element symbols, integrated them with the texture and plasticity of wood, summarized element characteristics using the Affinity Diagram method, and established a mapping relationship with design language through QFD to enable more precise cultural symbol transformation.

User Perceptual Needs and Kansei Engineering Methods

Accurately capturing user perceptual needs is essential for successful jewelry design, and KE provides scientific tools for quantifying and translating these needs. Research indicates that younger consumers pay greater attention to personalization and cultural meaning, while sustainable attributes such as material eco-friendliness and ethical sourcing have become important perceptual factors influencing purchase decisions (Fowler *et al.* 2013). KE employs quantitative methods to translate user emotions into design parameters. For example, eye tracking technology analyzes users' visual focus on jewelry form and material (Lerma *et al.* 2017), helping designers optimize decorative details; the SD method applies adjective pairs to evaluate users' perception of wood texture and craftsmanship (Baionmy 2013). In addition, user interviews and focus group discussions uncover deeper needs, such as wearing comfort and the cultural symbolism of wooden jewelry (Mei and Ahmad 2023).

Technological innovations can further enhance the precision of responding to perceptual needs. For instance, Artificial Intelligence predicts trend preferences by analyzing user behavior data (Tenuta *et al.* 2024), informing wooden jewelry style design. Likewise, Virtual Reality enables users to virtually try on pieces, experiencing both the wearing effect and emotional resonance beforehand (Mei and Ahmad 2023).

These studies demonstrate that KE methods have been effectively applied to quantify user needs, including analyzing visual preferences through eye tracking, assessing material perception with the SD method, and confirming younger consumers' emphasis on cultural meaning and sustainable attributes as central perceptual factors. However, research on user perceptual needs in the context of wooden jewelry remains limited. There is a lack of integrated analysis that links natural texture, cultural identity, and sustainability awareness, and the use of methods to quantify the priority of needs is still underdeveloped.

To address these gaps, this study applied the Affinity Diagram method to refine users' perceptual vocabulary for wooden jewelry, quantifies need priority through ORA, and employs GRA to verify the correspondence between design proposals and user needs, thereby ensuring precise design outcomes that align with user emotions and cultural expectations.

METHODOLOGY

Research Framework

Contemporary jewelry design increasingly integrates cultural elements and emotional value to meet consumer needs for cultural belonging and emotional connection. This study focuses on natural cultural element symbols, constructing an innovative wooden jewelry design system within a sustainability assessment framework. A multidisciplinary approach establishes a closed loop process from element extraction to design validation,

promoting innovative expression of cultural elements in jewelry design. The research process consists of four main stages (Fig. 1):

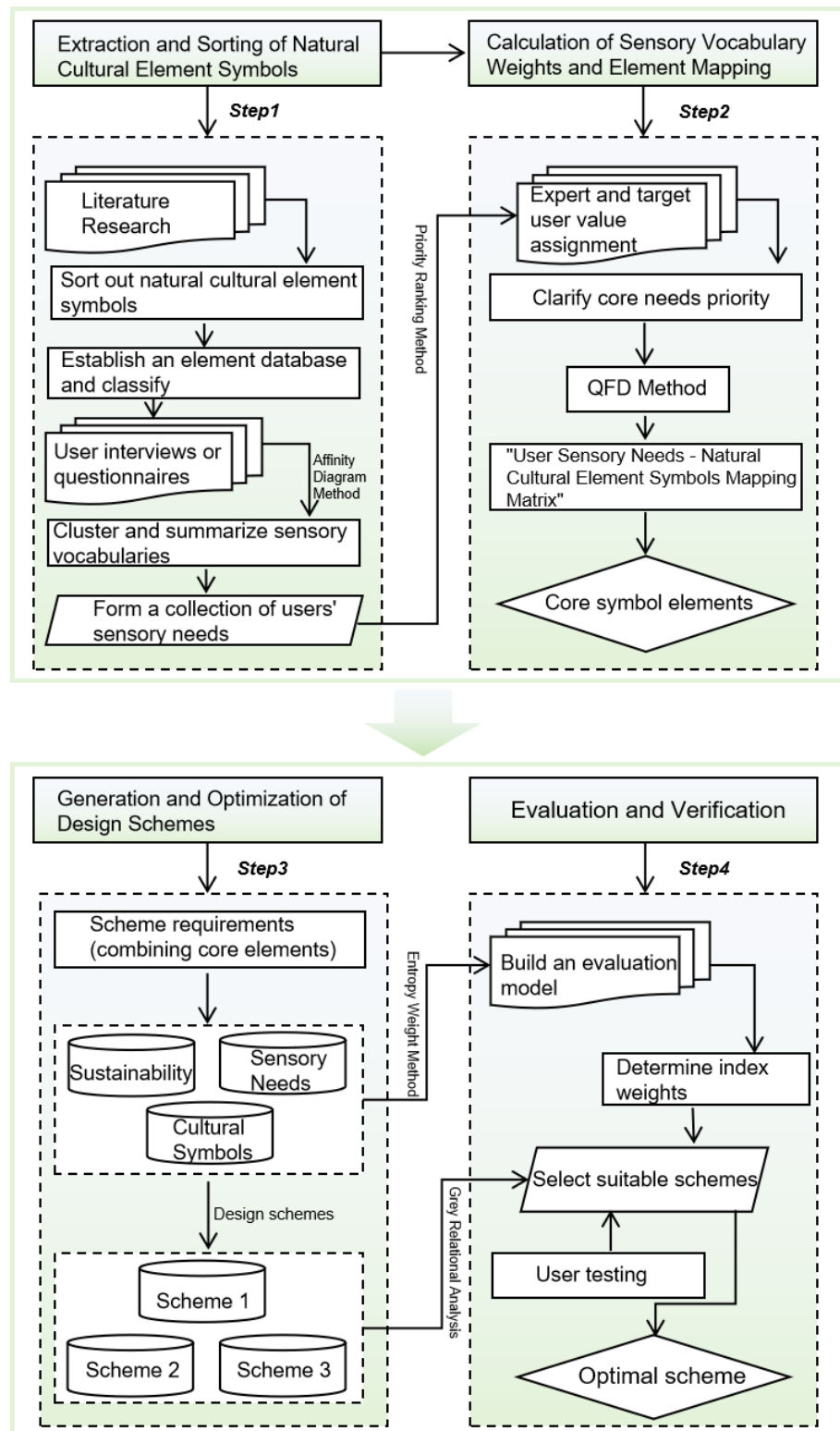


Fig. 1. Research framework diagram

- A literature review was conducted to organize natural cultural element symbols, establishing an element library and classification. User perceptual descriptive words for wooden jewelry were collected, and the Affinity Diagram method was applied for clustering and induction, forming a set of user perceptual needs.
- Based on this set of perceptual needs, the ORA method was applied, with design experts and target users ranking and assigning importance values to the indicators, thereby quantifying need priority. Combined with the QFD method, a mapping matrix between perceptual words and natural cultural element symbols was constructed to screen highly matching elements and determine core design symbols.
- Using the selected core elements, three differentiated wooden jewelry design proposals were developed, incorporating wooden materials. These proposals were required to satisfy cultural symbol accuracy, alignment with user perceptual needs, and sustainability indicators.
- An evaluation model was constructed using the EW Method, determining indicator weights through expert scoring and objective data collection. GRA was then employed to comprehensively score the three proposals, calculating the correlation degree of each proposal to the ideal solution and identifying the optimal design. Finally, a small-scale user scoring session was conducted, with results presented in a radar chart to validate the market adaptability of the design, thereby forming a generalizable wooden jewelry design methodology.

Affinity Diagram Method

The Affinity Diagram method is a qualitative analysis approach primarily used to synthesize the overall meaning of diverse issues (Lucero 2015). From the user perspective, it not only can summarize existing jewelry, but it also can generate new functional requirements based on interviewees' ideas, making it highly suitable for exploring users' perceptual needs regarding wooden jewelry. The basic procedure consists of four steps: identify interviewees, collect data, organize and cluster, and determine core needs.

(i) *Identification of interviewees*: A total of 20 interviewees were selected, including 10 females and 10 males aged 20 to 45. The participants consisted mainly of students, teachers, jewelry designers, and cultural researchers.

(ii) *Data collection*: Interviews and questionnaires focused on users' perceptual descriptions of wooden jewelry. Each description was recorded sentence by sentence on individual cards. Redundant or vague expressions were eliminated, while substantively meaningful descriptions were retained.

(iii) *Organization and clustering*: Researchers collaboratively grouped cards with similar semantics or related themes into clusters.

(iv) *Determination of core needs*: Each cluster was labeled with a theme, and the number of descriptions within each cluster was counted. The themes with the highest counts were identified as the core perceptual needs for wooden jewelry in this study.

Ordinal Relation Analysis Method

The ORA method is a subjective weighting approach used to determine indicator weights. It simplifies the weight calculation process by relying on ordered comparisons of indicator importance provided by experts or decision makers, and is suitable for quantifying the priority of user perceptual needs for wooden jewelry in this study.

(i) *Determination of the ordinal relation*: For N evaluation indicators $y_1, y_2, y_3, \dots, y_n$, if M experts rank them, the most important indicator is denoted as x_1 , the second most important x_2 , and so forth, resulting in the ordinal relation: $x_1 > x_2 > x_3 > \dots > x_m$.

(ii) *Determination of the ratio judgment between adjacent indicators*: Experts provide judgments on the relative importance between indicator $x_{(k)}$ and $x_{(k+1)}$. The ratio is expressed as: $r_k = w_k / w_{k+1}$, $k=1, 2, \dots, m-1$, where r_k represents the relative importance. Common assignments for r_k are listed in Table 1.

Table 1. The r_k Assignment Reference Table

r_k	Assignment Description
1.0	The former indicator is equally important as the latter one
1.2	The former indicator is slightly more important than the latter one
1.4	The former indicator is obviously more important than the latter one
1.6	The former indicator is significantly more important than the latter one
1.8	The former indicator is extremely more important than the latter one

Based on the ordinal relation, $w_k \geq w_{k+1}$, and it follows that $r_k \geq \frac{1}{r_{k+1}}$, $k=1, 2, \dots, m-1$.

(iii) *Calculation of weight coefficients*: Based on Step 2, the weight of the last indicator x_m in the ordinal relation is calculated using Eq. 1:

$$w_m = (1 + \sum_{k=1}^{m-1} \prod_{i=k}^{m-1} r_i)^{-1} \quad (1)$$

Then, the weight of indicator x_k preceding x_m in the sequence is:

$$w_k = r_k w_{k+1}, \quad k = m-1, m-2, \dots, 1 \quad (2)$$

QFD Method

The QFD method is a systematic product development approach, with its core tool being the House of Quality, as shown in Fig. 2 (Hu *et al.* 2024). In this study, QFD was applied to establish correlations between user perceptual needs for wooden jewelry and natural cultural symbol elements, thereby screening core design elements. The specific steps involved are as follows:

(i) *Construction of a matrix between emotional words and natural cultural symbol elements*: A matrix was built using the collected core perceptual vocabulary and the extracted natural cultural symbols. A group of experts was invited to assign values representing the degree of relevance between each emotional word and each natural cultural element, thus establishing a mapping relationship.

(ii) *Determination of the correlation degree between perceptual words and natural cultural symbol elements*: The core perceptual word weights (M_k) obtained from ORA were entered into the matrix as user weights. Rows represented natural cultural symbols, and columns represented core perceptual words. An expert panel then assessed the strength of correlation between each perceptual word and each symbol, forming a decision framework. Let the core perceptual word set be $Z = \{Z_1, Z_2, \dots, Z_n\}$, and $Y = \{Y_1, Y_2, \dots, Y_m\}$. In this

expression, Z represents perceptual words and Y represents natural cultural symbols. The mapping matrix M_{ZY} is defined as,

$$M_{ZY} = \begin{bmatrix} M_{11} & M_{12} & \cdots & M_{1d} \\ M_{21} & M_{22} & \cdots & M_{2d} \\ \vdots & \vdots & \ddots & \vdots \\ M_{n1} & M_{n2} & \cdots & M_{nd} \end{bmatrix} \quad (3)$$

where M_{ZY} denotes the correlation score between perceptual word Z_n and natural cultural symbol Y_d . The weighted score is calculated as,

$$V_{ri} = \sum_{i=1}^n (M_{Zi} \times M_{ZY}) \quad (4)$$

where V_{ri} is the weighted score of element T_i ; M_{Zi} is the weight of perceptual vocabulary obtained from ORA; and M_{ZY} is the correlation between perceptual vocabulary Z_n ; and natural cultural element Y_m .

(iii) *Calculation of the relative weights of natural cultural symbol elements*: The relative weight is expressed as,

$$w'_j = \frac{V_{ri}}{\sum_{k=1}^n I_k} \quad (5)$$

where w'_j is the relative weight of the natural cultural symbol element, V_{ri} is the importance score of the element, and k is the element index.

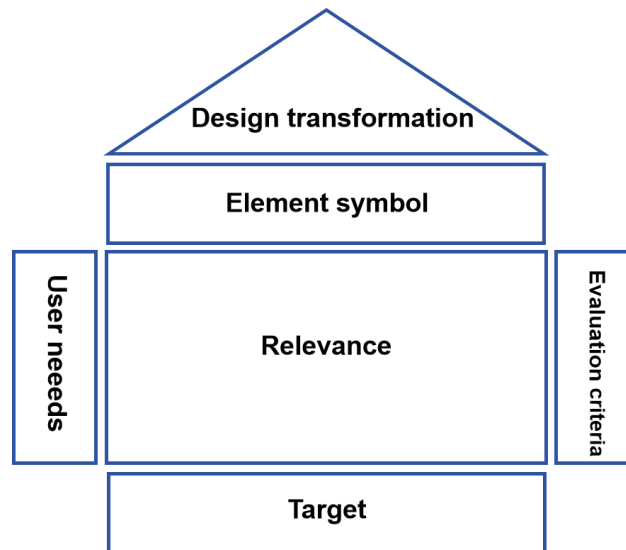


Fig. 2. House of Quality

Entropy Weight Method

The EW method (Zhong *et al.* 2023) determines the degree of influence of an indicator in a comprehensive evaluation by assessing its dispersion degree based on the amount of information. The analysis steps are as follows:

(i) *Calculation of the entropy value for each indicator*:

$$E_j = -K \sum_{i=1}^m b_{ij} \ln b_{ij} \quad (6)$$

In Eq. 6, $K = (\ln m)^{-1}$; E_j is the entropy value of indicator $j = 1, \dots, m$; and b_{ij} represents the element in row i , column j of the standardized.

(ii) *Calculation of the deviation degree for each indicator:*

$$d_j = 1 - E_j \quad (7)$$

In Eq. 7, d_j is the deviation degree of indicator $j = 1, \dots, m$.

(iii) *Calculation of the information weight:*

$$u_j = \frac{d_j}{\sum_{j=1}^m d_j} \quad (8)$$

In Eq. 8, u_j is the information weight of indicator $j = 1, \dots, m$.

Grey Relational Analysis Method

The GRA (Wang *et al.* 2016) evaluates the degree of correlation between data sequences by comparing the geometric similarity of their curves. The closer the curves, the higher the correlation. The basic steps are as follows:

(i) *Determination of the reference sequence and comparison sequences*

The reference sequence represents the desired standard, while the comparison sequences represent the indicator values of each alternative design,

$$X_{0j} = \{x_{01}, x_{02}, \dots, x_{0j}\}, X_{ij} = \{x_{i1}, x_{i2}, \dots, x_{ij}\} \quad (9)$$

where X_{0j} is the reference sequence; X_{ij} is the comparison sequence for alternative $i = 1, 2, \dots, q$; and j denotes the number of indicators $j = 1, 2, \dots, r$.

(ii) *Normalization*

To eliminate the influence of different measurement units, the data were normalized before analysis. Depending on the indicator type, various normalization methods were applied, such as larger the better, smaller the better, or nominal the best, thereby producing dimensionless sequences.

(iii) *Calculation of the Grey Relational Coefficient*

The relational coefficient was calculated as,

$$\zeta_{ij} = \frac{\min_i \min_j |x'_{0j} - x'_{ij}| + \rho \max_i \max_j |x'_{0j} - x'_{ij}|}{|x'_{0j} - x'_{ij}| + \rho \max_i \max_j |x'_{0j} - x'_{ij}|} \quad (10)$$

where ζ_{ij} is the relational coefficient; ρ is the distinguishing coefficient (commonly set to 0.5); x'_{0j} denotes the j -th indicator value of the optimal scheme after normalization; and x'_{ij} denotes the j -th indicator value of alternative i after normalization.

(iv) *Calculation of the Grey Relational Grade and Rank*

The grey relational grade was calculated as:

$$r_{ij} = \sum_{j=1}^r \varepsilon_j \zeta_{ij} \quad (11)$$

where r_i represents the grey relational grade of alternative i , and ε_j is the comprehensive weight of indicator j .

CASE STUDY

Element Organization and Perceptual Word Screening

The organization of natural cultural symbol elements followed the core logic of progressing from natural prototypes, through cultural connotations, to design adaptability. Considering the material characteristics of wooden jewelry, symbols with cultural significance and strong adaptability were selected from three natural categories: plants, animals, and geographical or astronomical phenomena. Through literature research and field investigation, the researchers further organized these symbols into 12 subcategories (Fig. 3): leaf and vine (A1), flower (A2), fruit and seed (A3), tree branch (A4), domestic and companion animal (B1), bird and fowl (B2), insect (B3), aquatic organism (B4), landform (C1), water body (C2), meteorological and celestial phenomenon (C3), and universe and celestial body (C4). These elements align with the global cultural context, as they stem from humans’ shared natural experiences. Plant-related elements (leaves, vines, flowers, *etc.*) symbolize vitality and reproduction; animal-related ones (birds, beasts, insects, fish, *etc.*) embody virtues and aspirations; geographical and astronomical elements (landforms, celestial bodies, *etc.*) relate to survival and awe. They are common carriers for cultures worldwide to interpret life and nature, free of cross-regional cognitive barriers, forming the foundation of universally accepted cultural symbols.

Category	Plant (A)		Animal (B)		Geographical and Astronomical Phenomenon (C)	
Legend						
Nmbering	A1	A2	B1	B3	C1	C2
Legend						
Numbering	A3	A4	B3	B4	C3	C4

Fig. 3. Symbol classification of natural-cultural elements

The organization of natural cultural symbol elements followed the core logic of progressing from natural prototypes, through cultural connotations, to design adaptability. Considering the material characteristics of wooden jewelry, symbols with cultural significance and strong adaptability were selected from three natural categories: plants, animals, and geographical or astronomical phenomena. Through literature research and field investigation, the researchers further organized these symbols into 12 subcategories (Fig. 3): leaf and vine (A1), flower (A2), fruit and seed (A3), tree branch (A4), domestic and companion animal (B1), bird and fowl (B2), insect (B3), aquatic organism (B4), landform (C1), water body (C2), meteorological and celestial phenomenon (C3), and universe and celestial body (C4).

Table 2. Perceptual Word Classification

No.	Core Perceptual Word	Valid Perceptual Words
D1	Warm and smooth	Soft, Warm and slippery, Skin-friendly
D2	Textured	Clear, Intertwined
D3	Healing	Relaxing, Soothing, Pleasing
D4	Nature-friendly	Close to nature, Wild
D5	Primitive and simple	Traditional, Elegant, Nostalgic
D6	Comfortable	Fit, Lightweight, Wearable, Unrestrained
D7	Tough	Wear-resistant, Anti-deformation, Durable
D8	Environmentally friendly	Degradable, Ecological, Low-consumption, Pollution-free

To quantify the importance of the core Kansei vocabulary and clarify the priority of each design dimension, the ORA method was applied to calculate the indicator weights. According to Eqs. 1 to 2, the weight values of the indicators were obtained (Table 3).

Table 3. Indicator Weight Values

Core Perceptual Word	Indicator Weight
Warm and smooth (D1)	0.3292
Textured (D2)	0.2058
Healing (D3)	0.1470
Nature-friendly (D4)	0.1225
Primitive and simple (D5)	0.0680
Comfortable (D6)	0.0567
Tough (D7)	0.0354
Environmentally friendly (D8)	0.0354

By arranging the weights of the core Kansei vocabulary in descending order, the ranking was obtained as follows: warm and smooth (D1), textured (D2), healing (D3), nature friendly (D4), primitive and simple (D5), comfortable (D6), tough (D7), and environmentally friendly (D8). This ranking serves as a reference for wooden jewelry design in this study.

QFD Method for Indicator Calculation

The natural cultural element symbol indicators and core perceptual word weights were entered into the corresponding positions of the House of Quality (HOQ). The correlations between perceptual words and natural cultural symbols were then analyzed and determined. Referring to the score–symbol correspondence in Table 4, the results were placed into the HOQ (Wen *et al.* 2025). In the HOQ, the roof uses “+” and “–” to indicate positive or negative relationships between indicators, while the basement calculates the absolute and relative weights of the natural cultural symbols using Eqs. 3 to 5. The final HOQ constructed through QFD is presented in Fig. 4. Analysis of the basement results highlights the relative importance of natural cultural symbols in wooden jewelry design.

Table 4. Correspondence Assignment for Core Perceptual Words and Natural-Cultural Element Symbols

Correlation Strength	Strong Correlation	Moderate Correlation	Weak Correlation	No Correlation
Symbol				
Score	1.5	1.2	1	0

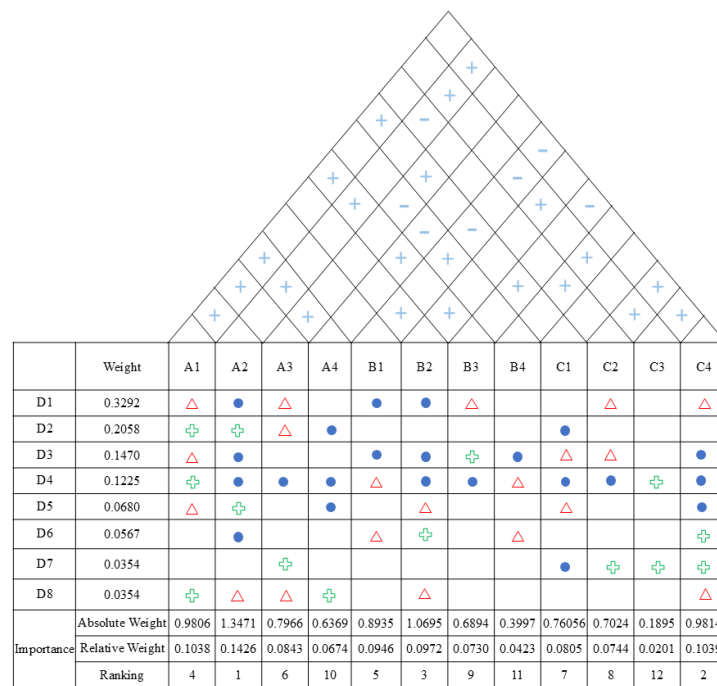


Fig. 4. Weight relationship between core perceptual words and natural-cultural element symbols

After ranking the relative weights of the natural cultural symbol elements in descending order, it was concluded that flowers (A2), birds and fowls (B2), and universe and celestial bodies (C4) hold higher importance. This indicates that experts considered these three categories of symbols to be more representative of the core Kansei vocabulary and thus more suitable for wooden jewelry design. Designers are therefore encouraged to give priority to these elements when developing new designs.

Design Practice

Guided by the core perceptual words and natural cultural element symbol weights obtained through ORA and QFD, three wooden jewelry design proposals were developed (Fig. 5).

Proposal 1 (F1): Openable flower bud wooden bracelet.

This bracelet takes the entwined form of rose branches and a half open bud as its prototype. Its core feature is a movable structure that creates a dynamic effect of “the flower moving with the wrist,” balancing sustainability with practicality.

- **Materials:** The main body uses FSC certified cherry wood branch scraps; the bud is made from recycled walnut wood; the connecting axle is industrially composable PLA plastic. FSC-certified cherry wood scraps and recycled walnut wood are first subjected to vacuum drying, then impregnated with food-grade beeswax (for waterproofing and anti-corrosion) and natural camphor oil (for mothproofing);
- **Form:** The bracelet body is carved with spiral rose vines; two openable buds employ an elastic mortise and tenon structure; the circumference is micro adjustable; the inner side fits closely to the wrist.

- Craft: The wood is polished only with beeswax, retaining a natural fragrance; the bud opening and closing adapts to different scenarios.
- Sustainability highlights: Increased material utilization; the PLA axle is bio-based; the openable structure extends user interest; wood can naturally degrade after disposal, metaphorically representing the life cycle of “blooming and withering.”

Proposal 2 (F2): Modular feather wing wooden bracelet.

This bracelet is inspired by the radial veins of bird feathers and the arc of wing flapping. It adopts the characteristic overlapping arrangement of feathers, recreating the dynamic sense of fluttering wings through six rotatable pine wood feather modules. A titanium alloy connecting axle ensures smooth rotation, combining dynamic qualities with sustainable principles.

- Materials: The main body consists of six symmetrical feather wing modules made from fast-growing pine wood; the connecting axle is recycled titanium alloy. The pine wood had undergone vacuum drying to stabilize dimensions, followed by coating with a beeswax-pine resin composite—beeswax enhances water resistance and anti-corrosion, while pine resin reinforces structural stability to avoid deformation and repels pests.
- Form: Each feather wing is carved with radial veins; three modules form one symmetric ring group; the circumference is micro adjustable; the edges feature gradually thinning feather tips.
- Surface: The item is polished with beeswax mixed with pine resin, retaining a pine scent; modules are rotatable, creating dynamic movement that adapts to daily actions.
- Sustainability highlights: Pine wood is sourced from thinned forests; the titanium alloy axle is fully recyclable; modular design allows replacement of damaged parts; the rotating structure extends the wearing cycle, ensuring durability for long term use.

Proposal 3 (F3): Biodegradable star ring wooden bracelet

This bracelet draws inspiration from lunar phase changes, abstracting cosmic imagery of orbiting star tracks. It recreates a dynamic effect of “the moon moving with the wrist” through an interactive structure, employing biodegradable materials to form a closed loop of the product lifecycle, echoing concepts of cosmic permanence and sustainable cycles.

- Materials: The main body is a linden wood ring; the surface is inlaid with biodegradable PLA strips simulating star tracks; the inner side is lined with plantable paper containing cosmos seeds. Linden wood is treated with low-temperature drying to maintain material integrity and prevent deformation, then impregnated with natural plant tannin (which imparts anti-corrosion and mild mothproofing properties) and surface-polished with food-grade beeswax to further improve waterproofing.
- Form: The bracelet exterior is carved with lunar phase outlines and micro dimples; a cotton linen elastic cord enables opening and closing.
- Craft: Linden wood is hand polished for a fine touch; the low proportion of PLA favors biodegradability; lunar phase patterns serve as time markers.

- Sustainability highlights: All components are bio-based; seed paper can cultivate flowers after disposal; hand polishing reduces energy consumption; the lightweight and simple form matches a variety of clothing styles, enhancing daily wearability.



Fig. 5. Wooden jewelry design proposals

Sustainability Evaluation Index System Construction and Entropy Weight Assignment

To ensure a scientific and fair sustainability evaluation of the three wooden jewelry designs, the Affinity Diagram method was applied to organize and summarize sustainability evaluation indicators, thereby constructing a rational index system (Wen *et al.* 2025). This system provided a theoretical basis for subsequent weight calculation and proposal evaluation. The specific steps were as follows:

First, literature and industry standards related to jewelry design and sustainable design were reviewed to identify common sustainability indicators for wooden jewelry. The collected indicator content was converted into visual cards, each containing one independent information point (for example, “Use of raw wood?”, “Low energy process?”). In total, 33 cards were produced for cluster analysis.

Second, an expert panel discussion was organized, involving four graduate students with research backgrounds in jewelry design. The panel classified and summarized the card content, clustering them into groups based on content relevance. After multiple rounds of refinement, a sustainability evaluation system was established, comprising five first level indicators, further subdivided into 15 second level indicators (Fig. 6).

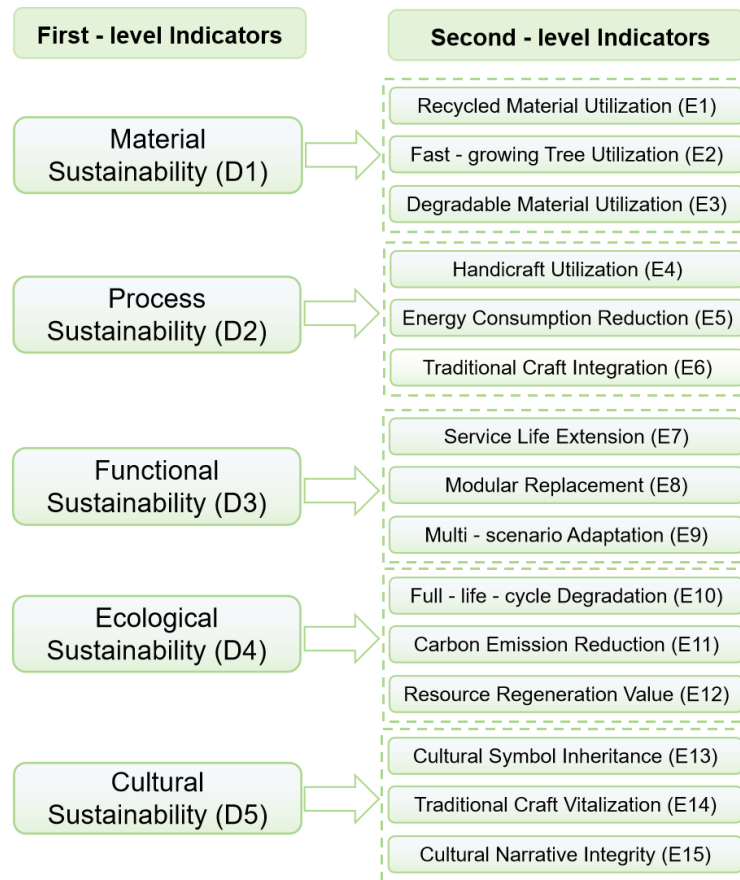


Fig. 6. Sustainability evaluation index system schematic

Ten experts (five jewelry designers and five user experience specialists) were then invited to score the comprehensive performance of the three wooden jewelry design proposals against the sustainability evaluation indicators using a scale from 1 to 10. The results were used to construct an evaluation matrix (Table 6). Applying the Entropy Weight (EW) method and using Eqs. 6 to 8, the weight values for the sustainability evaluation indicators were obtained (Table 7).

Table 6. Evaluation Matrix

1st-Level Ind	2nd-Level Ind	F1	F2	F3
D1	E1	5.8	7.3	9.2
	E2	8.3	6.9	5.7
	E3	6.1	8.7	9.5
D2	E4	7.9	9.3	6.5
	E5	5.2	8.4	9.1
	E6	9.4	7.6	6.8
D3	E7	8.1	6.3	9.3
	E8	7.3	9.1	6.2
	E9	6.5	8.5	9.4
D4	E10	8.6	6.7	9.6
	E11	5.9	8.8	9.4
	E12	8.2	6.4	9.5
D5	E13	9.1	7.5	6.3
	E14	7.7	9.4	5.9
	E15	8.4	6.2	9.3

Table 7. Sustainability Evaluation Indicator Weight Values

1st-Level Indicator	2nd-Level Indicator	Indicator Weight
D1	E1	0.070
	E2	0.069
	E3	0.061
D2	E4	0.067
	E5	0.060
	E6	0.080
D3	E7	0.064
	E8	0.074
	E9	0.062
D4	E10	0.063
	E11	0.060
	E12	0.064
D5	E13	0.071
	E14	0.067
	E15	0.062

Grey Relational Analysis for Proposal Selection

According to the GRA theory, the maximum value of each indicator was taken as the reference sequence, and the weighted scores of the three design schemes were regarded as the characteristic sequences (Table 8). The relational coefficient of each indicator was then calculated using Eqs. 9 to 11 (Table 9), and the relational degrees of the three schemes were obtained (Table 10).

Table 8. Weighted Evaluation Matrix

2nd-Level Indicator	Reference Sequence	F1	F2	F3
E1	0.6440	0.4060	0.5110	0.6440
E2	0.5727	0.5727	0.4761	0.3933
E3	0.5795	0.3721	0.5307	0.5795
E4	0.4355	0.5293	0.6231	0.4355
E5	0.5460	0.3120	0.5040	0.5460
E6	0.7520	0.7520	0.6080	0.5440
E7	0.5952	0.5184	0.4032	0.5952
E8	0.6734	0.5402	0.6734	0.4588
E9	0.5828	0.4030	0.5270	0.5828
E10	0.6048	0.5418	0.4221	0.6048
E11	0.5640	0.3540	0.5280	0.5640
E12	0.6080	0.5248	0.4096	0.6080
E13	0.6461	0.6461	0.5325	0.4473
E14	0.6298	0.5159	0.6298	0.3953
E15	0.5766	0.5208	0.3844	0.5766

The analysis results in Table 10 show that Scheme 2 (F2) achieved the highest grey relational degree. It was closer to the reference sequence in the dimensions of material sustainability (E1, E2), process sustainability (E5, E6), functional sustainability (E9), ecological sustainability (E11), and cultural sustainability (E13), indicating that this design scheme best met the sustainability goals.

Table 9. Grey Relational Coefficients

2nd-Level Indicator	$\zeta(F1)$	$\zeta(F2)$	$\zeta(F3)$
E1	0.514	0.794	0.680
E2	0.598	0.943	0.568
E3	0.558	0.857	0.706
E4	0.450	0.358	0.772
E5	0.490	0.846	0.720
E6	0.526	0.813	0.550
E7	0.906	0.570	0.699
E8	0.915	0.613	0.517
E9	0.636	0.895	0.704
E10	0.817	0.598	0.695
E11	0.546	0.802	0.712
E12	0.934	0.559	0.694
E13	0.566	0.900	0.543
E14	1.000	0.631	0.473
E15	0.805	0.564	0.707

Table 10. Grey Relational Degrees of Design Schemes

Evaluation Item	Relational Degree	Ranking
F1	0.684	2
F2	0.716	1
F3	0.649	3

Table 11. Demographic Characteristics of 40 User Testing Participants

Demographic Dimension	Specific Category	Number	Proportion (%)
Gender	Male	18	45.0
	Female	22	55.0
Age Group	20 to 25 years old	15	37.5
	26 to 35 years old	14	35.0
	36 to 45 years old	11	27.5
Educational Background	Bachelor's degree	23	57.5
	Master's degree and above	12	30.0
	College degree and below	5	12.5
Occupational Type	Jewelry industry practitioners (designers/craftsmen)	8	20.0
	Cultural and creative industry practitioners	7	17.5
	College students (design/art-related majors)	10	25.0
	Ordinary consumers (jewelry enthusiasts)	12	30.0
	Others (education, finance fields)	3	7.5
Jewelry Purchase Frequency	1 to 2 times per year	19	47.5
	3 to 5 times per year	11	27.5
	More than 5 times per year	5	12.5
	Rarely purchase (less than 1 time per year)	5	12.5

Design Feedback and Evaluation

To verify user acceptance of the design scheme (F2) that best met the sustainability goals, this study invited forty participants, including jewelry enthusiasts, consumers, and

experts, to conduct a comprehensive evaluation. The detailed demographic characteristics of the 40 participants are shown in Table 11. The evaluation covered five dimensions: material sustainability acceptance, process sustainability acceptance, functional sustainability acceptance, ecological sustainability acceptance, and cultural sustainability acceptance.

A five point Likert scale was used, with a scoring range of 1 to 5 for each indicator, where 1 represented “very unacceptable” and 5 represented “very acceptable.” The collected feedback data were statistically analyzed, the average score of each indicator was calculated, and the results were presented in a radar chart as shown in Fig. 7 (Qin *et al.* 2025).



Fig. 7. User acceptance radar chart

The evaluation results indicated that respondents had a relatively high overall acceptance of Scheme F2, with average scores above 3.8 across all five indicators. This not only verified the practical feasibility of the design but also provided strong data support for the optimization and future promotion of similar designs. The positive feedback from participants further confirmed the effectiveness of the design direction and contributed valuable practical insights for sustainable wooden jewelry design.

CONCLUSIONS

1. This study established a comprehensive symbol library of natural–cultural elements for wooden jewelry and, through Kansei Engineering methods, identified eight core perceptual needs such as warm and smooth, textured, and healing. By applying the Ordinal Relation Analysis and QFD, the study achieved a systematic mapping between user perceptual requirements and symbolic elements, thereby providing a structured pathway for element selection and transformation in sustainable jewelry design.
2. Guided by the prioritized perceptual needs and symbol weights, three wooden jewelry design proposals were developed. The evaluation combining the Entropy Weight Method and Grey Relational Analysis demonstrated that the modular feather-wing bracelet (F2) performed best across multiple dimensions, including material

sustainability, process sustainability, functional sustainability, ecological sustainability, and cultural sustainability.

3. User testing further confirmed the effectiveness of this approach: respondents rated the F2 design with an average score above 3.8 across all five sustainability dimensions, verifying its practical feasibility and market acceptance. These results demonstrate that the proposed framework effectively enhances both cultural expression and sustainability performance in wooden jewelry design.

ACKNOWLEDGEMENTS

The authors thank all participants and experts for their valuable contributions to user studies and evaluation. Institutional support from the School of Institute of Natural Culture, China University of Geosciences (Beijing), is gratefully acknowledged. To ensure transparency, the authors state that ChatGPT (OpenAI) was used only for English translation and language polishing, while all research design, data analysis, and conclusions are the independent work of the authors.

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Article submitted: August 29, 2025; Peer review completed: October 25, 2025; Revised version received: November 11, 2025; Accepted: November 12, 2025; Published: November 24, 2025.

DOI: 10.15376/biores.21.1.439-458