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Research on the Optimization and Selection of Table Grape Varieties

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Abstract

Table grapes are an important economic crop with a wide range of cultivars grown across temperate to subtropical regions worldwide. Because different cultivars show significant differences in attributes such as color, taste, shape, price, and seed presence, consumers often find it difficult to make trade-offs when choosing. To address this issue, this study constructed a comprehensive multi-criteria evaluation model for several common table grape cultivars based on the Analytic Hierarchy Process (AHP). By assigning weights to key indicators and ranking the alternatives accordingly, the advantages and disadvantages of each variety were compared, resulting in an overall score-based ranking of four table grape cultivars. This provides consumers with a quantitative basis for making purchasing decisions.

Subject Areas

Agricultural Science, Mathematics, Operational Research, Economics

Keywords

Table Grapes, Analytic Hierarchy Process (AHP), Comprehensive Evaluation

1. Introduction

Grapes (*Vitis vinifera* L.) are among the most popular fruits in the world and are often referred to as the "queen of fruits". With a cultivation history spanning thousands of years, they are not only rich in nutrients and characterized by a sweet and juicy taste, but also serve as an important raw material for fresh consumption, winemaking, and processing into raisins, juice, jam, and canned products [1]. Among these, fresh consumption best preserves the natural flavor of grapes and remains the most preferred form of consumption.

To date, approximately 7000 to 8000 grape cultivars have been reported worldwide, with major cultivars including Kyoho, Shine Muscat, and Red Globe. Every year, during the ripening season around August and September, a large number of grapes enter the market. Although grapes are widely popular, many consumers still struggle to determine which table grape cultivars are of higher quality. To enable consumers to make more informed choices, this study employs the Analytic Hierarchy Process (AHP) to comprehensively evaluate and compare the overall quality of different table grape cultivars in a scientific manner.

2. Model Preparation

2.1. Indicator Selection

Consumers primarily rely on five criteria to evaluate high-quality grapes: color, taste, shape, price, and seed presence [2]. Color serves as consumers' immediate visual indicator of grape quality, directly influencing first impressions and purchase intention. Taste is the core factor determining the eating experience and influences consumers' long-term preference for grape varieties. In this study, the "taste" criterion was operationalized as a composite evaluation score based on the characteristic descriptions of each grape variety and expert judgment, comprehensively considering factors such as sweetness, acidity, and texture. This qualitative information serves as an important basis for constructing the pairwise comparison matrix, thereby reducing ambiguity in the definition of this criterion. Shape functions as a supplementary visual cue that affects the assessment of grape development and perceived quality. Price reflects both purchasing power and value-for-money considerations, making it an important factor in economic decision-making. Seed presence represents convenience and ease of consumption, influencing consumers' varietal preferences. Together, these five criteria comprehensively capture the core logic underlying consumers' choices of table grape cultivars from visual, gustatory, economic, and functional dimensions.

2.2. Target Varieties

Based on the previously established evaluation criteria—color, taste, fruit shape, price, and seed presence—this study selected four common table grape cultivars that are widely distributed and highly consumed in the Chinese market: Kyoho, Shine Muscat, Red Globe, and Beauty Finger [3].

The main data sources include the Official Database of the China Grape Industry Technology System, the Blue Book on the Development of China's Grape Industry (2024), the Yimutian Agricultural Big Data Platform, and the China Fruit Network industry research section. These platforms respectively provide information on grape variety characteristics, market prices, and industry dynamics. Meanwhile, publicly available online data (such as Baidu search results and price information from major e-commerce platforms) was cross-verified to ensure the representativeness and accuracy of the data.

Specifically, appearance and seed-related information were mainly obtained from the Grape Variety Resource Census Dataset (2023) of the China Grape Industry Technology System; the taste indicator was primarily based on the China Fresh Table Grape Consumption Preference Report (2024) jointly released by the College of Food Science and Nutritional Engineering at China Agricultural University and the Yimutian Agricultural Data Platform; and the price data were mainly drawn from the average trading prices of fresh-eating grapes on the Yimutian platform during the third quarter of 2024, reflecting actual market circulation levels.

After data compilation and integration, the core characteristics of the four grape varieties—color, taste, shape, price, and seed presence—are summarized in **Table 1**.

Table 1. Core characteristics of four fresh-eating grape varieties.

Species	Color	Taste	Shape	Price	Seed presence
Kyoho	Purple-black	Sweet with a hint of tartness	Round, large fruit	6 - 15 Yuan per gram	Yes
Sunshine Muscat	Yellowish-green	Exceptionally crisp and sweet Sugar content as high as 20%	Elliptical	15 - 40 Yuan per gram	No
Red Globe	Dark red	Slightly sweet with a hint of tartness	Slightly flattened circle	8 - 20 Yuan per gram	Yes
Beauty Finger	Red and yellow stripes	Right balance of sweet and sour	Slender cylinder Resembling a finger	15 - 30 Yuan per gram	No

As shown in **Table 1**, different fresh table grape varieties each possess distinct advantages in terms of price, taste, appearance, and seed presence. Although Kyoho and Red Globe grapes contain seeds, their large berries and abundant juice make them suitable for consumers seeking value for money and a thirst-quenching effect. Sunlight Rose and Beauty Finger grapes are predominantly seedless, featuring firm, crisp flesh and unique appearances, but command higher prices, better aligning with demands for quality and convenience. This demonstrates that a single criterion cannot fully reflect superiority or inferiority, and consumer preferences vary. Therefore, it is necessary to establish a multi-criteria evaluation system that comprehensively balances factors across multiple dimensions to support the scientific selection of fresh table grapes.

2.3. Research Methods

In multi-criteria decision-making studies, common evaluation methods primarily include the general scoring method, weighted average method, Delphi method, and principal component analysis. The general scoring method is operationally simple but overly reliant on individual subjective judgment, lacking scientific rigor;

the weighted average method can partially reflect the importance of indicators, yet weighting criteria often lack uniform standards; The Delphi Method determines weights through multiple rounds of expert opinion aggregation, reducing individual bias but incurring high implementation costs while remaining susceptible to expert composition effects. In fruit quality assessment [4], principal component analysis may yield results deviating from practical evaluation needs [5] due to limitations imposed by linear assumptions and sensitivity to outlier samples. In contrast, the Analytic Hierarchy Process (AHP) decomposes complex problems into objective, criterion, and alternative layers while incorporating expert judgment through pairwise comparisons. This yields relatively scientific weight allocations and ensures result reliability via consistency tests. Therefore, this study employs AHP to construct an evaluation system for fresh-eating grape varieties, achieving a more rational and systematic comprehensive ranking.

The Analytic Hierarchy Process (AHP) is a systematic, hierarchical multi-criteria decision analysis method proposed by American operations researcher Thomas L. Saaty in the 1970s [6]. Its core principle involves decomposing complex problems into multiple levels—typically comprising the objective level, criterion level, and alternative level—to construct a hierarchical model. By pairwise comparing the importance of elements within the same level, a judgment matrix is established. Weights for each element are then calculated based on this matrix, followed by consistency tests to ensure scientific validity. Ultimately, by aggregating weights across levels, the comprehensive priority of each alternative can be determined, providing quantitative support for decision-making.

In grape variety evaluation, consumers often face multiple coexisting quality indicators that are difficult to balance. AHP decomposes this complex decision into a three-level structure—"objective-criteria-alternatives"—clarifying the relative weights of each indicator to achieve a scientific ranking of grape varieties.

3. Model Construction

This study systematically evaluated the quality characteristics of four fresh table grape varieties—Kyoho, Sunshine Muscat, Red Globe, and Beauty Finger—using the Analytic Hierarchy Process (AHP) across multiple dimensions. By constructing a hierarchical model and conducting comparative and comprehensive analyses, it provides consumers with scientific guidance for selecting fresh table grapes.

3.1. Establish Structural Model

The Analytic Hierarchy Process (AHP) model for this study is illustrated in **Figure 1**. The hierarchical structure comprises three levels: Objective Level (A): Evaluating the overall quality of different fresh table grape varieties. Criteria Level (B): Key indicators reflecting table grape quality, including color (BB_1), taste (BB_2), shape (BB_3), price (BB_4), and seed presence (BB_5). Option Level (C): Specific evaluation subjects, namely Kyoho grapes (CC_1), Sunshine Muscat (CC_2), Red Globe (CC_3), and Beauty Finger (CC_4).

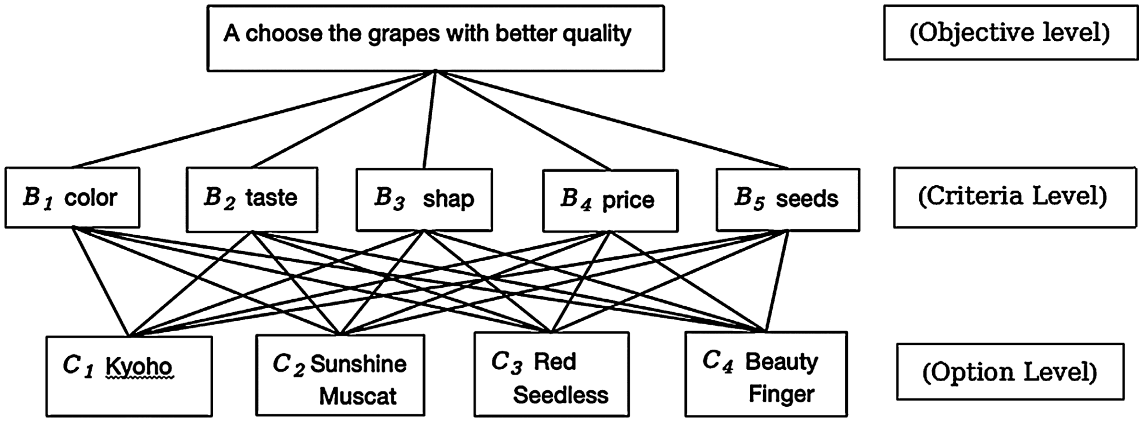

Figure 1. Establishing a hierarchical model for comprehensive grape evaluation.

Through the aforementioned three-tier structure, the complex problem of grape variety selection can be decomposed into comparable hierarchical elements. After establishing the hierarchical model shown in Figure 1, the next step involves quantitatively comparing indicators across different levels to determine their relative importance in decision-making.

3.2. Matrix Construction

Based on the hierarchical structure model, the importance of each evaluation indicator must be further determined through pairwise comparisons. The specific procedure involves pairwise comparisons of indicators within the same level based on the comprehensive quality evaluation system for fresh table grapes, constructing a judgment matrix using the 1 - 9 proportional scale (see Table 2). Subsequently, by calculating the matrix's eigenvectors and their maximum eigenvalues, the weights for each indicator are obtained. A consistency test is then performed to ensure the scientific validity and rationality of the results [7]. These weights will serve as the foundation for subsequent comprehensive evaluations.

Table 2. 1 - 9 scale method.

Scale	Meaning
1	The *i*-th factor has the same impact as the *j*-th factor
3	Factor *i* has a slightly stronger impact than factor *j*
5	Stronger impact of factor *i* than factor *j*
7	The effect of factor *i* is slightly stronger than that of factor *j*
9	The influence of the *i*-th factor is absolutely stronger than that of the *j*-th factor.

Additionally, 2, 4, 6, 8 indicates that the influence of the *i*-th factor relative to the *j*-th factor falls between the two adjacent levels mentioned above. Based on $a_{ij} = \frac{1}{a_{ji}}$, the meaning of the reciprocals of the above scales can be defined.

Construct a pairwise comparison matrix

Using the 1 - 9 proportional scale method, pairwise comparisons can be conducted among indicators within the same level to determine their relative importance. To facilitate calculation and analysis, these judgments should be represented in matrix form, specifically by constructing pairwise comparison matrices. The single-level ranking in the Analytic Hierarchy Process (AHP) essentially determines the relative influence of lower-level factors on higher-level factors through these pairwise comparison matrices [8]. This study requires establishing six pairwise comparison matrices within the fresh table grape evaluation system, comprising one fifth-order matrix (objective layer relative to criterion layer) and five fourth-order matrices (criterion layer relative to scheme layer).

To determine the comparative values in the pairwise comparison matrices, this study adopted the expert judgment method. Three experts with research experience in the grape industry and agricultural product markets were invited to conduct pairwise comparisons of the importance of each criterion based on their professional knowledge and market experience. The evaluations were made using Saaty's 1 - 9 scale, and the arithmetic mean of the experts' scores was taken as the final judgment value to construct the pairwise comparison matrices.

The comparison judgment matrix A is derived by comparing the importance of color, taste, shape, price, and seed presence. Similarly, for the four varieties—Kyoho, Sunshine Rose, Red Globe, and Beauty Finger—comparisons are made regarding their respective color, taste, shape, price, and seed presence, yielding the matrices BB_1, BB_2, BB_3 and BB_4.

$$A=\begin{bmatrix} 1 & \frac{1}{7} & 2 & \frac{1}{4} & \frac{1}{3} \\ 7 & 1 & 5 & \frac{1}{3} & 3 \\ \frac{1}{2} & \frac{1}{5} & 1 & 1 & 2 \\ 4 & 3 & 1 & 1 & \frac{1}{3} \\ 3 & \frac{1}{3} & \frac{1}{2} & 3 & 1 \end{bmatrix},\ \text{color } BB_1=\begin{bmatrix} 1 & 3 & \frac{1}{2} & 3 \\ \frac{1}{3} & 1 & \frac{1}{3} & 1 \\ 2 & 3 & 1 & 3 \\ \frac{1}{3} & 1 & \frac{1}{3} & 1 \end{bmatrix},\ \text{taste } BB_2=\begin{bmatrix} 1 & \frac{1}{7} & \frac{1}{3} & \frac{1}{5} \\ 7 & 1 & 5 & 3 \\ 3 & \frac{1}{5} & 1 & \frac{1}{3} \\ 5 & \frac{1}{3} & 3 & 1 \end{bmatrix},$$

$$\text{shape } BB_3=\begin{bmatrix} 1 & 3 & 2 & \frac{1}{2} \\ \frac{1}{3} & 1 & 1 & \frac{1}{3} \\ \frac{1}{2} & 1 & 1 & \frac{1}{2} \\ 2 & 3 & 2 & 1 \end{bmatrix},\ \text{price } BB_4=\begin{bmatrix} 1 & 5 & 2 & 3 \\ \frac{1}{5} & 1 & \frac{1}{3} & \frac{1}{2} \\ \frac{1}{2} & 3 & 1 & 2 \\ \frac{1}{3} & 2 & \frac{1}{2} & 1 \end{bmatrix},\ \text{seed presence } BB_5=\begin{bmatrix} 1 & \frac{1}{5} & 3 & \frac{1}{3} \\ 5 & 1 & 7 & 3 \\ \frac{1}{3} & \frac{1}{7} & 1 & \frac{1}{5} \\ 3 & \frac{1}{3} & 5 & 1 \end{bmatrix}$$

3.3. Hierarchical Single Sorting Weight Vector and Consistency Verification

To obtain the weights for each indicator, the weight vector must first be calculated based on the judgment matrix. The specific steps involve normalizing each column of the matrix, then averaging the values within each row to derive the weight vector. $u=(u_1,u_2,\cdots,u_n)^{\mathrm{T}}$ The calculation formula is as follows:

$$u_i=\frac{1}{n}\sum\nolimits_{j=1}^{n}\frac{a_{ij}}{\sum\nolimits_{i=1}^{n}a_{ij}},i=1,2,\cdots,n \tag{1}$$

Here, a_{ij} represents the judgment matrix element, and n denotes the order of the matrix. The resulting weight vector reflects the relative importance of each indicator within this level, with the sum of all components equaling 1. This paper obtains the weight vector for the criterion level relative to the objective level $u=(u_1,u_2,u_3,u_4,u_5)^{\mathrm{T}}$, reflecting the importance of the five indicators—"color, taste, shape, price, and presence of seeds"—in the objective level of "selecting high-quality fresh table grapes". This enables the determination of weight values for each indicator, forming the foundation for evaluation.

However, when consumers compare the importance of various quality indicators for grapes—such as color, taste, shape, price, and seedlessness—these judgments often carry a degree of subjectivity, inevitably leading to inconsistencies. For instance, consumers might deem taste more important than price, and price more important than shape, yet in actual purchasing decisions, shape may prove more significant than taste. This indicates a lack of transferability in judgment outcomes, leading to inconsistencies within the evaluation system. To ensure the scientific rigor and reliability of the final weighting calculations, consistency testing of the judgment matrix is essential to guarantee that consumer preferences are accurately reflected.

The consistency index (CI) serves as the metric for consistency testing, calculated using the following formula:

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{2}$$

Among these, $\lambda_{\max}$ denotes the maximum eigenvalue of the matrix, and n denotes the order of the matrix. Subsequently, calculate the Consistency Ratio, CR:

$$CR=\frac{CI}{RI} \tag{3}$$

Among these is the random consistency metric.

When the random consistency ratio is $CR < 0.10$, it indicates that the judgment matrix exhibits relatively satisfactory consistency and is acceptable. If $CR \geq 0.1$, the values in the judgment matrix need to be readjusted until the consistency test requirements are met.

3.4. Hierarchical Total Sorting

In this study, the hierarchical total ranking aims to integrate the weights of various evaluation criteria (color, taste, fruit shape, price, and presence of seeds) to calculate the comprehensive weight of four fresh table grape varieties (Kyoho, Sunshine Rose, Red Globe, Beauty Finger) relative to the target preferred fresh table grape. This step yields an overall priority ranking for the four grape varieties, providing consumers with a quantitative basis for selection.

Specifically, the weights for each evaluation criterion (color, taste, fruit shape, price, and presence of seeds) are first calculated at the criterion level. These are then combined with the performance of each grape variety at the scheme level under the corresponding criteria (e.g., Sunshine Muscat has higher weights for taste and fruit shape, while Kyoho holds an advantage in price). This integration yields the final weight values for each variety at the target level.

After obtaining the criterion-level weights *u*, it is necessary to further calculate the comprehensive weights of the scheme layer (four grape varieties: Kyoho, Sunshine Rose, Red Globe, Beauty Finger) relative to the objective layer.

In this study, each judgment matrix BB_j corresponds to a single criterion (e.g., color, taste, fruit shape, price, presence of seeds), with the matrix reflecting the relative performance of the four grape varieties under that criterion. For instance, in the matrix for the color criterion BB_1, Kyoho and Red Globe demonstrate superior performance, thus carrying greater weight in comparisons; whereas in the matrix for the price criterion BB_4, Kyoho exhibits a more pronounced advantage.

Each BB_j matrix represents a judgment matrix for the scheme layer (four grape varieties) relative to a specific criterion. It is used to compare the relative performance of different schemes (Kyoho, Sunshine Rose, Red Globe, Beauty Finger) under that criterion. For example, the matrix BB_1 represents "the comparison of Kyoho, Sunshine Rose, Red Globe, and Beauty Finger under the criterion of color." From the obtained weight vector BB_j, it can be recorded as

$$\omega_k^{(j)} = \left(\omega_{k1}^{(j)}, \omega_{k2}^{(j)}, \omega_{k3}^{(j)}, \omega_{k4}^{(j)}\right)^{\mathrm{T}}, j = 1, \cdots, 5 \tag{4}$$

Among these, $\omega_k^{(j)}$ represents the relative weight of the four grape varieties under criterion *j*. Ultimately, the comprehensive weight of the four grape varieties relative to the target layer is:

$$W_i = \sum\nolimits_{j=1}^{m} u_j \cdot \omega_k^{(j)}, i = 1, 2, 3, 4 \tag{5}$$

$W = \left(W_1, W_2, W_3, W_4\right)^{\mathrm{T}}$ reflects the final ranking of the four varieties—Jufeng, Sunshine Muscat, Red Globe, and Beauty Finger—under the target layer "Selecting Premium Fresh-Eating Grapes."

To ensure the scientific validity and rationality of the final composite weight values, the hierarchical total ranking weights must also undergo consistency testing. To guarantee the scientific and reasonable nature of the final composite weights, the hierarchical total ranking results must also undergo consistency testing. Let the consistency index $C_1, C_2, \cdots, C_n$ for the hierarchical single ranking of factor B_j ($j = 1, 2, \cdots, m$) in the upper layer (indicator B layer) for variety scheme layer CI_j, and the random consistency index be RI_j. Then, the consistency ratio of the hierarchical total ranking is:

$$CR = \frac{u_1 CI_1 + u_2 CI_2 + \cdots + u_m CI_m}{u_1 RI_1 + u_2 RI_2 + \cdots + u_m RI_m} \tag{6}$$

When $CR < 0.1$, it indicates that the judgment matrix has passed the one-time test, demonstrating relatively satisfactory consistency and is considered reasonable.

4. Model Solving

Using matrix A, we can calculate that $\lambda_{\max} = 5.136$, $CI = 0.034$, $CR = \frac{CI}{RI} \approx 0.030 < 0.1$, which meets the consistency test requirement. By solving the judgment matrix, we obtain the judgment vector for grape as

$$u = (0.082, 0.261, 0.129, 0.247, 0.181)^{\mathrm{T}}.$$

Pairwise comparison matrix BB_1, BB_2, BB_3, BB_4, and BB_5 can compute the weight vectors for hierarchical single sorting and hierarchical overall sorting, followed by consistency verification. The results are shown in Table 3.

Table 3. Computation of weight vectors for single-level sorting, overall hierarchical sorting, and consistency verification table.

K	1	2	3	4	5
ω_{k1}	0.273	0.036	0.251	0.483	0.108
ω_{k2}	0.091	0.540	0.084	0.088	0.540
ω_{k3}	0.546	0.108	0.167	0.272	0.036
ω_{k4}	0.091	0.316	0.498	0.157	0.316
λ_k	4.23	4.18	4.21	4.02	4.18
CI_k	0.077	0.06	0.07	0.01	0.06
CR_k	0.086	0.067	0.078	0.006	0.067

As shown in Table 3, the consistency ratio (CR) values for each judgment matrix are all less than 0.1. The consistency test indicates that the single-ranking weight results for the above indicators are acceptable.

Multiplying the weights at the criterion level by the weights at the scheme level for each criterion, then performing a weighted sum, yields the following direction vectors for the decision schemes Kyoho, Sunshine Rose, Red Globe, and Beauty Finger toward the overall objective: 0.2030, 0.2787, 0.1682, and 0.2501, respectively. The CR value is approximately 0.0493, which is less than 0.1.

5. Conclusions

This study employed the Analytic Hierarchy Process (AHP) to conduct a comprehensive evaluation of four fresh table grape varieties: Kyoho, Sunshine Muscat, Red Globe, and Beauty Finger. Results indicate that under the five criteria of "color, taste, fruit shape, price, and seed presence," Sunshine Muscat achieved the highest overall weighted value of 0.2787, followed by Beauty Finger, Red Globe, and Kyoho.

The results not only objectively reflect the quality differences among various table grape cultivars but also provide strong practical guidance for the grape industry. For grape growers, the findings can help optimize varietal structure and cultivation proportions based on consumer preferences regarding color, taste, and seed presence—for instance, by increasing the planting share of seedless varieties that enjoy higher market preference—to enhance product competitiveness. For marketers, the results can inform more precise market positioning and brand communication strategies, such as emphasizing the taste advantages of highly preferred varieties like Shine Muscat or developing differentiated pricing and packaging strategies tailored to distinct consumer segments. These measures can better align grape products with consumer demand and promote greater value creation within the industry.

This study's application of AHP has certain limitations [9]: First, constructing the judgment matrix heavily relies on expert experience, making it difficult to avoid subjective bias; Second, as the number of indicators increases, consistency tests become harder to satisfy, potentially compromising result stability. Repeated matrix adjustments to meet consistency requirements may also introduce significant human-induced modifications. Furthermore, relying solely on AHP may lack sufficient flexibility when handling certain complex decision scenarios.

Future research could explore integrating AHP with methods such as the Two-Operator Pseudo-Ideal Solution (TOPSIS) [10] and Entropy Weighting [11]. This approach would balance subjective expertise with objective data, reduce overreliance on expert judgment, enhance the scientific rigor of weight allocation, and yield more reliable grape quality evaluation outcomes. Furthermore, it could broaden application scenarios to enable more scientific and precise decision-making, thereby amplifying its impact in relevant fields.

At the same time, this study considered only four representative table grape cultivars and five main evaluation criteria, and thus, the sample scope and indicator dimensions are relatively limited. The analysis did not cover a wider range of regions, varieties, or consumer segments, which may, to some extent, affect the generalizability and applicability of the conclusions. Future research could expand the sample size and enrich the evaluation indicator system to further validate and refine the analytical framework, thereby enhancing the representativeness and practical relevance of the results.

Conflicts of Interest

The authors declare no conflicts of interest.

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