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Multi indicator analysis (MIA) of 19 trace elements, fats, and other components of five different types of seasonings in Guangxi, China, based on entropy analysis (EA) and systematic cluster analysis (SCA)

*Zhou, L. and Zhu, M.

Guangxi Science and Technology Normal University, Laibin, 546199, Guangxi, China

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Abstract

A multi indicator analysis (MIA) was conducted on 19 trace elements, fats, and other components of five different seasonings (bay leaf, vanilla, jambolan, fennel, and cumin) from Guangxi, China. This study aimed to establish a comprehensive multi-index evaluation system for these seasonings to provide a strong scientific basis for the large-scale development and classification of seasoning resources. The heat of combustion, ash content, thermogravimetric parameters, calcium content, trace element content, fat content, and crude fibre content were determined for each seasoning (n = 3; cv% < 3%). Gray pattern recognition (GPR), gray factor analysis (GFA), factor analysis (FA), entropy analysis (EA), and systematic cluster analysis (SCA) methods were applied to analyse the data. The results revealed that the order of combustibility was bay leaf > fennel > vanilla > cumin > jambolan, and that the order of fat content was cumin > bay leaf > jambolan > vanilla > fennel. The order of calcium content was jambolan > bay leaf > vanilla > cumin > fennel, and the ash content was highest in fennel, followed by cumin, vanilla, jambolan, and bay leaf. The entropy method was used to construct a comprehensive multiple index evaluation order on the basis of the combustion heat, fat content, combustibility, and calcium, ash, trace element, and crude fibre contents, which was determined to be fennel > jambolan > bay leaf > vanilla > curcumin. Systematic cluster analysis separated the five seasonings into three groups: fennel, bay leaf and vanilla, and jambolan and cumin. This study provides an innovative approach for the quality assessment of seasonings and provides a solid scientific basis for the extensive development of seasoning products and classification.

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Introduction

Seasoning can improve the colour, aroma, and flavour of dishes; increase appetite; and provide essential trace elements, fats, *etc*. Seasoning is important for quality evaluation and an auxiliary food that is beneficial to human health (Jianwei and Sheng, 2021). The primary purpose of seasonings is to improve dish quality and meet customer sensory requirements, consequently stimulating appetite and improving human health (Yiwen *et al.*, 2021).

The contents of ten inorganic elements—Ca, Mg, Al, Zn, Cu, Mn, Ni, Fe, Cr, and Pb—in seven natural spices (myrcia, *Foeniculum vulgare*, tsaoko, Chinese prickly ash, star anise, cassia, and pepper) were simultaneously measured *via* ICP-AES with microwave digestion. The results revealed that the seven natural species were rich in Ca, Mg, Fe, Zn, Mn, and Cu, which are essential to humans, and that the contents of Cr, Al, Ni, and Pb, which are harmful to humans, were low (Lihua, 2016).

To analyse the volatile oil components of fennel from multiple areas and the *trans*-anethole composition, Tingting *et al.* (2018) analysed the composition of the volatile oil components of fennel in Hubei, Xinjiang, Inner Mongolia, Sichuan, Jiangxi, and Guangxi *via* gas chromatography-mass spectrometry (GC/MS) and detected the content of *trans*-anethole *via* gas chromatography (GC). The results revealed that the content of volatile oil in fennel was 1.29~2.24 mL/100 g and that the content of *trans*-anethole was relatively high, but the difference was large. The *trans*-anethole content in the range of 12.5~200 μL/mL had a linear

*Corresponding author.
Email: zhanyou159@126.com

relationship (R^2 = 0.9999) with the peak area, and the detection limit was 0.015 μL/mL. The mean recovery was 99.76%, with an RSD of 0.50% (n = 5).

Yuqi *et al.* (2007) conducted qualitative and quantitative analyses of the chemical composition, nutritional composition, and trace elements of cumin seeds and revealed that these seeds contained chemical components such as flavonoids, volatile oils, oils, sugars, amino acids, proteins, and minerals. To understand the differences among cumin seeds from different regions, the contents of chemical and nutritional components such as volatile oils, crude fat, and flavonoids in cumin seeds from different regions in China were systematically determined, and the contents of amino acids were quantitatively analysed, which provided a scientific basis for the utilisation of cumin resources (Suling *et al.*, 2011). Vanilla (rosemary) contains volatile components and is commonly used in the cooking of beef, pork, mutton, chicken, and fish dishes, which can improve the flavour of both meat and dishes (Haibao, 2013).

In thermogravimetric analysis (TGA), the weight loss of a sample is measured as it is heating, providing insights into thermal stability, combustibility, and volatility. With respect to food seasonings, TGA reveals the thermal stability and combustion characteristics during cooking, which affect shelf life and safety. The integration of TGA data with nutritional and elemental data comprehensively elucidates the composition and health benefits of seasonings. TGA data on thermal behaviour are essential for culinary applications. This approach examines the properties and thermal responses of seasonings during cooking. The thermal properties of seasonings have not been extensively investigated alongside nutritional and trace element profiles, because food science research typically focuses on isolated aspects of food. Few studies have explored the relationships between these factors and thermal behaviours, which affect flavour and nutrient retention during cooking. In the present work, TGA, nutritional, and elemental analyses were combined to better elucidate the functional properties and nutritional value of seasonings (Zhou and Huang, 2025a).

Existing research on seasonings essentially involves sensory evaluations of properties such as colour, aroma, and taste, or involves seasoning quality evaluation or discriminant analysis based on indicators such as trace element measurement, chemical composition, and some organic components of seasonings. However, few studies include an overall assessment of food nutrition, including fat, calcium, ash, crude fibre, and energy of seasonings, and no related studies have measured seasoning combustibility *via* the thermogravimetric analysis method.

In the present work, a systematic analysis of the heat of combustion, fat content, combustibility, and calcium, ash, trace element, and crude fibre content data of seasonings was performed *via* the entropy method, gray factor analysis, and systematic cluster analysis. This gap can be filled systematically on the basis of a comprehensive multi index evaluation.

Bay leaf, vanilla, jambolan, fennel, and cumin were the five seasonings chosen as study subjects. A solid scientific basis for the expansion of resources for identifying and classifying seasonings was established by developing a multi index comprehensive rating methodology for five seasonings.

Materials and methods

Materials and instruments

Five seasonings—bay leaf (produced in August 2020, *Lindera fragrans* Oliv.); vanilla (produced in July 2020, *Vanilla planifolia*) from Laibin; jambolan (produced in August 2020, *Ligusticum chuanxiong* Hort.) from Laibin; fennel (produced in August 2020, *Foeniculum vulgare* Mill.) from Laibin; and cumin (produced in August 2020, *Cuminum cyminum* L.) from Guangxi Yulin, China—were chosen as the research subject. The samples were crushed into a fine powder using pestle and mortar, and sieved through a polytope with a 40-mesh opening (Zhou *et al.*, 2022a). To increase representativeness, we confirmed that the sample size and diversity were adequate to reflect the typical composition of each seasoning. Multiple batches from various suppliers were included to account for any batch-to-batch variation, and we meticulously selected seasonings that were widely available on the market. The five seasonings were authenticated by Prof. Caiyun Jiang of Guangxi Science and Technology Normal University and stored at Guangxi Normal University of Science and Technology.

HR-15BH series heat of combustion measurement experimental devices; ignition wire (nickel-chromium wire); tablet press (Changsha Changxing Higher Education Instrument and

Equipment Development Co., Ltd., Changsha, Hunan, China); pulveriser (FW135, Tianjin Taiste Instrument Co., Ltd.); FA200 electronic balance (Shanghai Shunyu Heping Scientific Instrument Co., Ltd.); NETZSCH STA 2500 thermogravimetric analyser; crucible (German NETZSCH); SE206 fat tester; F1600 automatic fibre tester (Jinan Alva Instrument Co., Ltd.); AUY120 1/10,000 electronic analytical balance (Shimadzu); GZX-GF101-3-S drying box (Shanghai Huyeming Scientific Instrument Co., Ltd.); SX-4-10P muffle furnace (Tianjin Tester Instrument Co., Ltd.); and ICP-OES spectrometer (iCAP 7000 SERIES, Thermo Scientific, USA) were used.

Benzoic acid (analytically pure, Tianjin Kemi Ou Chemical Reagent Co., Ltd.); 2006003 medicinal capsules (Guangdong Biological Co., Ltd.); petroleum ether (boiling range of 30~60°C) and petroleum ether (boiling range of 60~90°C) (analytically pure, Guangzhou Chemical Co., Ltd.); potassium hydroxide (analytically pure, Xiongda Chemical Co., Ltd.); nitric acid (analytically pure, Shanghai Kanglang Biotechnology Co., Ltd.); hydrochloric acid (analytically pure, Guangdong Wengjiang Chemical Reagent Co., Ltd.); sulphuric acid (analytical purity, Hubei Watson Chemical Technology Co., Ltd.); multielement mixed liquid standard samples (GNM-M218741-2013); and 30% hydrogen peroxide (analytically pure, Xilong Science Co., Ltd.) were also used.

Methods

The heat of combustion was determined using a bomb calorimeter for oxygen. The combustibility of the seasonings was determined by a thermogravimetric method. The fat content was determined using a fat detector. The calcium content was determined using a traditional analytical chemical titration method. The ash content of the seasonings was determined using a muffle furnace. The crude fibre content was determined using an F1600 automatic fibre detector. The determination of 19 trace elements was performed using microwave-based ICP-OES (Zhou and Huang, 2025b). On the basis of the heat of combustion, ash content, thermogravimetric parameters, calcium content, trace element content, fat content, and crude fibre content, the combustion stability and stoichiometric research of multiple indices of five seasonings in Guangxi, China were performed using gray pattern recognition (GPR), gray factor analysis (GFA), factor analysis (FA), entropy analysis (EA), and systematic cluster analysis (SCA) methods.

Results and discussion

Heat of combustion for seasoning

A heat measurement curve for bay leaf combustion was generated from the experimental data. The experiment was conducted three times. The Reynolds temperature ΔT curve is shown in Figure 1. Name of sample: First group of bay leaf test samples. Based on the calculations, $W_{cal\ bay\ leaf}$ = 29901.62063 J/°C, $Q_{capsule\ bay\ leaf}$ = 45473.1995 J/g, $\Delta m_{bay\ leaf}$ = 0.0880 g, $Q_{ignition\ wire}$ = 1400.8 J/g, $\Delta T_{bay\ leaf}$ = 0.340°C, $\Delta m_{ignition\ wire}$ = 0.0136 g, and the quality of empty capsules was 0.1010 g; based on $\Delta m_{bay\ leaf}$, $Q_v = W_{cal}\Delta T - Q_{ignition\ wire}\Delta m_{ignition\ wire} - Q_{capsule}\ m_{capsule}$, and $Q_{bay\ leaf}$ = 63121.6702 J/g.

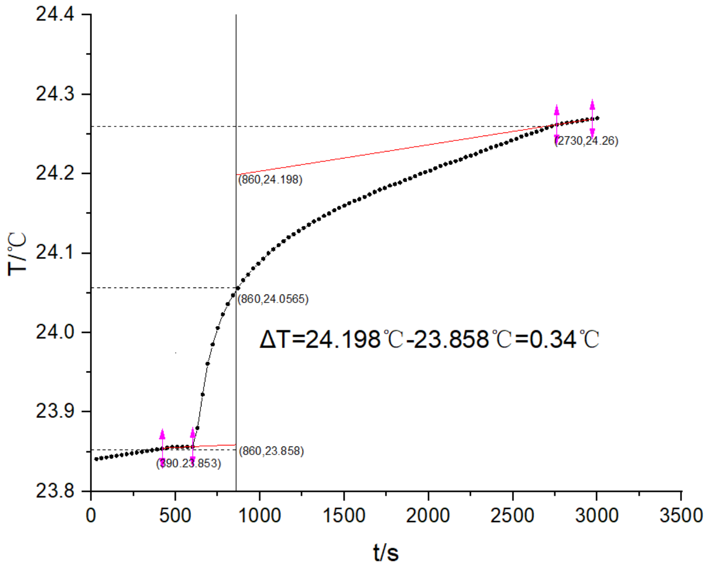


Figure 1. Reynolds temperature ΔT curve for bay leaf.

Similarly, the combustion heat (Sokolov *et al.*, 2020) of four seasonings in Guangxi, China—including vanilla, jambolan, fennel, and cumin—was determined, and the experiment was repeated three times. The heat of combustion data for five seasonings, namely, bay leaf, vanilla, jambolan, fennel, and cumin were 66467.3216, 74518.449, 54054.73973, 51923.2118, and 59077.839 J/g (CV < 0.03), respectively. The order of the heat of combustion of the five seasonings—bay leaf, vanilla, jambolan, fennel, and cumin—was vanilla > bay leaf > cumin > jambolana > fennel. The heat of combustion for the five test samples ranged between 51923~74518 J/g, and the CV was < 3%. The heat of combustion for vanilla was 74518.449 J/g, and vanilla had the highest energy level. Jambolan and fennel had combustion heats of 54054.7 and 51923.2 J/g, respectively, and their energy levels were relatively low. The heat of combustion reflects the total energy content of a food material and indicates the amount of heat released during complete oxidation. Although seasonings are used in relatively small quantities compared to staple foods, their energy contribution and chemical composition can still provide valuable insights into their nutritional density and functional characteristics. Considering the heat of combustion as significant physical data to determine the seasoning quality, the value of the energy of seasonings can be determined from the combustion heat for seasonings (Gao *et al.*, 2018).

Thermogravimetric analysis of five seasonings

Thermogravimetric analysis

Thermogravimetric analysis of bay leaves

The thermogravimetric data of the bay leaves are shown in Figures 2A1 and 2A2, and Table 1A, and indicate that decomposition started at approximately 53.9°C, which could explain the presence of minuscule molecules in the thermally desorbing sample. This resulted in a minor amount of loss in mass and a loss rate of 3.22%. The mass of the bay leaves started to decrease after heating at 142.1°C, at which point the process entered the second decomposition stage. The bay leaves subsequently further degraded as the temperature increased, and the remaining bay leaf mass was 31.21%. The DTG curve presented two peaks as the temperature increased, with inflection points at 96 and 336.3°C. Furthermore, as the temperature increased, the peak on the bay leaf DTA curve was not immediately obvious (Koran *et al.*, 2023).

Thermogravimetric analysis of vanilla

The thermogravimetric (dos Santos *et al.*, 2016; 2020; Santos *et al.*, 2018) data of vanilla are shown in Figures 2B1 and 2B2, and Table 1B. The data in Figures 2B1 and 2B2 indicate that decomposition started at 44.8°C, which could be attributed to the remaining minuscule molecules in the sample being thermally desorbed, causing a very small loss of mass in the sample and a loss rate of 8.49%. When the temperature increased to 163.85°C, the sample entered the second stage of decomposition. The vanilla sample began to lose a significant amount of mass until 440.1°C, at a loss rate of 54.1%. The sample subsequently further degraded as the temperature increased, and the mass of the residual sample was 29.74%.

When the temperature increased, the DTG curves had two peaks, with inflection points at 95.9 and 322.4°C. Additionally, with increasing temperature, the large exothermic peak in the vanilla DTA curve presented peak temperatures of 111.6 and 242.8°C, temperatures ranging from 85.6 to 156.7°C and 177.4 to 310.6°C, and peak areas of 351.9 and 387.3 J/g, respectively.

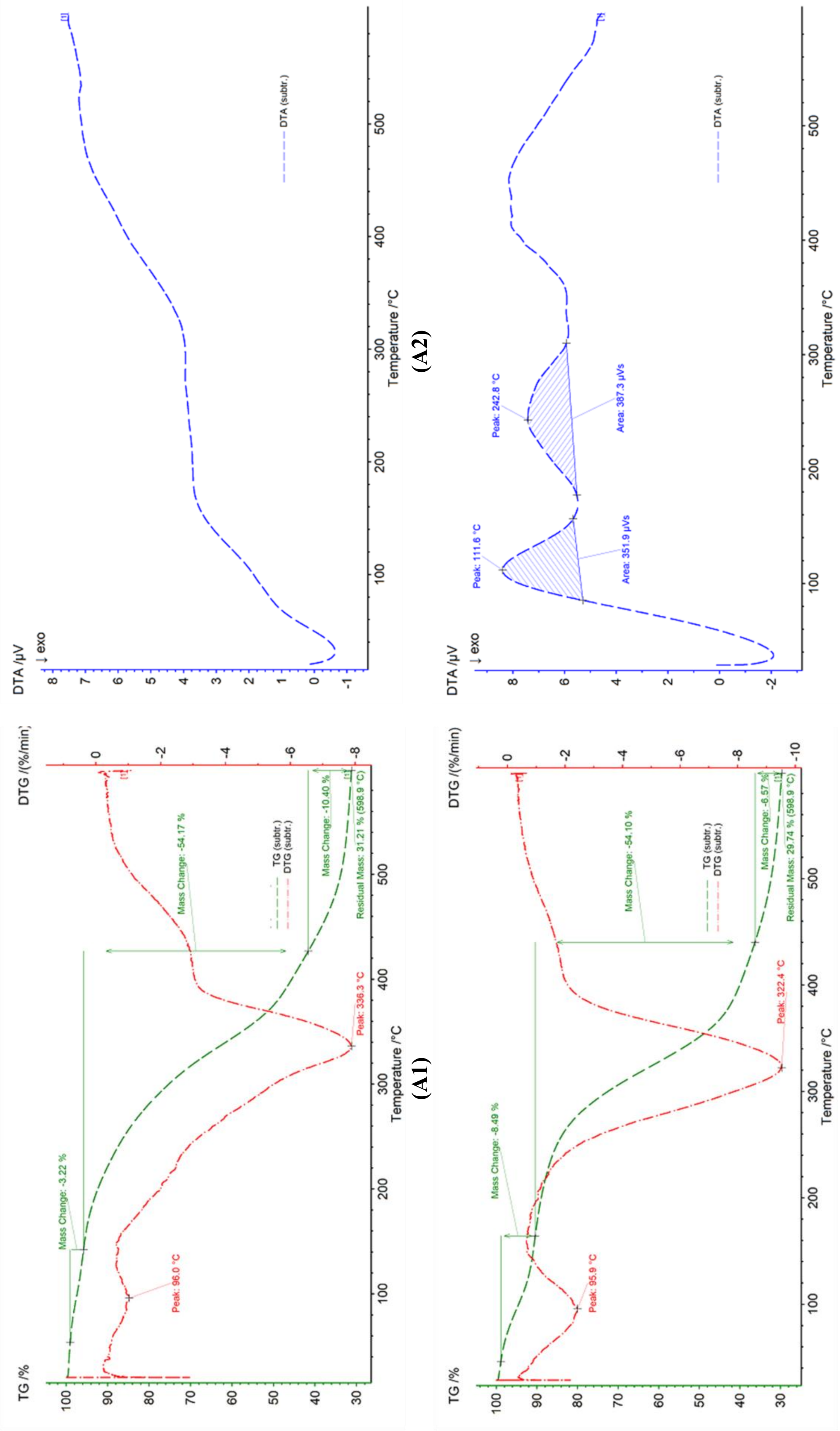
Thermogravimetric analysis of jambolan

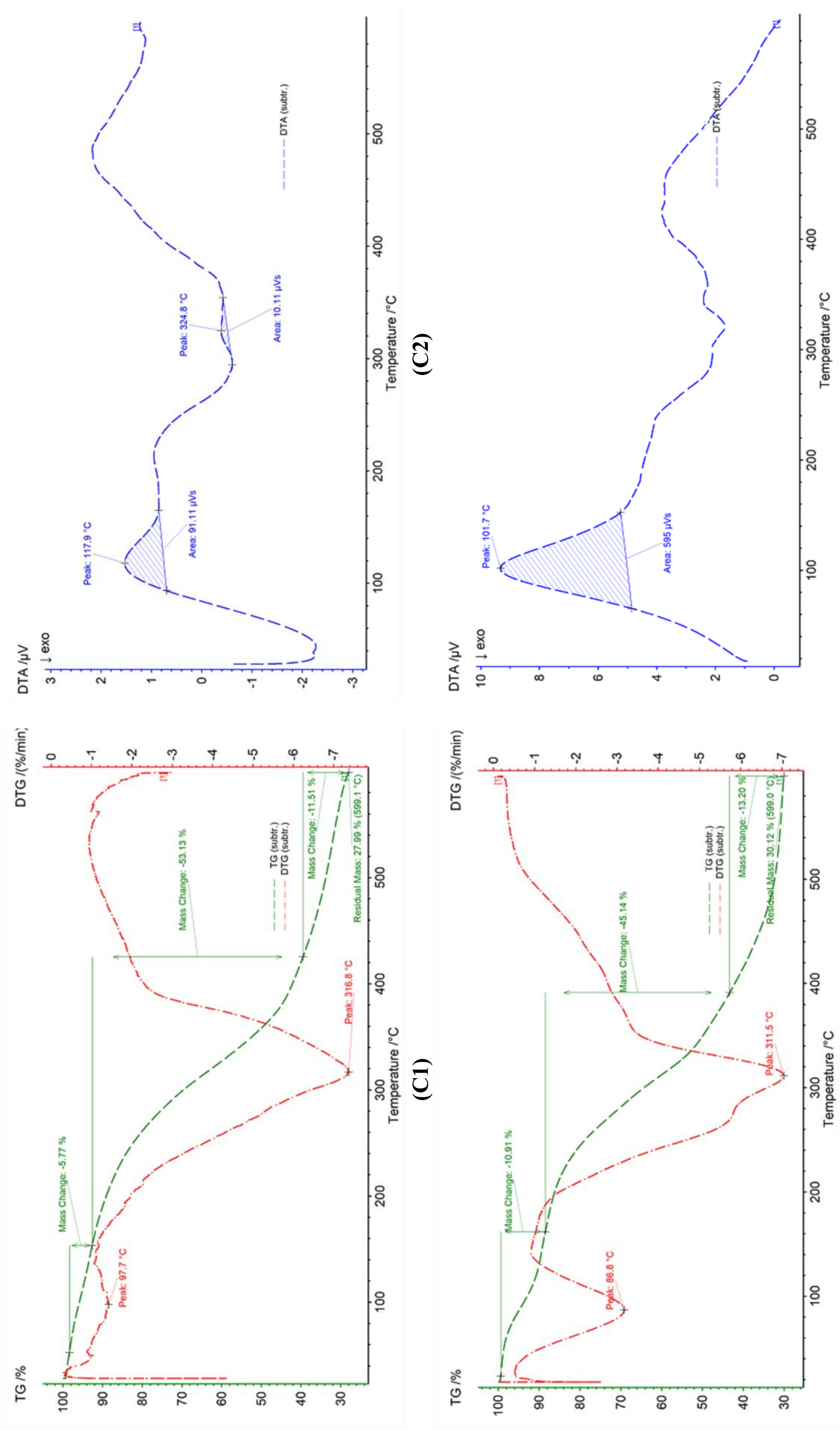
Jambolan thermogravimetric data are displayed in Figures 2C1 and 2C2, and Table 1C. As shown in Figures 2C1 and 2C2, the decomposition, which may be attributed to the presence of minuscule molecules in the sample being thermally desorbed, started at 51.7°C. This resulted in a minor mass loss, at a loss rate of 5.77%. After heating, the temperature increased to 151.5°C, and the sample entered the second phase of decomposition, in which a significant amount of mass was lost until 425.6°C, at a loss rate of 53.13%. The sample further degraded as the temperature increased, and the mass of the residual sample was 27.99%.

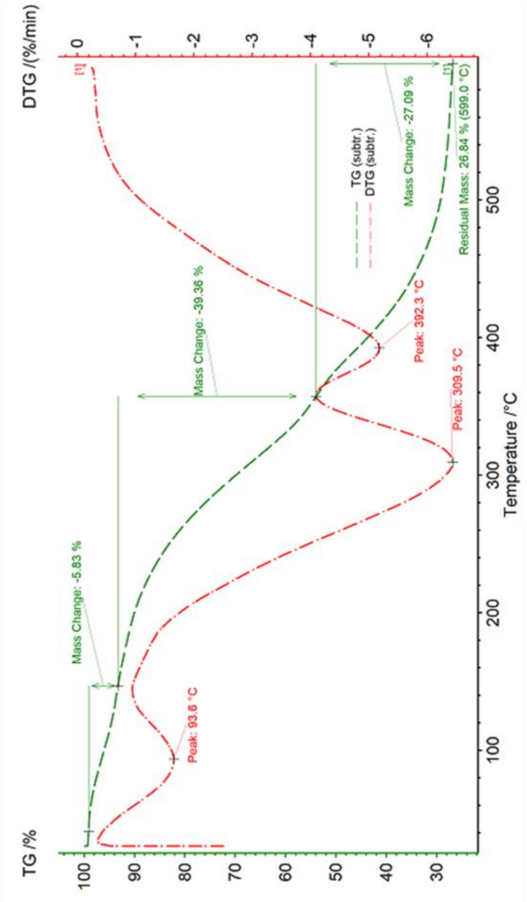
When the temperature increased, the DTG curve had two peaks, with inflection points at 97.7 and 316.8°C. Additionally, as the temperature increased, a large exothermic peak was observed in the DTA curve of jambolan, with peak values of 117.9 and 324.8°C, temperatures ranging from 93.4 to 165.9°C and 294 to 354°C, and peak areas of 91.11 and 10.11 J/g, respectively.

Thermogravimetric analysis of fennel

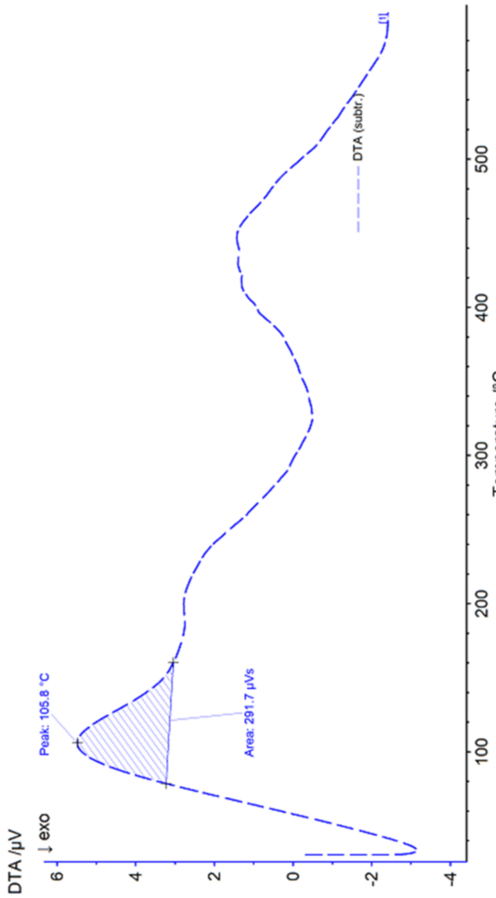
Information from the fennel thermogravimetric study is shown in Figures 2D1 and 2D2, and Table 1D. As shown in Figures 2D1 and 2D2, the decomposition, which may be attributed to the thermal desorption of a few minuscule molecules that were still present in the sample, started at approximately 23.2°C. Consequently, the sample experienced negligible mass loss, at a loss rate of 10.91%. The sample entered the second phase of decomposition at 161.7°C after a period of heating, and a substantial amount of mass was lost until 389.3°C, at a loss rate of 45.14%. As the temperature increased, the sample continued to degrade; its remaining mass was 30.12%.


(A1)
TG /%
DTG /(%/min)
Temperature /°C
Mass Change: -3.22 %
Mass Change: -54.17 %
Mass Change: -10.40 %
Residual Mass: 31.21 % (598.9 °C)
Peak: 96.0 °C
Peak: 336.3 °C
TG (subtr.)
DTG (subtr.)
(A2)
DTA /μV
↓ exo
DTA (subtr.)
(B1)
Mass Change: -8.49 %
Mass Change: -54.10 %
Mass Change: -6.57 %
Residual Mass: 29.74 % (598.9 °C)
Peak: 95.9 °C
Peak: 322.4 °C
(B2)
Peak: 111.6 °C
Area: 351.9 μVs
Peak: 242.8 °C
Area: 387.3 μVs


(C1)
(C2)
(D1)
(D2)
TG /%
DTG /(%/min)
DTA /µV
↓ exo
Temperature /°C
TG (subtr.)
DTG (subtr.)
DTA (subtr.)
Mass Change: -5.77 %
Mass Change: -53.13 %
Mass Change: -11.51 %
Residual Mass: 27.99 % (599.1 °C)
Peak: 97.7 °C
Peak: 316.8 °C
Mass Change: -10.91 %
Mass Change: -45.14 %
Mass Change: -13.20 %
Residual Mass: 30.12 % (599.0 °C)
Peak: 86.8 °C
Peak: 311.5 °C
Peak: 117.9 °C
Area: 91.11 µVs
Peak: 324.8 °C
Area: 10.11 µVs
Peak: 101.7 °C
Area: 595 µVs



(E1)



(E2)

Figure 2. TG, DTG, and DTA curves for bay leaf (**A1** and **A2**), vanilla (**B1** and **B2**), jambolan (**C1** and **C2**), fennel (**D1** and **D2**), and cumin (**E1** and **E2**).

Table 1. Thermogravimetric data for bay leaf **(A)**, vanilla **(B)**, jambolan **(C)**, fennel **(D)**, and cumin **(E)**.

(A)

Sample	Peak	Temperature (°C)	Loss rate (%)	Temperature for rapid weight loss (°C)
Bay leaf	Peak 1	53.9～142.1	3.22	96
	Peak 2	142.1～426.8	54.17	336.3
	Peak 3	426.8～600	10.4	—

(B)

Sample	Peak	Temperature (°C)	Loss rate (%)	Temperature for rapid weight loss (°C)
Vanilla	Peak 1	44.8～163.8	8.49	95.9
	Peak 2	163.8～440.1	54.1	322.4
	Peak 3	440.1～600	6.57	—

(C)

Sample	Peak	Temperature (°C)	Loss rate (%)	Temperature for rapid weight loss (°C)
Jambolan	Peak 1	51.7～151.5	5.77	97.7
	Peak 2	151.5～425.6	53.13	316.8
	Peak 3	425.6～600	11.51	—

(D)

Sample	Peak	Temperature (°C)	Loss rate (%)	Temperature for rapid weight loss (°C)
Fennel	Peak 1	23.2～161.7	10.91	86.8
	Peak 2	161.7～389.3	45.14	311.5
	Peak 3	389.3～600	13.2	—

(E)

Sample	Peak	Temperature (°C)	Loss rate (%)	Temperature for rapid weight loss (°C)
Cumin	Peak1	40.8～147	5.383	309.5
	Peak2	147～357	39.36	392.3
	Peak3	357～600	27.09	—

The fennel DTG curve presented two peaks as the temperature increased, with inflection points at 86.8 and 311.5°C. Furthermore, as the temperature increased, the DTA curves of fennel presented a large exothermic peak value of 101.7°C, a temperature range of 65.3 - 151.8°C, and a peak area of 595 J/g.

Thermogravimetric analysis of cumin

The thermogravimetric data for cumin are shown in Figures 2E1 and 2E2, and Table 1E. The data in Figures 2E1 and 2E2 indicate that decomposition began at 40.8°C, which could be attributed to the remaining minuscule molecules in the sample being thermally desorbed, resulting in a minor mass loss and a loss rate of 5.83%. After a period of heating, the sample temperature was 147°C, at which point the sample entered the second stage of decomposition. The sample continued to lose a significant amount of mass until 357°C, at a loss rate of 39.36%. As the temperature increased, the sample gradually disintegrated, resulting in 26.84% of the initial mass.

The DTG curves presented two peaks as the temperature increased, with inflection points at 93.6, 309.3, and 392.3°C. As the temperature increased, the cumin DTA curves presented a large exothermic peak at a peak temperature of 105.8°C, a temperature range of 78.6 to 160.7°C, and a peak area of 291.7 J/g.

Combustion stability of five seasonings

On the basis of the combustion parameter data of the five seasonings, a multi index assessment approach for combustion stability studies was developed. To assess the burning stability of food, thermogravimetric analysis was used to determine the combustion characteristics of seasoning particles at various heating rates. The correlation coefficient between every plan and the ideal plan that comprised the best indicators was calculated *via* the gray pattern recognition method. The correlation degree was determined from the correlation coefficient, and sorting and analysis were performed in accordance with the correlation degree to reach a conclusion.

The higher the F value is, the better the sampling result. On this basis, the F values were compared, and the evaluation results were obtained. Statistical analysis of bay leaf, vanilla, jambolan, fennel, and cumin was performed *via* MSEXCEL software, and the F values of the five seasonings—bay leaf, vanilla, jambolan, fennel, and cumin—were 0.5996, 0.3792, 0.2961, 0.4346, and 0.3344, respectively. On the basis of the thermogravimetric analysis results and the analysis of the combustibility of the seasonings, the order of the combustion stability of the five seasonings was bay leaf > fennel > vanilla > cumin > jambolan.

Crude fibre, fat, ash, and calcium contents

The crude fibre, fat, ash, and calcium contents of the five seasonings were tested and are shown in Table 2 (n = 3; CV% = 0.21%). Based on the data in Table 2, the order of the fat content (%) of the five seasonings was cumin > bay leaf > jambolan > vanilla > fennel; the order of the calcium content of the five seasonings was jambolan > bay leaf > vanilla > cumin > fennel; the order of the ash content of the five seasonings was fennel > cumin > vanilla > jambolan > bay leaf; and the order of the crude fibre content of the five seasonings was vanilla > bay leaf > fennel > jambolan > cumin. The contents of fat, calcium, and crude fibre in the seasonings can also provide minimal information about their nutritional value. The quality of seasonings was assessed on the basis of the fat, calcium, and crude fibre contents, which established a solid scientific basis for seasoning classification.

Table 2. Determination of fat, calcium, ash, and crude fibre contents in the five seasonings (n = 3; CV% < 0.21%).

Sample	Fat content (%)	Calcium content (%)	Ash (%)	Crude fibre (%)
Bay leaf	3.9758	5.8127	3.7778	31.0619
Vanilla	2.2145	4.2385	7.0421	33.1590
Jambolan	2.9097	10.1713	3.8320	24.2655
Fennel	0.3416	1.5162	11.0102	28.7373
Cumin	4.0187	1.7469	8.7744	11.5750

Trace elements of five seasonings

ICP-OES was used to analyse 19 trace elements, including Cd, Ba, Co, Cr, Al, Cu, Hg, K, Li, Mg, Fe, Sc, Ni, Zn, Mn, Na, Se, Sr, and Pb, *via* microwave digestion (Cuevas-Corona *et al.*, 2022; Giacomino *et al.*, 2022; Hika *et al.*, 2023; Ciriello *et al.*, 2023). The contents of 19 trace elements in the five seasonings are shown in Table 3A (μg/g; n = 6; CV% < 2.0%). The levels of the toxic elements Cd, Pb, and Hg were extremely low, which was consistent with the international regulations.

Trace element factor analysis of five seasonings

The eigenroots and variance contributions of the factor coefficient matrices for the trace elements Co, Cr, Cu, Al, Ba, Fe, Mg, Mn, Na, Ni, Sc, K, Li, Zn, Se, and Sr were obtained *via* factor analysis (Jafari *et al.*, 2021; Zhang *et al.*, 2021), as shown in Table 3B. Based on the data in Table 3B, the cumulative contribution rate of the first four main factors was 100.00%, and the first four main factors (λ > 1.0) had large eigenvalues. Four main influencing factors had the greatest effect on each explanatory factor. The best selection of four main related factors included 16 main components of bay leaf, vanilla, jambolan, and fennel from Laibin and cumin from Yulin in Guangxi, China, and five seasonings from China (Liu *et al.*, 2022).

Table 3C lists the component coefficient matrix after rotation, showing that the first principal

Table 3. (A) Data for the nineteen trace elements (μg/g; *n* = 6; and CV% < 2.0%); **(B)** factor characteristic root and variance contribution rates; **(C)** component coefficient matrix of the 16 trace elements; and **(D)** factor scores and comprehensive factor scores for the 16 trace elements in the 5 seasonings.

(A)

Element	Bay leaf	Vanilla	Jambolan	Fennel	Cumin
Al	8.2247 ± 0.0002	40.6219 ± 0.0017	34.9198 ± 0.0003	60.9438 ± 0.0010	31.9900 ± 0.0000
Ba	3.4102 ± 0.0001	1.8556 ± 0.0006	1.0020 ± 0.0000	3.6647 ± 0.0001	0.0498 ± 0.0000
Cd	0.1505 ± 0.0000	0.2508 ± 0.0001	0.1503 ± 0.0001	0.2008 ± 0.0000	0.2488 ± 0.0000
Co	0.2006 ± 0.0000	0.2006 ± 0.0001	0.3006 ± 0.0001	0.2510 ± 0.0001	0.3483 ± 0.0000
Cr	2.1565 ± 0.0001	2.0060 ± 0.0000	1.1022 ± 0.0000	7.1285 ± 0.0002	2.1393 ± 0.0001
Cu	15.7472 ± 0.0002	18.2046 ± 0.0001	29.1082 ± 0.0000	21.2851 ± 0.0006	19.4527 ± 0.0002
Fe	234.8546 ± 0.0011	231.5948 ± 0.0050	324.1483 ± 0.0007	316.3153 ± 0.0038	333.6816 ± 0.0007
Hg	1.3541 ± 0.0002	1.3541 ± 0.0004	1.4028 ± 0.0003	1.4056 ± 0.0003	1.3930 ± 0.0001
K	6649.9498 ± 0.1300	10521.5647 ± 0.0900	0.0000 ± 0.0000	9412.6506 ± 0.1800	—
Li	0.1003 ± 0.0000	0.2006 ± 0.0000	5.9619 ± 0.0000	0.2510 ± 0.0000	0.2985 ± 0.0000
Mg	1143.9318 ± 0.0190	1694.5838 ± 0.0080	—	1272.0884 ± 0.0070	—
Mn	149.1474 ± 0.0006	218.4554 ± 0.0021	25.4509 ± 0.0001	41.5161 ± 0.0005	50.7960 ± 0.0001
Na	413.3902 ± 0.0112	407.9238 ± 0.2062	—	780.1205 ± 0.0040	—
Ni	19.0572 ± 0.0002	24.5236 ± 0.0003	35.7715 ± 0.0009	4.1165 ± 0.0001	9.3035 ± 0.0001
Pb	4.0622 ± 0.0005	3.1595 ± 0.0008	5.6112 ± 0.0001	5.7229 ± 0.0001	4.3781 ± 0.0007
Sc	0.2006 ± 0.0000	0.2006 ± 0.0000	0.2004 ± 0.0000	0.2510 ± 0.0000	0.1990 ± 0.0000
Se	1.8054 ± 0.0006	0.9027 ± 0.0011	1.6533 ± 0.0008	1.2048 ± 0.0006	1.6418 ± 0.0003
Sr	12.7884 ± 0.0000	18.7061 ± 0.0002	8.0410 ± 0.0011	11.1446 ± 0.0002	63.9801 ± 0.0006
Zn	105.3159 ± 0.0005	38.6660 ± 0.0025	216.0321 ± 0.0012	36.1448 ± 0.0001	210.4975 ± 0.0036

(B)

Principal factor	Characteristic root	Contribution rate (%)	Cumulative contribution rate (%)
1	8.1300	50.8090	50.8090
2	3.9830	24.8940	75.7030
3	2.4810	15.5040	91.2070
4	1.4070	8.7930	100.0000
…	…	…	…

(C)

Element	Component coefficient matrix 1	Component coefficient matrix 2	Component coefficient matrix 3	Component coefficient matrix 4
Al	0.066	0.705	0.128	0.695
Ba	-0.725	0.551	0.147	-0.386
Co	0.978	0.037	-0.162	0.122
Cr	-0.202	0.968	-0.134	0.070
Cu	0.616	0.094	0.751	0.220
Fe	0.899	0.418	0.040	0.123
K	-0.921	0.322	-0.063	0.210
Li	0.524	-0.203	0.827	0.013
Mg	-0.964	0.190	-0.074	0.170
Mn	-0.833	-0.494	-0.195	0.157
Na	-0.711	0.702	-0.043	-0.005
Ni	0.023	-0.677	0.734	0.050
Sc	-0.148	0.984	0.048	0.092

Se	0.522	-0.211	0.004	-0.827
Sr	0.533	-0.211	-0.803	0.163
Zn	0.880	-0.414	0.078	-0.221

(D)

Sample	F_1	F_2	F_3	F_4	F	Ranking
Bay leaf	-0.76749	-0.39594	-0.17907	-1.55632	-0.65309	5
Vanilla	-1.08172	-0.70959	-0.05439	1.23426	-0.62618	4
Jambolan	0.90483	-0.37985	1.49564	-0.00763	0.59650	1
Fennel	-0.22645	1.76549	0.05136	0.17065	0.34734	2
Cumin	1.17083	-0.28012	-1.31354	0.15904	0.33543	3

factor F_1 of the correlation coefficient reflected the data for the original variables Fe, Se, Co, Sr, and Zn. The second principal factor F_2 of the correlation coefficient reflected the data for the primary variables Al, Ba, Cr, K, Mg, Na, and Sc. The data for the initial variables Cu, Li, and Ni were mostly reflected in the third principal factor of the correlation coefficient, F_3. The information regarding the original variable Mn was primarily reflected in the fourth main factor of the correlation coefficient, F_4.

Table 3D lists the factor scores and total factor scores, showing that the order of the 16 trace element contents in the five seasonings was jambolan > fennel > cumin > vanilla > bay leaf. Jambolan presented the highest concentration of trace elements among all the samples analysed, indicating the presence of elements such as Zn, Se, and Cu in various forms within plant tissues. The chemical composition of the soil, intrinsic plant properties, geographic location, and specific climatic conditions can result in significant variations in trace element contents (Huangfu *et al.*, 2025).

Construction of seasoning evaluation system

Construction of selection evaluation system through gray factor analysis

By calculating the correlation coefficient between every solution and the ideal solution that comprised the most effective indications, a multi index analysis of the comprehensive assessment of the gray correlation coefficient can be used to evaluate the performance of a method. Gray factor analysis is performed on the basis of the gray correlation coefficient (Ewunie *et al.*, 2022; Li *et al.*, 2022). Based on the combustion heat data X_1, fat content data X_2, calcium content data X_3, ash data X_4, crude fibre data X_5, the first-stage loss rate X_6, first-stage weight loss fastest temperature X_7, second-stage loss rate X_8, second-stage weight loss fastest temperature X_9, third-stage weight loss percentage X_{10}, residual mass percentage X_{11}, and first-phase peak area X_{12}, a multi index analysis and method of extensive evaluation were established through gray factor analysis for the five seasonings.

The results of the contribution rates and characteristic roots for the variance of the gray correlation coefficient factor analysis for the five seasonings are listed in Table 4A, which shows that the cumulative contribution rate of the first four major components was greater than 85%, so the first four main factors were selected, which represented 100% of the combustion heat X_1, fat content X_2, calcium content data X_3, ash content data X_4, crude fibre content data X_5, first-stage loss rate X_6, first-stage weightlessness fastest temperature X_7, second-stage weight loss percentage X_8, second-stage weightlessness fastest temperature X_9, third-stage weight loss percentage X_{10}, residual mass percentage X_{11}, and first-phase peak area X_{12} for the five seasonings produced in Guangxi.

The rotated component matrix of the five seasonings is shown in Table 4B, which shows that the first gray correlation value factor had high gray correlation coefficients for the ash index X_4, the first-stage loss rate X_6, the second-stage weightlessness fastest temperature X_9, and the first-phase peak area X_{12}, which reflected mainly the ash content and combustion stability of the seasonings. The second common factor had a large load on the index calcium content X_3, crude fibre X_5, first-stage weightlessness fastest temperature X_7, second-stage weight loss percentage X_8, and residual mass percentage X_{11}. The calcium level of the five seasonings was also very high, suggesting that while seasonings were only consumed in modest amounts, they might be used as a source of calcium supplementation. The third

Table 4. Characteristic root of the correlation coefficient and the variance contribution rate **(A)** and rotated component matrix **(B)** of the five seasonings.

(A)

Principal factor	Characteristic root	Contribution rate (%)	Cumulative contribution rate (%)
1	5.242	43.680	43.680
2	3.698	30.814	74.493
3	1.999	16.658	91.151
4	1.062	8.849	100.000
…	…	…	…

(B)

Indices	1	2	3	4
Combustion heat X_1	-0.242	0.397	0.099	0.88
Fat content X_2	-0.904	-0.414	0.031	0.105
Calcium content X_3	-0.131	0.052	-0.964	-0.227
Ash X_4	0.69	-0.183	0.659	-0.238
Crude fibre X_5	0.091	0.96	0.02	0.263
The first stage weight loss percentage X_6	0.943	0.11	0.295	-0.111
First stage weightlessness fastest temperature X_7	-0.838	0.486	0.189	-0.164
The second stage weight loss percentage X_8	-0.253	0.763	-0.539	0.253
Second stage weightlessness fastest temperature X_9	0.837	-0.443	-0.235	0.22
The third stage weight loss percentage X_{10}	-0.154	-0.927	0.341	-0.012
Residual mass percentage X_{11}	-0.169	0.93	0.313	-0.092
The first phase peak area X_{12}	0.795	0.111	0.524	-0.284

common factor had a large load on the weight loss percentage X_{10} of the third stage, which reflected mainly the weight loss percentage of seasoning combustion. The fourth common factor had a large load on the index combustion heat X_1 and fat content X_2, primarily reflecting the seasoning energy. The seasoning energy value can be expressed by the combustion heat and level of fat. The heat of combustion and fat content are crucial physical data for quantifying seasoning quality, analysing the nutritive value of food from an energy standpoint, and providing a sound scientific basis for seasoning classification.

Construction of complete evaluation system via entropy analysis

The entropy technique was used to create a comprehensive multi index evaluation system for seasonings comprising bay leaf, vanilla, jambolan, and fennel in Guangxi, China, on the basis of thermogravimetric parameters, calcium, ash, combustion heat, trace element content, crude fibre, and fat content data from five seasonings. This topic evaluates the unpredictability and disarray of an event by computing the value of entropy and evaluates the dispersion of an index on the basis of the value of entropy, in accordance with the properties of entropy (Zhou *et al.*, 2022b). The effect (weight) of an index on a comprehensive evaluation increases with the degree of dispersion of an index, whereas the entropy value decreases. The F value was calculated by weighing five seasonings *via* the entropy approach. The evaluation sample value was determined *via* the weighted summation method. The higher the comprehensive score F is, the better the sample effect. All F values were compared; that is, an evaluation conclusion was reached. As determined by MSEXCEL, the F values of the five seasonings were 0.3755, 0.3651, 0.3974, 0.4759, and 0.3421, respectively. The findings from the comprehensive multi index analysis revealed that the order for the combustion heat, fat content, calcium content, combustibility, ash content, crude fibre content, and trace element content of the five seasonings produced in Guangxi was fennel > jambolan > bay leaf > vanilla > cumin. From a nutritional standpoint, the concentrations of fat, fibre, ash, and trace elements can substantially affect the nutritional value and digestibility of condiments (Wang, 2025).

Comprehensive evaluation system construction via systematic cluster analysis

The numerous characteristics of the sample serve as a basis for the systematic clustering analysis, and the coefficient of correlation is used to create the clustering method diagram. Based on the level of affinity of the sample, classification is performed. Every case is categorised into separate classes, with individuals in the same class having more similarities and individuals in multiple categories having more differences (Nury *et al.*, 2022; Arrona-Cardoza *et al.*, 2023). In Guangxi, a multi index thorough cluster analysis method for combustion heat, seasoning combustibility, calcium content, fat content, trace element content, crude fibre content, and ash content data for seasonings was constructed. The systematic cluster analysis tree diagrams are shown in Figure 3. As shown in Figure 3, the five seasonings were separated into three groups on the basis of the findings of a systematic cluster analysis. The fennel constituted a class, the bay leaf and vanilla formed one class, and the jambolan and cumin formed another class. We determined the similarity level and genetic connections between the attributes of seasonings *via* systematic cluster analysis, which can facilitate the classification of seasoning. We also determined the degree of resemblance and genetic relationship between the characteristics of seasonings from various locations *via* methodical cluster analysis, which can also facilitate the classification of seasonings.

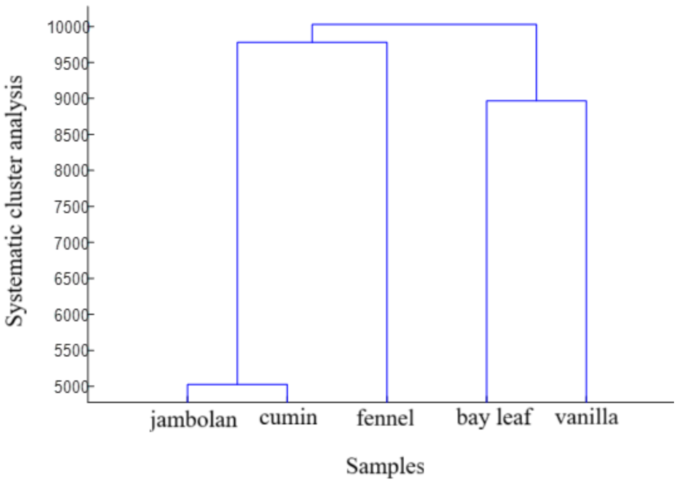


Figure 3. Tree diagram of the systematic cluster analysis of multiple indices for the five seasonings.

Conclusion

In the present work, a multi indicator analysis of 19 trace elements, fats, and other components of five seasonings (bay leaf, vanilla, jambolan, fennel, and cumin) from Guangxi, China was conducted. The heat of combustion, ash content, thermogravimetric parameters, calcium content, trace element content, fat content, and crude fibre content were determined for each season. Gray pattern recognition, gray factor analysis, factor analysis, entropy analysis, and systematic cluster analysis methods were used to analyse the data. The results revealed the order of combustibility, fat content, calcium content, and ash level among the seasonings. The entropy method was used to construct a comprehensive multiple index evaluation order. Systematic cluster analysis separated the five seasonings into three groups. The present work provided not only an innovative approach for the quality assessment of seasonings by integrating thermogravimetric analysis with nutritional and elemental data, but also a solid scientific basis for the extensive development and classification of seasoning products.

The present work contributed to the integration of thermogravimetric analysis (TGA) with nutritional and elemental data, which established a comprehensive framework for the evaluation of seasonings. This approach combined the combustibility, heat of combustion, fat content, calcium content, ash content, and trace element content into a cohesive multi index system, providing a holistic perspective on the properties of the five seasonings. The application of advanced analytical methods, such as gray pattern recognition (GPR), entropy analysis (EA), and systematic cluster analysis (SCA) facilitated a nuanced classification of seasonings on the basis of multiple properties to improve quality control and resource management. The limitations of the present work were attributed to the use of three samples (n = 3) for each seasoning, resulting in a small sample size. The multi index evaluation system has significant potential for application within the food industry, particularly for optimising seasoning blends. This system ensures that seasoning not only improves flavour but also preserves nutritional integrity and thermal stability during cooking processes. These considerations are particularly pertinent to processed foods and ready-to-eat meals. Insights into fat content, trace element content, and combustion stability can provide healthconscious consumers with valuable information about the nutritional value and cooking properties of seasonings, facilitating more informed dietary choices. Furthermore, the present work contributed to the sustainable development of seasoning resources, especially in regions such as Guangxi, by identifying seasonings with optimal nutritional properties and combustion behaviour that are consistent with sustainable agricultural practices.

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