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ORIGINAL ARTICLE

Quality Evaluation of Raw Moutan Cortex Using the AHP and Gray Correlation-TOPSIS Method

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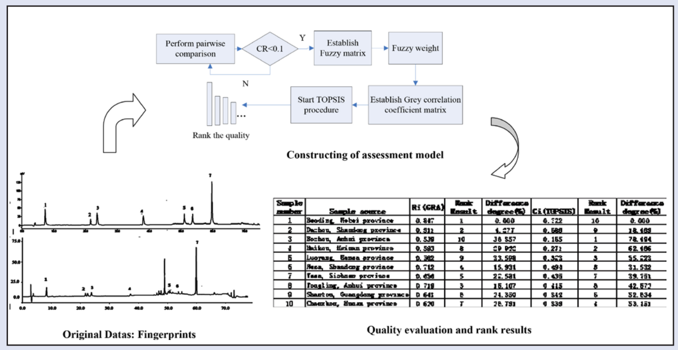
ABSTRACT

Background: Raw Moutan cortex (RMC) is an important Chinese herbal medicine. Comprehensive and objective quality evaluation of Chinese herbal medicine has been one of the most important issues in the modern herbs development. **Objective:** To evaluate and compare the quality of RMC using the weighted gray correlation- Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method. **Materials and Methods:** The percentage composition of gallic acid, catechin, oxypaeoniflorin, paeoniflorin, quercetin, benzoylpaeoniflorin, paeonol in different batches of RMC was determined, and then adopting MATLAB programming to construct the gray correlation-TOPSIS assessment model for quality evaluation of RMC. **Results:** The quality evaluation results of model evaluation and objective evaluation were consistent, reliable, and stable. **Conclusion:** The model of gray correlation-TOPSIS can be well applied to the quality evaluation of traditional Chinese medicine with multiple components and has broad prospect in application.

Key words: AHP, gray correlation, Moutan cortex, quality evaluation, TOPSIS

SUMMARY

- The experiment tries to construct a model to evaluate the quality of RMC using the weighted gray correlation- Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method. Results show the model is reliable and provide a feasible way in evaluating quality of traditional Chinese medicine with multiple components.



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INTRODUCTION

Moutan Cortex, the root bark of *Paeonia suffruticosa Andrews* (*Paeoniaceae*), is used as a common traditional Chinese medicine (TCM) drug.[1] The RMC is prepared by collecting the root bark of *P. suffruticosa*, washed, cleaned, and sun-dried. According to the TCM theory, the raw moutan bark serves to clear excessive heat, cool the blood, promote blood circulation, and remove blood stasis; it is indicated for diseases associated with the "heat syndromes" (typically manifesting in inflammation and related symptoms), stagnated blood conditions, and traumatic injuries.[2,3] For the differences of growing environments and planting ways, RMC from different producing areas are uneven in quality. In order to evaluate the quality of RMC overall, multiple components should be considered. Pharmacology researches showed that paeoniflorin, benzoylpaeoniflorin, paeonol, catechin, and oxypaeoniflorin have been reported to be able to inhibit platelet aggregation, promote blood circulation, and remove blood stasis,[4,5] In this study, gallic acid, catechin, oxypaeoniflorin, paeoniflorin, quercetin, benzoylpaeoniflorin, and paeonol were included for efficient quality control of RMC.

The main objective of this study is to propose a systematic quality assessment model based on multiple components of RMC. Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), known as one of the most classical Multiple Attribute Decision Making (MADM) methods, is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance from the negative ideal solution. But this method is mostly used in linear relationship. For nonlinear problems, this method works not so well. Gray relational

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Table 1: Sources and components of RMC samples (mg.g-1) (n = 3)

Sample	Sample source	Gllic acid	Catechin	Oxypaeoniflorin	Paeoniflorin	Quercetin	Benzoylpaeoniflorin	paeonol
1	Baoding, Hebei province	10.01 ± 0.08	0.41 ± 0.01	1.55 ± 0.01	3.56 ± 0.05	0.13 ± 0.03	8.58 ± 0.02	12.02 ± 0.13
2	Dezhou, Shandong province	10.01 ± 0.08	0.41 ± 0.01	1.55 ± 0.01	3.56 ± 0.05	0.13 ± 0.03	8.58 ± 0.02	12.02 ± 0.13
3	Bozhou, Anhui province	3.63 ± 0.02	0.11 ± 0.13	0.64 ± 0.02	2.85 ± 0.02	0.12 ± 0.24	7.28 ± 0.02	3.92 ± 0.4
4	Haikou, Hainan province	3.54 ± 0.01	0.15 ± 0.03	0.55 ± 0.001	3.54 ± 0.03	0.11 ± 0.01	7.15 ± 0.03	11.08 ± 0.61
5	Luoyang, Henan province	6.49 ± 0.02	0.27 ± 0.004	0.64 ± 0.002	2.77 ± 0.09	0.07 ± 0.02	8.59 ± 0.02	4.81 ± 0.13
6	Heza, Shandong province	12.31 ± 0.01	0.11 ± 0.01	1.08 ± 0.003	3.95 ± 0.03	0.14 ± 0.01	7.51 ± 0.01	11.07 ± 0.21
7	Yaan, Sichuan province	10.82 ± 0.07	0.11 ± 0.01	0.90 ± 0.01	3.87 ± 0.04	0.12 ± 0.03	7.19 ± 0.10	11.05 ± 0.20
8	Tongling, Anhui province	2.54 ± 0.02	0.19 ± 0.001	0.98 ± 0.001	6.10 ± 0.03	0.12 ± 0.01	8.62 ± 0.06	11.81 ± 0.72
9	Shantou, Guangdong province	3.56 ± 0.04	0.14 ± 0.02	1.03 ± 0.03	4.23 ± 0.13	0.12 ± 0.32	7.32 ± 0.05	11.32 ± 0.14
10	Chenzhou, Hunan province	3.25 ± 0.02	0.24 ± 0.01	0.73 ± 0.23	3.21 ± 0.02	0.12 ± 0.05	8.02 ± 0.06	10.24 ± 0.2
Average		7.07 ± 4.46	0.19 ± 0.09	0.94 ± 0.31	3.91 ± 1.02	0.12 ± 0.02	7.97 ± 0.81	9.92 ± 2.98

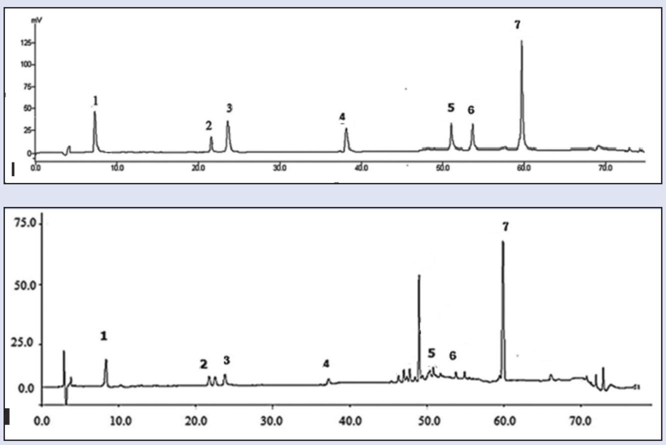

Figure 1: (A) HPLC chromatogram of standard solution and (B) a typical HPLC chromatogram of RMC.1, gallic acid; 2, catechin; 3, oxypaeoniflorin; 4, paeoniflorin; 5, quercetin; 6, benzoylpaeoniflorin; 7, paeonol

analysis (GRA) can cover the shortage. GRA is applied mostly in the area of system modeling, predicting and controlling, which can solve MADM problem containing subjectivity, uncertainty, and ambiguity in assessment process and uncover the non-linear relationship. By introducing gray correlation coefficient to traditional TOPSIS and combining gray correlation coefficient and traditional Euclidean distance, a new relative closeness is built, which reflects position relation between ideal solution and negative ideal solution, and similarity difference of data curve.[6]

Different components of samples have different important weights of evaluation; this study first utilizes analytic hierarchy process (AHP)[7] to establish the assessment structure then determines the important weights of evaluation criteria according to a group of decision-makers, and last applies gray correlation-TOPSIS to obtain the final ranking order of quality.

The uses of gray correlation-TOPSIS method have been reported in the application of mining method optimization,[8] evaluation of channel width design guidelines,[9] customer value assessment,[10] and so on. However, this study is the first report to apply the method for quality evaluation of RMC. The study can add to knowledge of the quality assessment of Chinese herbal medicine.

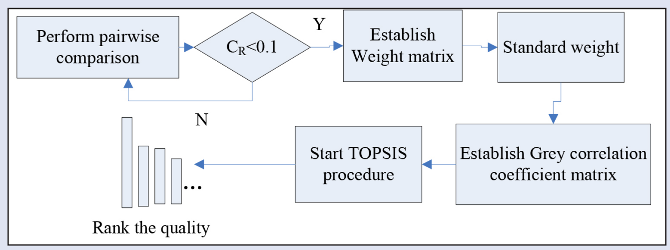

Figure 2: Phases of constructing assessment model.

MATERIALS AND METHODS

Chemicals and materials

Samples of RMC were collected from different regions of People's Republic of China shown in Table 1 and authenticated by Dr. Shumei-Wang from the School of Chinese Medicine, Guangdong Pharmaceutical University. Seven compounds were simultaneously determinate with high-performance liquid chromatography coupled (HPLC-DAD-MS), shown in Figure 1. The methods and results of content determination had been reported in the article of "Liquid chromatography-diode array detector-electrospray mass spectrometry and principal components analyses of raw and processed Moutan cortex."[3]

Reference standards (purity >98%) of gallic acid, catechin, oxypaeoniflorin, paeoniflorin, quercetin, paeonol, and benzoylpaeoniflorin were obtained from the National Institute for Food and Drug Control, Beijing, People's Republic of China. HPLC-grade acetonitrile (Yu-Wang Chemical Factory, Shandong, People's Republic of China), formic acid (Beijing Reagent Co., Beijing, People's Republic of China), and analytical grade methanol (East giant Experimental Instrument Co., Guangzhou, People's Republic of China) were used. Water was purified by the Milli-Q water system (Millipore, Bedford, MA, USA).[3]

Methods

The proposed model for assessment of the quality of RMC by the weighted gray correlation-TOPSIS method consists of three basic phases: (1) AHP is utilized to determine the important weights of evaluation criteria of RMC, (2) gray correlation analysis method is used to get gray correlation coefficient, and (3) TOPSIS is employed to achieve the final ranking results based on the above phases. Schematic diagram of the proposed model is explained in Figure 2.

AHP weights

Comprehensive evaluation means overall evaluation of multicriteria. In most conditions, the important weights of attributes differ from each other. This should be taken into account when using the gray correlation-TOPSIS analysis method. And then the evaluation results would be more reliable and stable. There are many methods of determining the importance weights of evaluation criteria, including Delphi method,[11] AHP, entropy method,[12] and so on. By far, AHP is one of the frequently used methods for its simplicity and ease of use. AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Saaty and Peniwati.[13] It has particular application in group decision making. The procedure for using the AHP can be summarized as follows[14]:

(1) **Perform pair-wise comparisons**

For the quality evaluation of RMC, different components of samples have different important weights of evaluation. The nine scale method[7] shown in Table 2 is utilized to get the relative importance of each indicator.

(2) **Assess the consistency of pairwise judgments**

To avoid the subjective judgment that will make the result inaccurate. Consistency check to verify the rationality of the matrix[15] is necessary. Eigenvector is calculated as the following:

$$AW = \lambda_{max} W$$

Where, A represents judgment matrix, λ_{max} represents the max eigenvalue and W represents the weight matrix.

$$C_I = \frac{\lambda_{max} - n}{n-1}$$

C_R should satisfy the condition as $C_R = C_I/R_I$. Where, C_I means values of consistency check indicators and R_I means values of average stochastic coincidence indicators. A consistency index (C_R) of 0.1 or less was considered acceptable.[16]

(3) **Standardize the weight matrix**

$$W_I = \frac{C_I}{Sum(C_I)}$$

Gray correlation coefficient matrix

The gray correlation is one method that uses the correlation degree between the referring series and the comparing series to evaluate the proposed schemes.[17] The steps of calculating the correlation degree summarized as follows:[9]

Determination of positive and negative ideal scheme

Suppose there are n kinds of samples of Chinese herb and each sample with m evaluation index. The evaluation unit sequence is$\{X_{ij}\}$ (i =1, 2, 3……n; j =1, 2, 3……m); in this topic, n = 10,m = 7. $\{X\}_{sj}$ represents the positive ideal scheme, while $\{X\}_{tj}$ means the negative ideal scheme: $\{X\}_{sj}= \max (1 \le i \le n) \{X\}_{ij}$, $\{X\}_{tj}= \min (1 \le i \le n) \{X\}_{ij}$

Normalization of original index value

First, the original index value should be normalized to be the value belonging to [0, 1] for making sure of the evaluation accuracy. Here adopts equalization method in dimensionless treatment to reduce the loss of information in data. So, the index after being normalized by equalization method is as follows:

$$Y_{ij}= X_{ij}/ X_j$$

where, X_j represents the mean value of j index of the sample.

Calculation of the weighted normalized decision matrix

The weighted normalized decision matrix is constructed by multiplying the normalized decision matrix by its associated weights. The weighted normalized value is calculated as follows:

$$Y_{ij} = W_i \times Y_{ij}, \ i = 1, 2, \ldots, m; \ j = 1, 2, \ldots, n;$$

where, W_i means the weight matrix got from AHP method.

Calculation of the gray correlation coefficient

The gray correlation coefficient on the jth index between the scheme Y_{ij} and the Y_{sj} and Y_{tj} respectively is $\xi_{j(s)}$ and $\xi_{j(t)}$

$$\xi_{j(s)} = \frac{\Delta_{min} + \rho\Delta_{max}}{\left|Y_{ij} - Y_{sj}\right| + \rho\Delta_{max}}$$

where, $\Delta_{min}= \min|Y_{ij}-Y_{sj}|$, $\Delta_{max}= \max|Y_{ij}-Y_{sj}|$ (i =1, 2……n; j =1, 2……m)

$$\xi_{j(t)} = \frac{\Delta'_{min} + \rho\Delta'_{max}}{\left|Y_{ij} - Y_{tj}\right| + \rho\Delta'_{max}}$$

where, $\Delta'_{min}= \min|Y_{ij}-Y_{tj}|$,$\Delta'_{max}= \max|Y_{ij}-Y_{tj}|$(i =1, 2……n; j =1, 2……m) , $\rho \in [0,1]$, ρ is introduced as the resolution coefficient to reduce the influence of the extreme value, usually values 0.5.

TOPSIS based on gray correlation degree

Considering that when using gray correlation method on comparing of different schemes, one scheme with a great correlation degree to the positive ideal scheme does not mean a relatively little correlation degree to the negative ideal scheme. So, for making sure of the accuracy of the comparison, the TOPSIS method, a preference decision method using relative closeness to consider synthetically the Euclidean distance between the evaluated scheme and both the positive and negative ideal

Table 2: Nine scale method

Rate	Definition	Explanation
1	Equalimportance	Two elements contribute equally to the objective
2	Weak	Between equal and moderate
3	Moderate importance	Experience and judgments lightly favor one element over another
4	Moderate plus	Between moderate and strong
5	Strong importance	Experience and judgment strongly favor one element over another
6	Strong plus	Between strong and very strong
7	Very strongor demonstrated importance	An element is favored very strongly over another;its dominance demonstrated in practice
8	Very,very strong	Between very strong and extreme
9	Extreme importance	The evidence favoring one element over another is one of the highest possible order or affirmation

scheme, was introduced into calculating the gray correlation degree between the evaluated scheme and both the positive and negative ideal scheme respectively.[18,19]

(1) Determine the positive ideal and negative ideal solution.

$$\xi^{+} = \left\{ \left(\max_{1\le i\le m} \xi_i(j), j = 1,2,\ldots,n \right) \right\} \xi^{-} = \left\{ \left(\min_{1\le i\le m} \xi_i(j), j = 1,2,\ldots,n \right) \right\}$$

(2) Calculate the weighted Euclidean distance.

The weighted Euclidean distance of each alternative from the ideal solution is given as follows:

$$D_i^{+} = \sqrt{\sum_{j=1}^{n}\left[\xi_i(j) - \xi_0^{+}(j)\right]^2} \quad D_i^{-} = \sqrt{\sum_{j=1}^{n}\left[\xi_i(j) - \xi_0^{-}(j)\right]^2}$$

(3) Calculate the relative closeness to the ideal solution. The relative closeness of the alternative C_i with respect to D_i^+ is defined as follows:

$$C_i = \frac{D_i^{+}}{D_i^{-} + D_i^{+}}$$

(4) Rank the alternatives $C_i (i = 1, 2, \ldots, m)$ according to the relative closeness.

The best alternatives are those that have higher value C_i because they are closer to the positive ideal value. The alternatives are ranked in descending order of the C_i index.[20]

RESULTS AND DISCUSSION

Results of AHP weights

According to the experts of Chinese medicine, the importance of different components may be group like this:

Group 1: Paeoniflorin, benzoylpaeoniflorin, paeonol

Group 2: Catechin, oxypaeoniflorin

Group 3: Quercetin, gallic acid

And then based on nine scale method, the pair-wise comparisons of different components of RMC can be represented as matrix A.

After calculating, the weight value of the seven components of RMC is shown in Table 3.

$$A = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & 1 & \frac{3}{5} & 3 & \frac{3}{5} & \frac{3}{5} \\ 3 & 1 & 1 & \frac{3}{5} & 3 & \frac{3}{5} & \frac{3}{5} \\ 5 & \frac{5}{3} & \frac{5}{3} & 1 & 5 & 1 & 1 \\ 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{5} & \frac{1}{5} \\ 5 & \frac{5}{3} & \frac{5}{3} & 1 & 5 & 1 & 1 \\ 5 & \frac{5}{3} & \frac{5}{3} & 1 & 5 & 1 & 1 \end{bmatrix}$$

Result of gray correlation coefficient

Samples of RMC from different regions of People's Republic of China were analyzed by gray analysis method mentioned above. Programed using Matlab (Matrix Laboratory) R2010a, the running result was shown in Table 4.

Quality evaluation result of weighted gray correlation-TOPSIS method

On the basis of gray correlation coefficient result of Table 4 and constructed by method of TOPSIS, the quality evaluation and rank result of RMC from different batches was shown in Table 5. Results showed that RMC from Dezhou, Baoding, Tongling, and Heza were of good quality. For contrast, a single method of GRA or TOPSIS was also adopted to evaluate quality of RMC [Table 6]. Difference degree was also counted to show the significance level of difference. From the contrast result, we could see the biggest difference degree of the weighted gray correlation-TOPSIS method (80.444%) was larger than GRA (36.357%) and TOPSIS (78.494). And the weighted gray correlation-TOPSIS method could evaluate the quality of RMC comprehensively and objectively.

Table 3: Weight value of components of RMC

Components	Gallic acid	Catechin	Oxypaeoniflorin	Paeoniflorin	Quercetin	Benzoylpaeoniflorin	Paeonol
Weight value	0.0433	0.1304	0.1304	0.2175	0.0433	0.2175	0.2175

Table 4: Correlation coefficient of RMC compared with the best reference sequence

		Grey correlation coefficient						
Sample number	Sample source	Gallic acid	Catechin	Oxypaeoniflorin	Paeoniflorin	Quercetin	Benzoylpaeoniflorin	Paeonol
1	Baoding, Hebei province	0.869	1.000	1.000	0.396	0.946	0.564	1.000
2	Dezhou, Shandong province	1.000	0.481	0.735	0.604	0.898	1.000	0.981
3	Bozhou, Anhui province	0.734	0.455	0.478	0.339	0.898	0.346	0.333
4	Haikou, Hainan province	0.732	0.490	0.455	0.394	0.854	0.333	0.812
5	Luoyang, Henan province	0.789	0.641	0.478	0.333	0.715	0.567	0.360
6	Heza, Shandong province	0.930	0.455	0.640	0.436	1.000	0.372	0.810
7	Yaan, Sichuan province	0.889	0.455	0.562	0.427	0.898	0.337	0.807
8	Tongling, Anhui province	0.715	0.532	0.594	1.000	0.898	0.575	0.951
9	Shantou, Guangdong province	0.733	0.481	0.616	0.471	0.898	0.350	0.853
10	Chenzhou, Hunan province	0.727	0.595	0.504	0.366	0.898	0.444	0.695

Table 5: Quality evaluation and rank result of RMC by weighted gray correlation-TOPSIS method

		Grey correlation coefficient				
Sample number	Sample source	Di+	Di-	Ci	Rank Result	Difference degree(%)
1	Baoding, Hebei province	0.758	1.083	0.588	2	1.800
2	Dezhou, Shandong province	0.712	1.063	0.599	1	0.000
3	Bozhou, Anhui province	1.400	0.186	0.117	10	80.444
4	Haikou, Hainan province	1.224	0.503	0.291	7	51.340
5	Luoyang, Henan province	1.253	0.310	0.198	9	66.893
6	Heza, Shandong province	1.087	0.633	0.368	4	38.535
7	Yaan, Sichuan province	1.147	0.555	0.326	6	45.557
8	Tongling, Anhui province	0.811	0.971	0.545	3	9.051
9	Shantou, Guangdong province	1.106	0.591	0.348	5	41.847
10	Chenzhou, Hunan province	1.140	0.447	0.282	8	52.995

Table 6: Quality evaluation and rank result of RMC by single GRA or TOPSIS method

				Grey correlation coefficient			
Sample number	Sample number	Ri(GRA)	Rank Result	Difference degree(%)	Ci(TOPSIS)	Rank Result	Difference degree(%)
1	Baoding, Hebei province	0.847	1	0.000	0.722	10	0.000
2	Dezhou, Shandong province	0.811	2	4.277	0.588	9	18.488
3	Bozhou, Anhui province	0.539	10	36.357	0.155	1	78.494
4	Haikou, Hainan province	0.593	8	29.922	0.271	2	62.486
5	Luoyang, Henan province	0.562	9	33.598	0.323	3	55.223
6	Heza, Shandong province	0.712	4	15.931	0.494	8	31.532
7	Yaan, Sichuan province	0.656	5	22.581	0.435	7	39.751
8	Tongling, Anhui province	0.719	3	15.107	0.415	6	42.572
9	Shantou, Guangdong province	0.641	6	24.350	0.342	5	52.634
10	Chenzhou, Hunan province	0.620	7	26.781	0.338	4	53.151

CONCLUSION

The uses of weighted gray correlation-TOPSIS method have been successfully applied in many areas as effective MADM methods. However, there is no report regarding the application of these methods for quality evaluation of RMC. This research sought to develop a comprehensive, objective method for quality evaluation of RMC and proposes a decision-making method on the basis of gray correlation degree and ideal solution, offering a new idea for quality evaluation of Chinese herb. Simulation results indicate that the decision-making method by combination of gray correlation degree and TOPSIS can get rid of errors caused by subjective factors using one single method, improve reliability of selection solution evaluation, and have a great value of application in quality evaluation of Chinese herb.

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Conflicts of interest

There are no conflicts of interest

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