Comprehensive Evaluation of Outdoor Furniture Design Using the SD–AHP–GRA Method

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Amid the rise of the experience economy, the integration of perceptual experiences into outdoor furniture evaluation was identified as a critical requirement. An integrated SD–AHP–GRA model, combining Semantic Differential (SD), Analytic Hierarchy Process (AHP), and Grey Relational Analysis (GRA), was employed. User emotional needs through semantic analysis were quantified, and the design elements were determined by expert assessments. The results showed that three core design dimensions, namely functionality, aesthetics, and interactive experience, were identified using the AHP method. Three design schemes were comparatively assessed using AHP–GRA, with Scheme B confirmed as optimal (weighted correlation: 0.873). The AHP–GRA composite model, which combines expert weights with grey relational analysis to reduce the subjectivity and uncertainty inherent in AHP weighting, highlighted excellence in high-weight attributes of outdoor furniture design, demonstrating its superiority in balancing multidimensional criteria. Overall, the SD–AHP–GRA method was validated as a means to resolve conflicts between subjective preferences and engineering constraints in outdoor furniture design.

DOI: 10.15376/biores.21.1.750-769

Keywords: Outdoor furniture design; Semantic differential; Analytic hierarchy process; Grey relational analysis

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INTRODUCTION

In the context of the evolving global economy, the "experience economy" has emerged following the agricultural, industrial, and service economies (Chang 2018). Different from previous economic forms, consumer-centered, personalized experiences, and subjective satisfaction are emphasized in the "experience economy" (Godovykh and Tasci 2020; Tanrikulu 2021). In this era, outdoor furniture, as a component of urban spaces, has received increased attention due to its excellent functionality and emotional value. Especially in the post-COVID-19 pandemic period, people are more willing to go outdoors, which increases the chances of purchasing and using outdoor furniture (Marwah *et al.* 2024). However, the research on the design of outdoor furniture is relatively limited compared to that of indoor furniture. It is necessary to conduct a multi-dimensional evaluation study on outdoor furniture design, including user experience, functionality, and aesthetics.

Evaluation studies on furniture design have shifted from the original single evaluation model to the multi-dimensional evaluation model stage. The comprehensive evaluation method involves integrating multiple models, such as human factors engineering, the Kano model, fuzzy logic (FL), analytic hierarchy process (AHP), grey correlation analysis (GRA), and quality function deployment (QFD), to overcome the limitations of individual models (Wang and Yang 2023). Since a single model may be influenced by the biases of the designer and experts, the evaluation results may be inaccurate. Taifa and Desai combined the Kano model, QFD, and the Pareto principle to design a student desk that conforms to ergonomics (Taifa and Desai 2021). An integrated Kano–AHP–GRA framework has been proposed to reveal design preferences for modular children's wooden storage cabinets, providing an innovative evaluation tool for manufacturers (Zhao and Xu 2023). In open-plan office contexts, the Kano–QFD method has been used to identify specific user needs and design elements of wooden desks, improving design rationality and scientific validity (Lyu *et al.* 2022). By integrating affective ergonomics and GRA, imagery modeling of electric recliners has been evaluated using emotional word scoring and fuzzy/grey methods, highlighting the practical application of affective models in product design (Zhou *et al.* 2023). User-centered multi-criteria evaluation systems based on AHP and FAHP have been built for dining chairs, offering quantitative support for subsequent scheme optimization (Liu *et al.* 2023). These studies show that composite evaluation models enhance the comprehensiveness of design decisions and improve the applicability and competitiveness of design solutions.

In outdoor public seating, integrated methods for sustainable design have been applied at the urban community scale, illustrating a systematic route from needs identification to scheme optimization (Zhang and Sun 2024). Li combined AHP, QFD, and FBS for the evaluation of community benches in a study, first quantifying user and environmental needs through AHP, then mapping the needs through QFD, and finally optimizing the form through FBS, ultimately constructing a comprehensive sustainable design element and evaluation system (Li 2023). Although the multi-dimensional evaluation paradigm is relatively systematic for indoor furniture, research on outdoor furniture remains comparatively sparse. Additionally, some new technologies, such as AIGC, have improved design efficiency, but due to the lack of systematic integration with the evaluation index system, the output results often deviate from the core design goals. Therefore, it is necessary to propose a comprehensive evaluation method for outdoor furniture.

Semantic Differential (SD) method, as a core technical approach of Kansei Engineering, is an effective way to capture users' emotional cognition and emotional needs regarding products (Nagamachi 1995). By quantifying users' emotional demands through semantic analysis, it helps designers understand and meet the emotional expectations of different users. The Analytic Hierarchy Process is a structured decision-making tool that is adept at converting vague preferences into clear weight matrices (Saaty 1990). It has been shown to be reliable in sorting product design-related indicators. In addition, grey Relational Analysis (GRA) has unique advantages in handling multi-factor decision-making problems involving uncertain and incomplete information, such that it can effectively evaluate the comprehensive performance of multiple schemes (Deng 1989). Therefore, an integrated SD–AHP–GRA strategy for outdoor furniture design was proposed in this study, aiming to achieve functional usability, cultural value, and user experience in furniture design, ultimately presenting high-quality design works.

EXPERIMENTAL

Research Framework

A multi-dimensional comprehensive evaluation of outdoor furniture design was set as the core objective of this study. An integrated SD-AHP-GRA research framework was constructed to realize a systematic analysis from user needs to the optimization of design schemes. The technical roadmap is shown in Fig. 1.

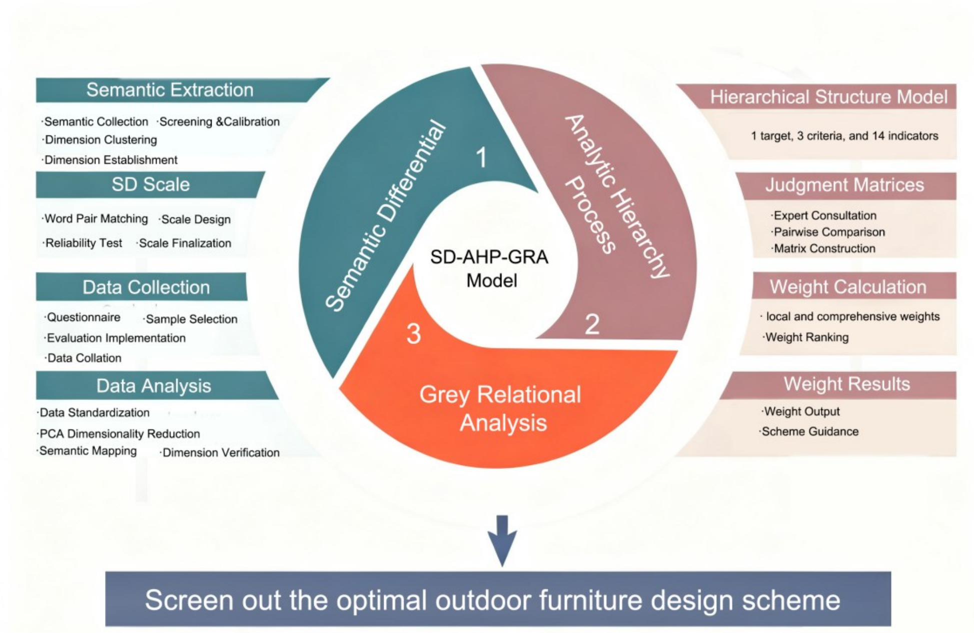

Fig. 1. Technical Roadmap of SD-AHP-GRA

Materials

The sample images used were selected from authoritative design competition platforms such as the Red Dot Award, the German Design Award, and Pentawards, as well as professional design websites including Tmall, JD.com, and Stationery Cool.

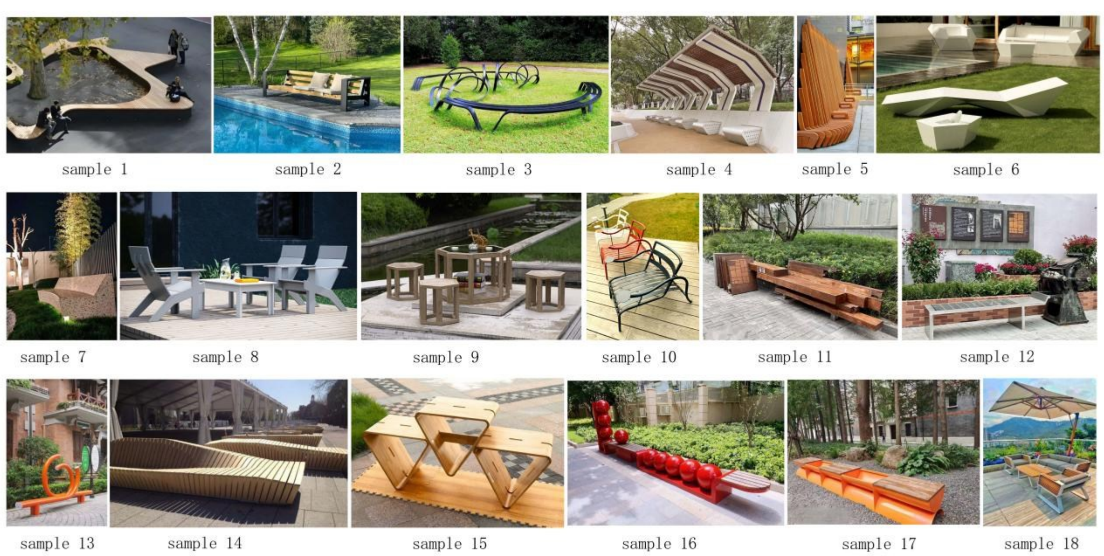

Fig. 2. Sample images of outdoor furniture

Outstanding outdoor furniture design cases with innovative features were chosen to obtain 42 sample images. Subsequently, an expert team composed of professionals in related fields such as furniture design and industrial design was formed. They conducted in-depth discussions and analyses of the samples from multiple dimensions, including design style, functional characteristics, and material application, eliminating duplicate or highly similar works and retaining unique and representative samples. Finally, 18 representative samples were selected. To avoid potential biases caused by the order effect, these sample images were randomly sorted after removing interfering elements such as brand logos, as shown in Fig. 2. To grasp the product semantic evaluation status of outdoor furniture, 5-point Likert scale questionnaire containing 16 pairs of positive and negative words was designed based on the 18 outdoor furniture sample images selected by the expert group (Cronbach 1951).

Semantic Acquisition

The Google Form (Google LLC, United States) was used to create an electronic questionnaire to focus on the sustainable design of outdoor furniture. The questionnaires were distributed through various channels such as Xiaohongshu, Wenzheng, and the design forums (Nagamachi 1995). All questionnaires were originally designed and distributed in Mandarin Chinese to ensure the accuracy of users' emotional expression. For the purpose of international publication, the questionnaire, expert discussion records, and related semantic materials have been translated into English. The translation process was reviewed by two bilingual researchers in design field to ensure consistency between the original meaning and the translated content.

Qualitative Data Analysis

The data were statistically processed based on the questionnaire results, yielding 577 original emotional semantic words. Using word frequency analysis software, the semantic words were screened in the first stage. Given that some words had ambiguous semantics, the research team adopted the Delphi Method to form an expert group for decision-making. Through two rounds of anonymous feedback and opinion convergence, semantic category review and semantic calibration were completed, and 38 high-frequency emotional words were ultimately extracted. In the second stage, experts were organized to rate the 38 high-frequency emotional words on a scale of 1 to 10, and the average value and standard deviation were calculated to reflect the degree of user consensus and cognitive differences.

Semantic Likert Scale Analysis

A total of 21 participants were invited to participate, including 4 master's students with design backgrounds, 6 undergraduate students, 5 industry experts specializing in product or furniture design, and 5 front-line furniture product developers or sales personnel from enterprises. As shown in Fig. 3, each participant rated all 18 samples, and a total of 6,048 valid rating data points were obtained. To facilitate subsequent analysis, the study calculated the average value of each sample on each semantic dimension in each group, constructed an 18 × 16 sample average rating matrix, and used it as the data basis for principal component analysis, cluster analysis, and regression modeling (Cattell 1966).

Fig. 3. Sample evaluation process

Principal Component Analysis

Principal component analysis (PCA) is the method involving normalizing data, reducing the dimensionality of the data, extracting the key principal components from large number of indicators, and thereby explaining the correlations among the indicators and the underlying latent structure. With this method, researchers can easily identify the core dimensions influencing users' evaluations of outdoor furniture.

The Min-Max standardization method was adopted to normalize the data with Eq. 1, transforming the data linearly to the interval [0,1], as follows,

$$x_{norm}=\frac{x\text{-}x_{min}}{x_{max}\text{-}x_{min}} \tag{1}$$

where x_{norm} is the original data, x_{min} is the minimum value, and x_{max} is maximum value.

The covariance matrix is used to describe the relationships between multiple features, as shown in Eq. 2,

$$\Sigma = \frac{1}{n-1}X^T X \tag{2}$$

where X is the standardized data matrix, and n is the sample quantity. By performing eigenvalue decomposition on the covariance matrix as shown in Eq. 3, the principal components were obtained,

$$\Sigma v = \lambda v \tag{3}$$

where Σ is the covariance matrix, v is the eigenvector, and λ is the eigenvalue.

AHP Analysis

To convert the semantic clustering of users' emotional needs into the criterion layer of the AHP, 15 experts in outdoor furniture design were first organized for a discussion to clarify the definition boundaries, connotations, and extensions of each factor. Based on the results of the PCA, the semantic clustering of the three core dimensions (functionality, aesthetics, interactive experience)—was further abstracted into functionality, aesthetics, and interactive experience. Referring to the specifications in the EN 581-1 (2017), ISO/TC 136 (2024), and BIFMA G1-2022 (2022) standards, it was confirmed that the evaluation of outdoor products should at least cover eight dimensions: structure, materials, safety, maintenance, cost, human factors, emotion, and aesthetics. The original emotional vocabulary semantics were transformed into term mappings, and the high-load terms from factor analysis were compared with standard terms in ISO/TC 136 (2024) and EN 581-1 (2017). Finally, 14 effective sub-criteria were determined through the 5-point Likert scale.

RESULTS AND DISCUSSION

Qualitative Data Analysis

A semantic evaluation experiment was conducted to assess the 38 high-frequency emotional words. Experts were organized to score these words on a scale from 1 to 10, and the average value and standard deviation were calculated. High-frequency sensory words for outdoor furniture are shown in Table 1.

The results of keyword frequency and semantic scoring showed that “Comfort”, with an average value of 9.7 and a very small standard deviation of 0.1, became the attribute with the highest consensus among users, indicating its stability as a core need. “Durability”, with an average value of 9.1 and a standard deviation of 0.3, also demonstrated high attention and evaluation consistency. In contrast, “Luxury” had an average value of only 1.8 and a standard deviation of 0.1, indicating generally low user interest in this attribute and convergent cognition. Meanwhile, “Retro style” had a standard deviation of 2.4, reflecting significant preference differences among users for this attribute.

In accordance with the principle of second nature in the semantic differential method, repetitive interfering terms were excluded, and ambiguous expressions were substituted with more specific adjectives. Subsequently, through antonymic pairing, a total of 16 perceptual semantic word pairs were finalized to describe the three core dimensions of sustainable design for outdoor furniture products. These word pairs were: comfortable/ uncomfortable; durable/fragile; aesthetic/ugly; cost-effective/overpriced; stable/unstable; safe/hazardous; portable/heavy; easy to clean/difficult to maintain; smooth/rough; exquisite/crude; stylish/outdated; simple/complex; warm/cold; harmonious/disharmonious; multi-functional/single-functional; and fine-textured/poorly-textured.

Average Value of Emotional Semantic Vocabulary

From the reliability analysis results, the Cronbach's α coefficient (0.939) was much higher than the standard threshold of 0.9, as shown in Table 2. This indicates that the 18 items of this scale had achieved extremely strong internal consistency. Thus, these items were able to stably and consistently measure the same trait (such as a specific psychological attitude or behavioral tendency), and respondents' scores on these items exhibited a high degree of correlation.

Results of Principal Component Analysis

KMO and Bartlett’s sphericity test results

The questionnaire survey data were subjected to principal component factor analysis using SPSS software. The results are shown in Table 3. The KMO and Bartlett’s sphericity test were used to determine whether the obtained questionnaire data were suitable for the next factor analysis. Among them, the KMO test is an indicator comparing the simple correlation coefficient matrix of variables and the partial correlation coefficient. The closer the KMO value is to 1, the more suitable the data are for factor analysis. When the value is greater than 0.9, it indicates a very suitable situation; between 0.8 and 0.9 indicates a very suitable situation; between 0.7 and 0.8 indicates a suitable situation; between 0.6 and 0.7 indicates a barely suitable situation; between 0.5 and 0.6 indicates an unsuitable situation; and below 0.5 indicates an extremely unsuitable situation. The Bartlett’s sphericity test evaluates whether the correlation matrix is significantly different from the identity matrix, indicating the presence of correlations among variables. A p-value < 0.05 suggests that the data are appropriate for factor analysis.

Table 1. High-frequency Sensory Words for Outdoor Furniture

Serial Number	Word	Average Value	Standard Deviation	Serial Number	Word	Average Value	Standard Deviation
1	Comfort	9.7	0.1	20	Softness	2.8	2.6
2	Durability	9.1	0.3	21	Vibrancy	2.8	1.1
3	Beauty	8.4	1.2	22	Coziness	2.7	1.3
4	Cost - effectiveness	8.1	0.9	23	Rusticity	2.5	1.1
5	Sturdiness	8.1	0.5	24	Sophistication	2.4	2.3
6	Safety	8.0	1.1	25	Harmony	2.3	2.2
7	Portability	7.5	1.3	26	Playfulness	2.3	0.7
8	Cleanability	7.5	1.1	27	Elegance	2.3	0.8
9	Sociability	7.1	1.3	28	Simplicity	2.3	0.6
10	Versatility	6.3	0.8	29	Warmth	2.3	0.5
11	Fluidity	5.7	1.2	30	Airiness	2.2	0.2
12	Refinement	5.2	1.9	31	Nostalgia	1.8	0.2
13	Retro style	4.8	2.4	32	Luxury	1.8	0.1
14	Minimalist style	4.6	1.6	33	Freshness	1.7	0.2
15	Light - shadow beauty	4.6	1.4	34	Stability	1.7	0.8
16	Texture	4.3	1.9	35	Intimacy	1.7	0.4
17	Spaciousness	3.9	2.0	36	Tranquility	1.4	0.3
18	Weather resistance	3.7	1.7	37	Creativity	1.4	0.3
19	Flexibility	3.2	1.6	38	Glamour	1.2	0.2

Table 2. Average Data of Likert Scale

Index	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
Comfortable	3.1	4.2	2.8	3.2	2.8	3.3	3.0	3.9	3.5	3.3	2.3	2.7	2.6	3.2	2.9	3.0	3.1	4.4
Durable	3.9	3.8	4.0	4.0	3.3	3.7	4.5	3.7	3.4	3.7	2.8	3.6	3.3	3.5	2.9	3.4	3.2	3.7
Aesthetic	2.7	3.1	2.8	2.4	3.1	2.8	2.0	2.7	3.2	2.8	2.8	2.4	2.6	2.5	3.0	2.6	2.8	2.9
Cost-effective	3.8	3.4	3.5	3.2	2.9	3.4	3.4	3.4	3.7	3.6	3.0	3.1	3.2	3.4	3.1	3.0	3.0	3.5
Stable	4.5	4.1	3.8	4.2	3.5	3.9	4.5	3.8	3.4	3.6	3.3	3.6	3.3	4.0	2.9	3.6	3.4	4.2
Safe	4.0	3.7	3.2	3.9	3.3	3.7	3.9	3.7	3.6	3.5	2.9	3.3	3	3.7	3.1	3.5	3.4	4.2
Portable	2.0	2.7	2.6	2.0	2.2	2.6	2.3	3.1	3.6	2.9	2.1	2.0	2.1	2.0	3.0	2.1	2.3	2.6
Easy to clean	3.1	3.2	3.3	2.8	2.4	4.1	4.2	3.6	3.6	3.7	2.7	3.5	3.5	2.9	3.3	3.1	2.8	2.7
Smooth	4	3.5	4.1	3.6	3.7	4.2	3.9	3.6	3.6	4.0	2.9	3.6	4.0	3.9	3.2	3.4	3.2	3.7
Delicate	3.5	3.7	3.7	3.6	3.9	4.2	3.0	3.6	3.9	3.4	2.9	3.2	3.3	3.6	3.4	3.2	3.1	4.0
Fashionable	3.9	3.9	3.8	3.6	4.1	4.2	2.9	3.6	3.7	3.8	3.0	3.0	3.5	3.6	3.6	3.5	3.1	3.9
Contracted	4.2	3.8	3.9	3.7	3.7	4.5	3.8	3.7	3.7	3.9	3	3.3	3.9	4.0	3.7	3.0	3.1	3.9
Cozy	3.5	4.2	2.6	3.2	3.6	3.4	3.1	3.4	4.1	3.0	2.8	2.7	3.0	3.5	3.5	3.1	2.8	4.2
Harmonious	4.1	4.2	3.3	3.7	3.7	3.8	3.7	3.6	4.2	3.6	3.2	3.1	3.2	4.0	3.6	3.3	3.2	4.1
multifunctional	2.8	3.2	2.7	3.6	3.2	3.1	2.8	3.2	3.7	3.3	2.3	2.7	2.6	3.1	3.3	2.6	3.2	3.7
With a delicate texture	3.3	3.4	3.0	3.4	3.4	3.5	3.3	3.1	3.7	3.1	3.0	2.8	2.7	3.6	3.4	3.0	2.9	3.9

The KMO value was 0.892, indicating a highly suitable condition for principal component analysis. This suggests that many of the variables share common factors. The p-value was less than 0.001, indicating an extremely significant result. This confirms that the 16 indicators (*e.g.*, "durability," "style," *etc.*) were not independent but had strong internal associations (*e.g.*, "durability" may correlate positively with "safety"). In summary, the data met the requirements for principal component analysis, and dimension reduction can be effectively applied to extract the core dimensions (Kaiser 1974).

Table 3. KMO and Bartlett's Sphericity Test Results

Test Indicators	Result Values	Standard Judgment
KMO	0.892	>0.6, suitable for PCA
Bartlett's Spherical Test	The chi-square statistic χ^2=3254.82, with degrees of freedom df=120, p<0.001	p<0.05, rejecting the assumption of variable independence

Stone fragment diagram

Factor analysis derived from the semantic differential method was employed in this study. The average evaluation data presented in Table 2 were used to compute the total variance explained for the initial intention indicators, with the results detailed in Table 4. A scree plot of perceptual image components was also generated using SPSS software, as illustrated in Fig. 4. By analyzing the eigenvalues associated with the component factors in the scree plot, factors with eigenvalues greater than 1 were extracted as the main components. Because the cumulative contribution rate of the first five component factors reached 82.78%, these five factors (from the data in Table 4) were selected for further discussion as the principal components. Commonly used methods for selecting principal components include Cattell's scree plot criterion and Kaiser's rule (selecting factors with eigenvalues greater than 1). The data in Table 4 show that the initial eigenvalues of the first five factors all exceeded 1, with a cumulative total variance proportion of 87.38%, which sufficiently captured the overall information contained in all factors. Furthermore, in Fig. 4, the line began to flatten from the sixth factor, further validating the selection of the first five factors as the principal components.

Table 4. Total Variance Explanation

Principal Component Number	Characteristic Value	Individual Variance Contribution Rate (%)	Cumulative Variance Contribution Rate (%)
PC1	7.25	37.124	37.124
PC2	2.86	22.212	59.336
PC3	1.92	16.825	76.161
PC4	1.35	6.615	82.776
PC5	1.08	4.598	87.375
PC6	0.82	4.112	91.487
PC7	0.57	2.569	94.056
PC8	0.37	1.68	95.736
PC9	0.2	1.577	97.313
PC10	0.11	1.209	98.522
PC11	0.05	0.651	99.173
PC12	0.03	0.399	99.573
PC13	0.01	0.274	99.846
PC14	0.003	0.147	99.993
PC15	0.001	0.007	100
PC16	0.000	0	100

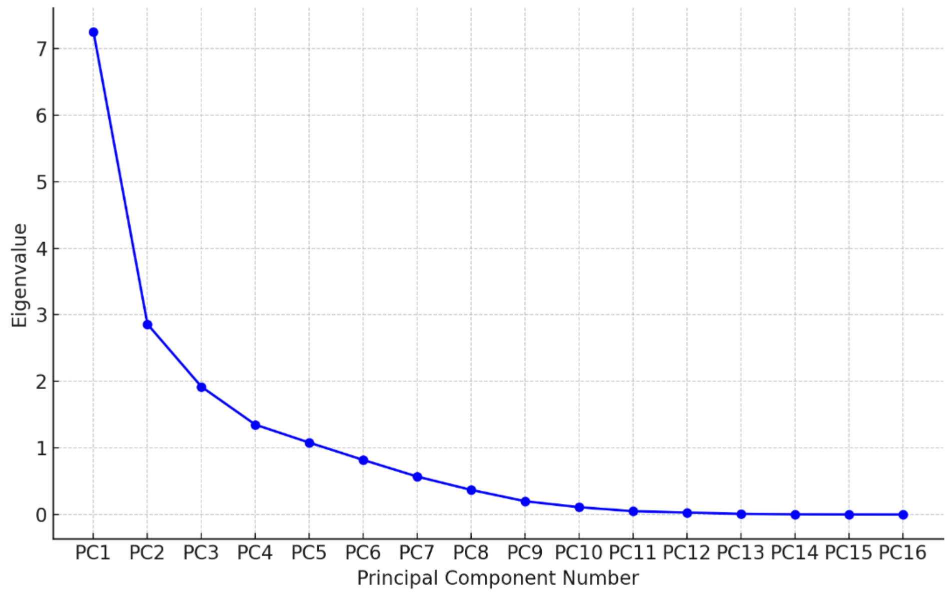

Fig. 4. Stone fragment diagram

Heatmap of PCA

The principal component factor loading heatmap is a key visualization of the PCA results. It effectively reveals the intrinsic structure of the high-dimensional perceptual evaluation data in a low-dimensional space and assists in identifying the core perceptual dimensions associated with each potential principal component.

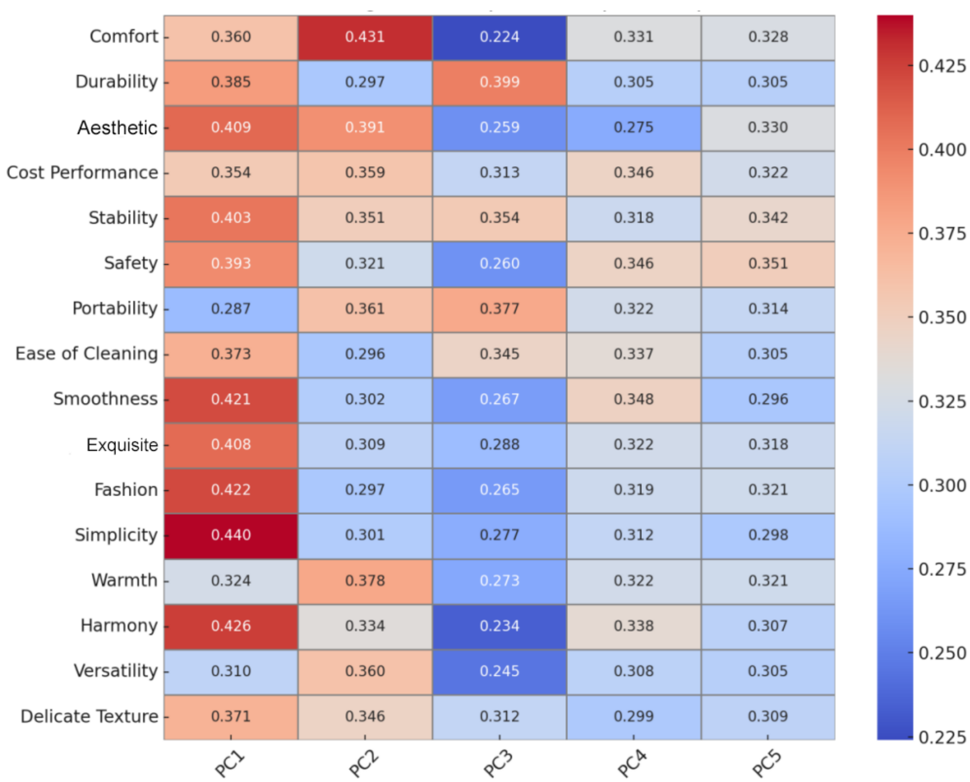

Fig. 5. Principal component factor loading heatmap

To analyze the explanatory power of each principal component for the variables and how these variables are represented within the components, a visualized factor loading heatmap was created, as shown in Fig. 5. In this heatmap, the vertical axis represents the first five principal components (PC1 to PC5), and the horizontal axis lists the 16 perceptual evaluation indicators. The color intensity indicates the factor loading coefficient of each variable within the corresponding principal component; darker shades signify higher contributions. This visualization highlights which perceptual attributes strongly influence each component and helps interpret the underlying dimensions shaping users' emotional evaluations of outdoor furniture.

Based on the visualization results of the heatmap, the five principal components (PCs) can be interpreted as follows. PC1 exhibited high loadings on variables such as "stable," "durable," "safe," and "cost-effective," indicating that this component primarily represented rational functional attributes—including structural strength, reliability, and safety in usage. PC2 showed strong loadings on "fashionable," "simple," "exquisite," and "harmonious," suggesting that it captures aspects related to aesthetic style and emotional expression, reflecting the product's visual appeal and design consistency. PC3 was heavily associated with "portable," "easy to clean," and "multi-functional," emphasizing the practicality of the furniture—ease of handling, maintenance, and functional adaptability. PC4 loaded highly on "warmth," "comfort," and "harmony," reflecting users' emotional and psychological comfort, or the perceptual-emotional dimension of the product experience. PC5 showed meaningful loadings for "fine texture," "exquisite," and "smooth," representing refinement in detail, manufacturing precision, and the user's perception of visual and tactile quality. These interpretations reveal the multidimensional perceptual structure of outdoor furniture design, as perceived by users.

Construction and feature analysis of user demand model for outdoor furniture based on PCA

Five principal components (PC1-PC5) with eigenvalues greater than 1 were initially extracted through factor analysis, with a cumulative variance contribution of 87.4%. PC5 was excluded due to its low individual variance contribution (4.6%) and the absence of significant high-load indicators. PC3 and PC4 were merged into a single dimension named "interactive experience," as both were focused on users' practical experience and emotional perception during use. Finally, the 5 initial principal components were optimized into 3 core evaluation dimensions—functionality, aesthetics, and interactive experience—through expert discussions and in combination with the actual evaluation needs of outdoor furniture design, which laid a clear foundation for the subsequent construction of the AHP evaluation system.

From Table 5 and Fig. 5, the main features of each principal component were identified as follows: PC1 was reflected in "durability, safety, and functional reliability," serving as the core functional foundation; PC2 was represented by "visual aesthetics and fashion design;" the merged PC3 and PC4 corresponded to "portability, multi-functionality, and emotional warmth," and PC5 was excluded due to its weak explanatory power. Indicators such as "harmonious" and "comfortable" exhibited medium to high loadings across multiple components, which reflected the integration of rational and emotional perceptions in users' evaluation.

Table 5. Relationship between Core Dimensions and Principal Components

Core Dimension	Corresponding Principal Component	Connotation of Principal Component	Key Demand Characteristics
Functional Baseline Dimension	PC1	Durability, safety and functional reliability	Stability, durability, safety, easy cleaning, high cost-effectiveness, comfort, structure and practical functions
Visual expression dimension	PC2	Visual aesthetics and fashion design	Fashionable sense, smooth form, exquisite details, simple style, fine texture
Expansion dimensions of functions	PC3	Portability and vulnerability	Portability, versatility, lightweight structure (with the concurrent risk of damage)
Emotional Interaction Dimension	PC4	Warm emotional experience	Warm atmosphere, friendliness, emotional connection, and the sensory perception brought by colors and materials
——	PC5 (Weak Factor)	Random factors, with low contribution degree	There are no significant high-load indicators, and the impact is weak. It can be ignored in the actual design.

Table 6. Principal Component Clustering Transformation

Semantic Clustering Dimension	Original Perceptual Vocabulary	Abstract Results of Expert Discussion	AHP Criterion Layer Definition
PC1: Functional Factor	Stable, durable, safe, easy to clean, cost-effective, comfortable.	Focuses on the basic functions of furniture such as structural stability, durability, and safety, as well as practical attributes like easy cleaning, economy, and comfort.	Functionality
PC2: Visual Factor	Smooth, fashionable, exquisite, simple, fine-textured,aesthetic.	Emphasizes the furniture's shape fluency, fashion sense, detail exquisiteness, style simplicity, and material texture, reflecting visual aesthetic needs.	Aesthetics
PC3 + PC4: Experience Factor	Portable, multi-functional, warm, *etc.*	Covers the use experience of furniture such as portability and versatility, as well as emotional interaction needs like a warm feeling.	Interactive Experience

To convert the semantic clustering of users' emotional needs into the criterion layer of the AHP, a group of 15 experts in outdoor furniture design was organized to clarify the definition boundaries, connotations, and extensions of each factor. Based on the results of principal component analysis, the semantic clustering across the three dimensions was further abstracted into three criteria of the AHP including functionality, aesthetics, and interactive experience. The specific transformation logic, which mapped perceptual vocabulary and evaluation indicators to the AHP hierarchy, is shown in Table 6.

AHP Evaluation Results

Indicator system based on AHP

Based on standards such as EN 581-1 (2017) and ISO/TC 136 (2024), and following two rounds of expert evaluation, the indicators at each level were finalized. The 8 industry dimensions were mapped and matched with the high-loading terms extracted by PCA. As a result, 14 secondary indicators were determined. Using the design decision matrix derived from principal component analysis and taking "mass-market practical furniture" as the core objective, the demand structure was quantitatively decomposed through a three-level hierarchy model established in this study. The target layer was defined as "outdoor furniture design" (coded as A), which was also the central research subject. The criterion layer included three primary indicators: functionality (B1), aesthetics (B2), and interactive experience (B3). These were further subdivided into 14 secondary indicators at the indicator layer, coded as C1 to C14, as detailed in Table 7. Based on the 16 pairs of perceptual semantic word pairs obtained from SD method, the indicators in the AHP evaluation system were derived through semantic clustering and expert consensus. 'Form Smoothness (C7)' was derived from the semantic connotation of 'smooth' in the semantic word pair 'smooth/rough', reflecting the fluency of outdoor furniture's shape lines; 'Style Simplicity (C10)' originates from the semantic meaning of 'simple' in the bipolar word pair 'simple/complex' from the SD scale. It corresponds to users' perceptual preference for concise, uncluttered design style of outdoor furniture, which is consistent with the aesthetic demand for minimalism in modern outdoor space design. 'Emotional Warmth' (C14) is derived from the 'warm/cold' word pair, focusing on the emotional resonance brought by the product's color and material.

Table 7. Framework of the AHP Model for Outdoor Furniture

Target Layer	Criterion Layer	Indicator Layer
Outdoor Furniture Design A	Functionality B1	Structural Stability C1
		Material Durability C2
		Usage Safety C3
		Maintenance Convenience C4
		Cost Performance C5
		Comfort C6
	Aesthetics B2	Form Smoothness C7
		Design Fashionability C8
		Exquisite C9
		Style Simplicity C10
		Material Texture C11
	Interactive Experience B3	Portable Flexibility C12
		Function Diversity C13
		Emotional Warmth C14

AHP indicator weights

Table 8 shows results of the weight calculation based on AHP. The prioritized order of user demands for outdoor furniture at the criterion level was as follows: functionality B1 (0.5396) > aesthetics B2 (0.2970) > interactive experience B3 (0.1634). This weight structure reflects the expert consensus that functional attributes—such as safety and structural stability—held the dominant position in sustainable design evaluation. Aesthetic factors, including smooth form and material texture, were of secondary importance but remained essential for product appeal. Experience-related aspects, such as emotional warmth and portability, had the lowest weights and served more as supporting enhancements.

Further analysis at the sub-indicator level revealed that within the functional dimension, use safety (combined weight: 0.197) and structural stability (0.139) significantly outweighed material durability, comfort, and maintenance ease—underscoring the importance of compliance with standards such as EN 581-1 (2017). In the aesthetic dimension, smooth form (0.110) and material texture (0.074) accounted for nearly three-quarters of the visual weight, emphasizing the value of refined shapes and high-quality CMF (Color, Material, Finish) in shaping first impressions. Within the interactive experience dimension, emotional warmth (0.106) ranked notably higher than portability and functional diversity, highlighting the importance of elements like soft color tones and skin-friendly materials in fostering emotional engagement.

In summary, sustainable outdoor furniture design should be grounded in 'safety – stability,' articulated through 'smoothness – texture,' and enhanced with 'warmth – portability,' to achieve multi-dimensional optimization across function, aesthetics, and emotional experience. The bar chart illustrating the comprehensive weights of C1–C14 (Fig. 6) reveals a distinct "three-step" hierarchical structure in the evaluation of outdoor furniture design. The first step includes Use Safety (C3) and Structural Stability (C1), which together accounted for over one-third of the total weight, emphasizing the fundamental importance of safety protection and structural reliability as the core foundation. The second step includes Form Smoothness (C7), Emotional Warmth (C14), Material Texture (C11), Material Durability (C2), and Comfort (C6), with weights ranging from approximately 0.06 to 0.11. These indicators collectively highlight the sensory and experiential dimensions, balancing visual form, CMF texture, and emotional resonance to help products achieve differentiation once basic functional needs are met. The third step includes Maintenance Convenience, Fashion, Portability, Exquisite, Functional Diversity, and Cost, all with weights below 0.04. Though less influential overall, these elements can be selectively optimized based on specific scenarios or user groups. Accordingly, design strategies should follow the principle of "foundation laid by safety and stability, highlighting the form, emotions, and long-tail elements as needed for refinement." This means that cost-cutting should never compromise critical attributes such as C3 and C1, while design focus should be directed toward second-step indicators to boost market appeal through form, material, and emotional touchpoints. Third-step indicators should be treated as optional upgrades to suit particular application contexts, enabling targeted investment and achieving an optimal balance of functionality, aesthetics, and user experience in outdoor furniture design. Based on the weight ranking results of the design elements for outdoor furniture, three different outdoor furniture schemes were designed using Stable diffusion, as shown in Fig. 7.

Table 8. Composite Weight Values of Outdoor Furniture Design Elements

Target Layer	Secondary Criterion Layer	Requirement Weight w	Criterion Layer Consistency CR	Tertiary Index Layer	Local Weight w*	Comprehensive Weight w·w*	Index Layer Consistency CR	Priority
Outdoor Furniture Design A	Functionality B1	0.5396	0.0079 < 0.10	C3 Usage Safety	0.3648	0.1968	0.025 < 0.10	1
				C1 Structural Stability	0.2566	0.1385		2
				C2 Material Durability	0.155	0.0836		5
				C6 Comfort	0.1154	0.0623		6
				C4 Maintenance Convenience	0.065	0.0351		10
				C5 Cost Performance	0.0433	0.0234		12
	Aesthetics B2	0.297	0.0190 < 0.10	C7 Form Smoothness	0.3718	0.1104	0.021 < 0.10	3
				C11 Material Texture	0.2156	0.064		7
				C8 Design Fashionability	0.1293	0.0384		9
				C9 Exquisite	0.0973	0.0289		11
				C10 Style Simplicity	0.0618	0.0184		14
	Interactive Experience B3	0.1634	0.0032 < 0.10	C14 Emotional Warmth	0.6483	0.1059	0.003 < 0.10	4
				C12 Portable Flexibility	0.2297	0.0375		8
				C13 Functional Diversity	0.122	0.0199		13

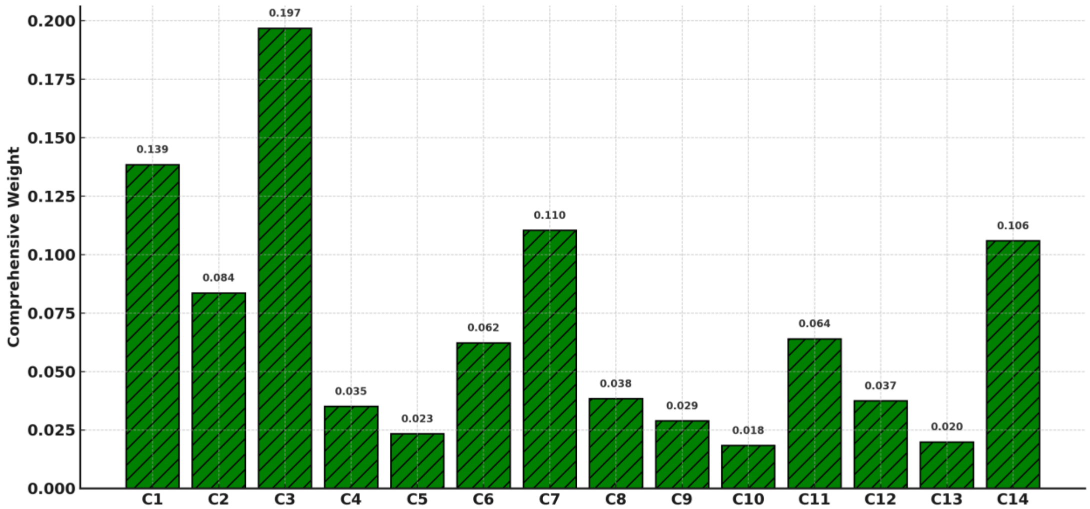

Fig. 6. Comprehensive weight bar chart of outdoor furniture indicators

Fig. 7. The design scheme based on AHP

GRA Results

To determine the degree of user satisfaction with the three design schemes, a 5-point Likert scale was used to evaluate the design elements of each scheme, with satisfaction levels rated from 1 to 5. The respondents were young users aged 20 to 40, with a male-to-female ratio of 3:2. A total of 110 questionnaires were distributed, and 61 valid responses were collected. By calculating the grey correlation degree between each design scheme and the satisfaction levels for its design elements, and then comparing these correlation values, the optimal design scheme was identified. A higher grey correlation degree value indicates greater user satisfaction with the corresponding scheme.

The average score of each design element for each of the three design schemes was calculated and compared. The maximum value for each element among the three schemes was selected to form the reference sequence $X_0 = \{X_0(n), n = 1, 2, ..., 14\}$, where $X_0(n)$ represents the maximum average score of the n^{th} design element. Meanwhile, the average scores of the 14 design elements in each scheme were used to construct the comparison sequences $X_i = \{X_i(n), n = 1, 2, ..., 14; i = 1, 2, 3\}$, where $X_i(n)$ represents the average score of the n^{th} element in the i^{th} scheme. Based on this data, an evaluation matrix was generated as the foundation for calculating the grey correlation degrees between each design scheme and the reference sequence.

Table 9. Correlation Coefficient Matrix of Design Scheme and Design Elements

No.	scheme 1	scheme 2	scheme 3
1	1	0.778	0.533
2	1	0.875	0.848
3	1	0.727	0.5
4	1	0.757	0.949
5	1	0.675	0.812
6	0.434	1	0.737
7	0.333	1	0.483
8	0.392	1	0.583
9	0.509	1	0.709
10	0.609	0.949	0.918
11	0.5	1	0.629
12	0.412	0.727	1
13	0.434	1	0.431
14	0.337	1	0.589
Average correlation degree γ_i	0.64	0.892	0.694
Sorting	3	1	2

When calculating the correlation coefficients of the judgment matrix, the process begins with computing the absolute differences between the reference sequence and each of the comparison sequences across the 14 design elements. Based on these differences, the range of the matrix sequence—*i.e.*, the maximum and minimum difference values—was determined. Using this range, the correlation coefficients between the three design schemes and the 16 design elements were then calculated, as shown in Table 9. The resulting correlation coefficient matrix was subsequently sorted to assess the relative strength of association between each scheme and the evaluated design elements.

AHP-GRA Weighted Correlation Degree Analysis

The results of the AHP and weighted grey correlation calculations are presented in Table 10. In the unweighted grey correlation analysis, where all 14 design elements were treated equally, the average correlation degrees for the three outdoor furniture schemes were as follows: Scheme B (0.892) > Scheme C (0.694) > Scheme A (0.640). This outcome indicates that Scheme B—characterized by smoothness and comfort—most closely aligned with young users' "ideal values," making it the most preferred option. Scheme C, which emphasizes emotional interaction, ranked second, largely due to its strengths in creating a warm atmosphere and offering portability. Scheme A, focused on core structural stability, ranked last due to its comparatively weaker performance in experiential elements such as form and emotional resonance.

After applying AHP-derived weights, which give greater priority to high-weight indicators such as safety protection (C3) and structural stability (C1), the ranking changed to: Scheme B (0.873) > Scheme A (0.699) > Scheme C (0.603). Scheme B retained its top position due to its strong performance across medium- to high-weight indicators such as form smoothness, comfort, and material texture. Scheme A improved to second place, benefiting from full scores in two high-weight indicators, which significantly boosted its weighted correlation degree. In contrast, Scheme C dropped to last place, as its strengths—emotional warmth and portability—fell into lower-weighted categories, reducing its overall score after weighting.

The AHP-GRA combined evaluation model demonstrated clear advantages in the multi-scheme design assessment of outdoor furniture, particularly by effectively balancing user perception with expert assessment and integrating qualitative and quantitative analysis. Through the AHP method, a subjective weight system was established for each design element, allowing high-risk factors such as safety and structural stability to be appropriately prioritized. Meanwhile, GRA quantitatively captured user perception data and calculated the closeness degree between each design scheme and the ideal reference, thereby achieving a cohesive alignment between real user experience and expert-defined priorities.

The evaluation results further validated the model's robustness: Scheme B ranked first in both unweighted and weighted analyses, highlighting its comprehensive strength in user preference and key performance indicators. Scheme A, although initially ranked third, moved up to second place after applying AHP weights—thanks to its strong performance in high-weight indicators—demonstrating the AHP method's effectiveness in elevating schemes that prioritize critical design factors.

Table 10. Weighted Correlation Degree with AHP-GRA

Code	AHP weight *wj*	Scheme 1 Correlation coefficient *ξAj*	Scheme 2 Correlation coefficient *ξBj*	Scheme 3 Correlation coefficient *ξCj*
C1	0.1385	1	0.778	0.533
C2	0.0836	1	0.875	0.848
C3	0.1968	1	0.727	0.5
C4	0.0351	1	0.757	0.949
C5	0.0234	1	0.675	0.812
C6	0.0623	0.434	1	0.737
C7	0.1104	0.333	1	0.483
C8	0.0384	0.392	1	0.583
C9	0.0289	0.509	1	0.709
C10	0.0184	0.609	0.949	0.918
C11	0.064	0.5	1	0.629
C12	0.0375	0.412	0.727	1
C13	0.0199	0.434	1	0.431
C14	0.1059	0.337	1	0.589
Average correlation degree γ_i with AHP-GRA	——	0.699	0.873	0.603
Sorting	——	2	1	3

CONCLUSIONS

1. Through the processing of qualitative data using the semantic differential (SD) method and subsequent semantic calibration, vague user requirements were effectively quantified, resulting in 16 pairs of bipolar perceptual semantic terms. Five principal components were initially extracted through factor analysis, and after subsequent screening and merging, 3 core evaluation dimensions were finally determined.
2. The analytic hierarchy process (AHP) was used to determine the hierarchical structure of user needs for outdoor furniture, with functionality prioritized over aesthetics and interactive experience. Specific indicators such as bottom-line factors and differentiation factors were clarified in terms of their weight distribution, providing a

scientific basis for design resource allocation. Simultaneously, the weighted results from AHP and grey relational analysis (GRA) minimized subjectivity, enhancing the objectivity and credibility of the analysis.

3. After evaluating three design schemes using GRA, it was found that the unweighted results reflected users' intuitive preferences, while the weighted results incorporating AHP weights emphasized the influence of professional bottom-line factors. This indicates that combining GRA with SD and AHP can balance users' perceptual preferences with industry standards, offering flexible and reliable references for decision-making.
4. The joint application of SD, AHP, and GRA methods achieved an organic integration of users' emotional demands and professional rational requirements, forming a closed-loop design process from demand acquisition to scheme optimization. The SD-AHP-GRA framework enhanced the accuracy and scientific validity of outdoor furniture design and provided a replicable methodology applicable to related product fields.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Industry-University Collaborative Education Program of the Ministry of Education of China (Grant No. 231007598091518), the Taizhou Philosophy and Social Sciences Project (Grant No. 23GHB10) and Zhejiang Provincial Graduate Student Teaching Reform Project (JGCG2024450).

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Article submitted: August 16, 2025; Peer review completed: September 18, 2025; Revised version received and accepted: October 28, 2025; Published: December 8, 2025.
DOI: 10.15376/biores.21.1.750-769