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Entropy analysis and grey correlation coefficient cluster analysis of multiple indexes of 5 kinds of condiments

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Abstract

Five condiments, including cinnamon, tangerine peel, clove, licorice, amomum, were selected as the research objects in Guangxi, China. The combustion heat, differential thermal gravimetric analysis, fat, crude fiber, trace element, calcium and ash content data for 5 condiments were determined. According to the combustion heat, differential thermal gravimetric analysis, fat, crude fiber, trace element, calcium and ash content data of condiments, we constructed a systematic multi-index comprehensive evaluation system using entropy analysis, gray pattern recognition and grey correlation coefficient cluster analysis. The multi-index comprehensive evaluation system established by the research provides a new idea for the nutritional evaluation of condiments. This research provides a strong scientific basis for the large-scale development of condiment resources and condiment classification research, basic support for the selection of condiment raw materials.

Keywords: condiments; entropy method; thermo gravimetric analysis; ICP-OES; trace elements.

Practical Application: The multi-index comprehensive evaluation system established by the research provides a new idea for the nutritional evaluation of condiments. This research provides a strong scientific basis for the large-scale development of condiment resources and condiment classification research, and basic support for the selection of condiment raw materials.

1 Introduction

Condiments are auxiliary food that can increase the color, aroma and taste of dishes, promote appetite (Chungchunlam et al., 2016; Tsuboi & Suzuki, 1974; Van Wymelbeke et al., 2020), and benefit human health. Its main function is to improve the quality of dishes and meet the sensory needs of consumers, so as to stimulate appetite, improve human health (Aheto, 2020).

Quanzeng et al. (2020) put forward to investigate the differences of volatile substances in cinnamon from 5 different producing areas by Cluster analysis and principal component analysis (PCA), the results showed that 127 components were detected in cinnamon from 5 areas, including 17 alcohols, 8 esters, 31 alkenes, 6 aldehydes, 3 phenols and 62 others. The main volatile components of cinnamon are cinnamaldehyde, α-muurolene, α-copaene, γ-muurolene. As potential characteristic markers, cinnamaldehyde, α-copaene and anise could be used to distinguish cinnamon from 5 different producing areas, which provided reference for the comprehensive utilization of cinnamon from 5 different producing areas.

Luowen et al. (2021) analyzed the volatile components of Xinhui Citri Reticulatae Pericarpium and Citri Reticulatae Pericarpium from other habitats by headspace solid-phase microextraction two-dimensional gas chromatography time-of-flight mass spectrometry (HS/SPME-GC × GC-TOFMS) combined with chemometrics. The volatile components of Citri Reticulatae Pericarpium were enriched and concentrated by headspace solid-phase microextraction (HS-SPME). The volatile components were analyzed by two-dimensional gas chromatography time-of-flight mass spectrometry. The fingerprint chromatograms were used for distinguishing Xinhui Citri Reticulatae Pericarpium from different sources. Canvas software was used to obtain the qualitative information of the volatile components and the relative peak areas of the samples. Principal component analysis (PCA) and orthogonal partial least squares discrimination analysis (OPLS-DA) were used to differentiate the compounds between Xinhui Citri Reticulatae Pericarpium and others. The results showed that HS/SPME-GC × GC-TOFMS combined with chemometrics is promising method for identifying Xinhui Citri Reticulatae Pericarpium, and proposed a new strategy to evaluate the quality ofother traditional Chinese medicines.

The extract and essential oil of clove (Syzygium aromaticum) are widely used because of their medicinal properties (Bachiega et al., 2012). Licorice (Gancao) is derived from the dried roots and rhizomes of Glycyrrhiza species (Leguminosae) and appears as a component herb in about 60% of traditional Chinese medicine (TCM) prescriptions (Ishimi et al., 2019; Kitagawa et al., 1997; Li et al., 2018; Shan et al., 2021; Xu et al., 2013).Amomum tsao-ko, as an edible and medicinal variety, has been cultivated for more than 600 years in China (Qin et al., 2021).

Gao et al. (2018) took combustion heat as an important physical data to measure the quality of teas when studying the quality of 12 kinds of teas, and provided a new idea and method

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for evaluating the quality of similar foods from the perspective of energy.

Through retrieval, it is found that the application of thermogravimetric analysis (Bajaj et al., 2020; Chen et al., 2020b; Gong et al., 2021; Ingale et al., 2020; Moseson et al., 2020; Olopade et al., 2020; Porshnov et al., 2020; Pyra et al., 2020; Ren et al., 2020; Wu et al., 2020) technology in the evaluation of condiment combustion stability has not been reported. Therefore, the research on the combustion heat and thermogravimetric analysis of condiments has important theoretical and practical significance,which can make up for the gaps in this area and provide scientific basis and research significance for the study of condiment quality. 5 condiments in different regions of China, including cinnamon, tangerine peel, clove, licorice, amomum, were selected as the research objects. The multi-index comprehensive evaluation system (Jiang et al., 2020; Zhang et al., 2020) of five kinds of condiments was established, and the entropy method and cluster analysis method were used to evaluate the food classification. The quality of condiments was evaluated by stoichiometric method from the aspect of food nutrition, which provided a strong scientific basis for the large-scale development of condiment resources and the research of condiment classification.

2 Materials and methods

2.1 Materials

Five condiments, including cinnamon (produced in June 2018, Latin name: Cinnamomum tamala (Bauch.-Ham.) Nees et Eberm), tangerine peel (produced in July 2018, Latin name: Pericarpium Citri Reticulatae), clove (produced in June 2018, Latin name: Syringa oblata Lindl.), licorice (produced in September 2018, Latin name: Glycyrrhiza uralensis Fisch.), amomum (produced in September 2018, Latin name: Amomum villosum Lour.) from Laibin, Guangxi, China, were selected as the research objects. Samples were finely ground with a mortar and sieved through 40 mesh pharmacopoeias.

2.2 Methods

Instruments and reagents

Materials used included a BH-series combustion heat experimental measurement device, oxygen cylinder, oxygen meter, grinder, sheet press, ignition wire (nickel-chromium wire, Changsha Changxing Higher Education Instrument Equipment Co., Ltd.), electronic balance (model FA2004, Shanghai Shunyu Hengping Scientific Instrument Co., Ltd.), benzoic acid (AR, Tianjin KERMEL Chemical Reagent Co., Ltd.), medicinal capsules, STA 2500 thermogravimetric analyzer (NETZSCH, Germany), crucible, SE206 fat tester, analytical balance, filter paper, a 100 mL beaker, drying oven, petroleum ether (China Jinan Alva Instrument Co., Ltd.), an F1600 automatic fiber tester, air drying oven, muffle furnace, crucible, filter bag, acid- and alkali-resistant pen, tertiary water, sulfuric acid solution (0.13 mol/L), potassium hydroxide solution (0.23 mol/L), hydrochloric acid solution (0.5 mol/L), petroleum ether (China Jinan Alva Instrument Co., Ltd.), an iCAP7200 ICP–OES (Thermo Scientific, USA), CEM MARS-6 microwave digestion instrument (CEM, USA), Milli-Q ultrapure water preparation system (Millipore, USA), AUY120 millionth electronic analytical balance (Shimadzu Company), nitric acid, hydrogen peroxide (super pure, Guangzhou Chemical Reagent Co., Ltd.) and ultrapure water prepared in-house.

Methods

The combustion heat, thermo gravimetric analysis, determination of calcium content, fat determination and ash determination data were determined (Zhou et al., 2022c); Crude fiber contents (Zhou et al., 2022d) and trace element contents (Ikem & Egilla, 2008; Misic et al., 2022) were determined. According to the combustion heat, thermo gravimetric parameters, fat contents, crude fiber contents, calcium content contents, trace element contents and ash contents, entropy analysis and grey correlation coefficient cluster analysis of multiple indexes for 5 kinds of condiments were performed in Guangxi, China.

3 Results and discussion

3.1 Determination of combustion heat of condiments

1) According to the experimental data, the combustion heat measurement curve of the cinnamon was drawn. The experiment was repeated three times. The ΔT Curve of Reynolds temperature is shown in Figure 1. Sample name: the first group of experimental samples of cinnamon. According to the calculation, $W_{cal\ average}$ = 29901.62063 J/°C, $Q_{capsule\ average}$ = 45473.1995 J/g, $\Delta m_{cinnamon}$ = 0.0975 g, $Q_{ignition\ wire}$ = 1400.8 J/g, $\triangle T$ = 0.363 °C, $\Delta m_{ignition\ wire}$ = 0.0113 g, the actual mass of ignition wire involved in the reaction was 0.0098 g, the mass of the sample was 0.2586 g, the mass of the empty capsule was 0.9999 g, according to, $\triangle m_{sample}\ Qv = W_{cal}\triangle T - Q_{ignition\ wire}\ \triangle m_{ignition\ wire} - Q_{capsule}\ m_{capsule}$, $Q_{cinnamon}$ = 63311.8869 J/g.

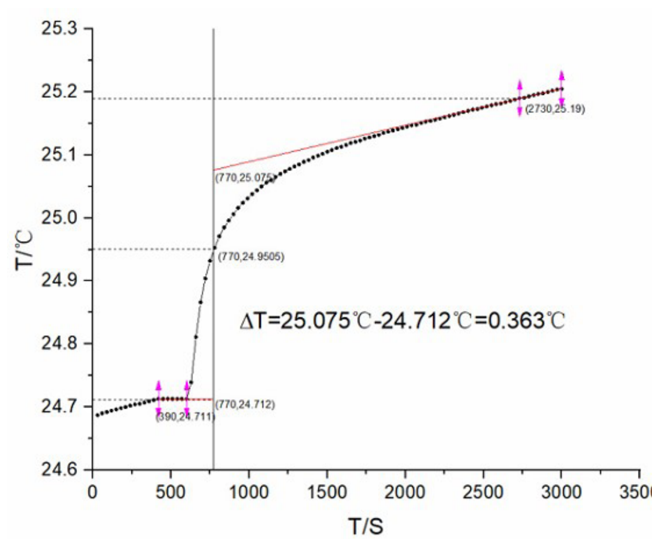

Figure 1. ΔT curve of Reynolds temperature of cinnamon.

2) Similarly, determine the combustion heat of 4 condiments in Guangxi, China, including tangerine peel, clove, licorice, amomum, and repeat the test for three times. The heat of combustion data of 5 kinds of condiments are shown in Table 1. According to Table 1, the order of combustion heat of 5 condiments in Guangxi, China, including cinnamon, tangerine peel, clove, licorice, amomum, was tangerine peel > amomum > cinnamon > licorice > clove. The combustion heat of the five condiment test samples had ranged from 39815.33 to 98298.34 J/g, CV% < 3%. The combustion heat of tangerine peel was 98298.344 J/g, and the energy was the highest. The combustion heat of clove was 39815.3346 J/g, and the energy was relatively small. Combustion heat was regarded as an important physical data to measure condiment energy (Gao et al., 2018).

3.2 Thermo gravimetric analysis of 5 kinds of condiments

The results of thermo gravimetric analysis

1) Thermo gravimetric analysis of cinnamon

(Abbinante et al., 2020; Aqel et al., 2021; Assali et al., 2020; Bashiri et al., 2021) The thermo gravimetric data of cinnamon are shown in Figure 2, Figure 3 and Table 2. It can be seen from Figure 2 and Figure 3 that the decomposition began at 36.3 °C, which might be due to the pyrolysis and absorption of residual small molecular substances in the sample, resulting in a small amount of mass loss of the sample, and the loss rate was 11.68%. After a period of heating up, the temperature reached 174.8 °C, into the second stage of decomposition, the sample began to appear a lot of mass loss, until 425.9 °C, the loss rate was 47.53%; as the temperature continued to rise, the sample was further decomposed, and the mass of the remaining sample was 32.88%.

(Boruah et al., 2021; Brenner & Weichold, 2020) With the increase of temperature, the DTG curve showed two peaks, and the inflection points of the peak shape were 98.1 °C and 320.5 °C, respectively. In addition, with the increase of temperature, the DTA curve of cinnamon had a wide exothermic peak, with the peak of 104.9 °C, the temperature range of 61.7 °C-177.3 °C, peak area of 1315J/g.

Table 1. Combustion heat of condiments (n = 3).

Sample	$Q_{Vaverage}/(J{\cdot}g^{-1})$	CV/%
Cinnamon	68786.55207	CV < 0.03
Tangerine peel	98298.34427	
Clove	39815.3346	
Licorice	54099.765	
Amomum	87863.70147	

2) Thermo gravimetric analysis of tangerine peel

The thermo gravimetric (Santos et al., 2020; Santos et al., 2016; Santos et al., 2018) data of tangerine peel are shown in Figure 4, Figure 5 and thermo gravimetric analysis data are shown in Table 3. It can be seen from Figure 4 and Figure 5 that the decomposition began at 140.5 °C, which might be due to the pyrolysis and absorption of residual small molecular substances in the sample, resulting in a small amount of mass loss of the sample, and the loss rate was 31.59%. After a period of heating up, the temperature reached 287.4 °C, entering the second stage of decomposition, the sample began to appear a lot of mass loss, until 433.8 °C, the loss rate was 28.9%; Then, as the temperature continued to rise, the sample was further decomposed, and the remaining sample mass was 22.44%.

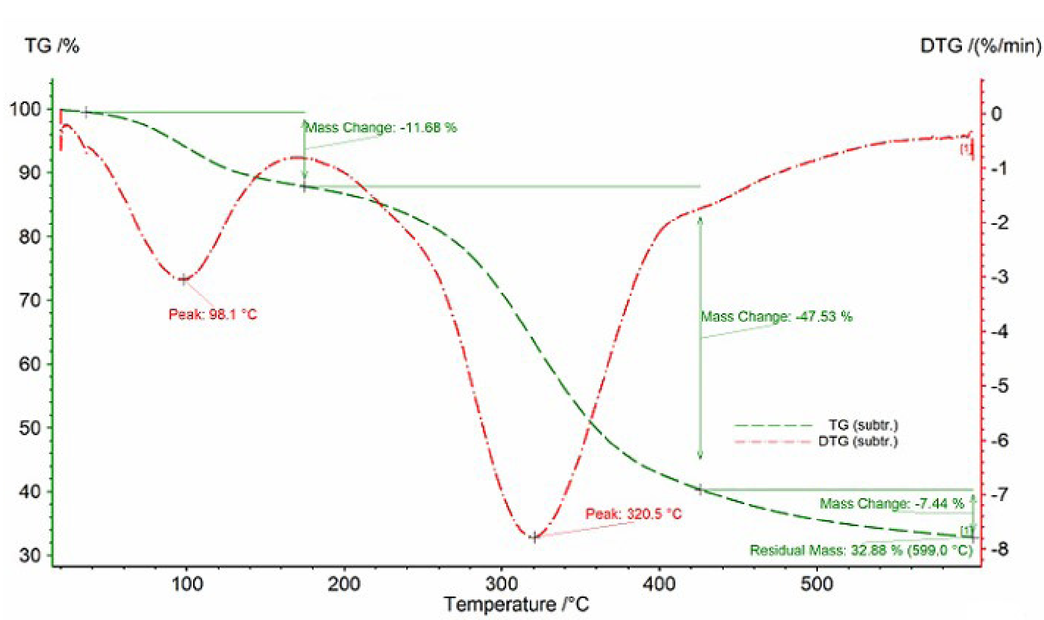

Figure 2. Thermo gravimetric (TG), derivative thermo gravimetric (DTG) curves of cinnamon.

With the increase of temperature, the DTG curve showed two peaks, and the inflection points of the peak shape were 91.4 °C, 229.8 °C and 331.2 °C, respectively. In addition, with the increase of temperature, the DTA curve of tangerine peel had a wide exothermic peak, with the peak value of 101.1 °C, the temperature range of 67.6 °C-154.2 °C, and the peak area of 609.7 J/g.

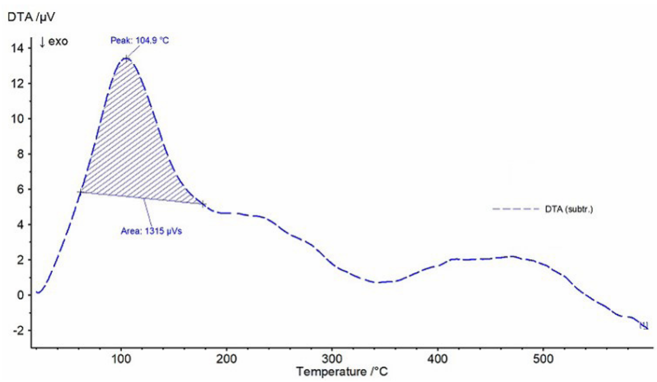

Figure 3. Differential thermal analysis (DTA) curves of cinnamon.

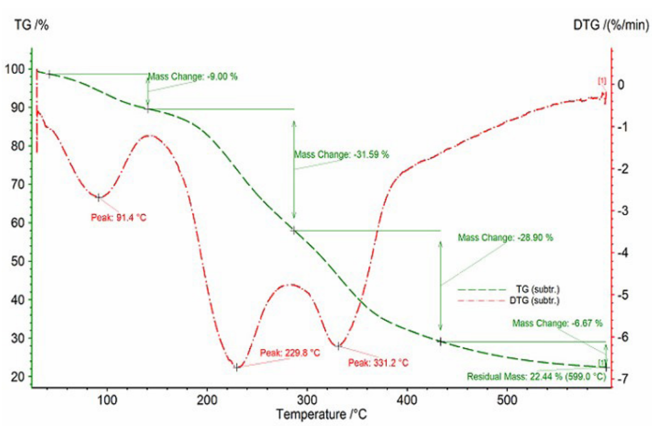

Figure 4. Thermo gravimetric (TG), derivative thermo gravimetric (DTG) curves of tangerine peel.

3)Thermogravimetric analysis of clove

The thermo gravimetric data of clove are shown in Figure 6, Figure 7 and Table 4. It can be seen from Figure 6 and Figure 7 that the decomposition began at 75.1 °C, which might be due to the pyrolysis and absorption of residual small molecular substances in the sample, resulting in a small amount of mass loss of the sample, and the loss rate was 55.03%. After a period of heating up, the temperature reached 427.9 °C, entering the second stage

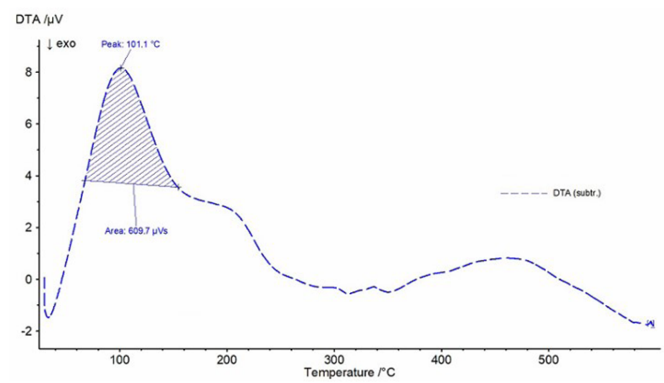

Figure 5. Differential thermal analysis (DTA) curves of tangerine peel.

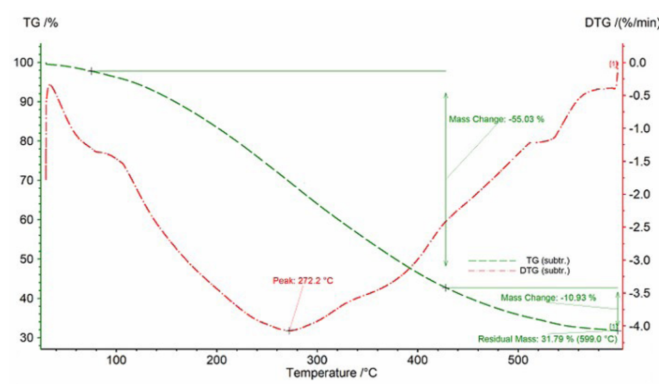

Figure 6. Thermo gravimetric (TG), derivative thermo gravimetric (DTG) curves of clove.

Table 2. TG-DTG data of cinnamon.

Sample	Project	Temperature range/°C	Percentage weight loss/%	The fastest weight loss temperature/°C
Cinnamon	Peak 1	36.3~174.8	11.68	98.1
	Peak 2	174.8~425.9	47.53	320.5
	Peak 3	425.9~600	7.44	—

Table 3. TG-DTG data of tangerine peel.

Sample	Project	Temperature range/°C	Percentage weight loss/%	The fastest weight loss temperature/°C
Tangerine peel	Peak 1	140.5~287.4	31.5	229.8
	Peak 2	287.4~433.8	28.9	331.2
	Peak 3	433.8~600	6.67	—

of decomposition, the sample began to appear a lot of mass loss, until 600 °C, the loss rate was 10.93%; Then, as the temperature continued to rise, the sample was further decomposed, and the remaining sample mass was 31.79%. With the increase of temperature, the DTG curve showed two peaks, and the inflection point of the peak shape was 272.2 °C. In addition, with the increase of temperature, the DTA curve of clove had a broad exothermic peak, with the peak temperature of 105.7 °C, 191.2 °C, the temperature range of 81.5 °C-147.7 °C, 160.2 °C-214.8 °C, peak areas of 232.2 J/g, 48.33 J/g (Lorenzo et al., 2021; Zhou et al., 2022a; Zhou et al., 2022b).

4)Thermo gravimetric analysis of licorice

The thermo gravimetric analysis data of licorice are shown in Figure 8, Figure 9 and Table 5. It can be seen from Figure 8 and Figure 10 that the decomposition began at 42.4 °C, which might be due to the pyrolysis and absorption of the residual small molecular substances in the sample, resulting in a small mass loss of the sample, and the loss rate was 9.48%. After a period of heating up, the temperature reached 164.1 °C, entering the second stage of decomposition, the sample began to appear a lot of mass loss, until 441.2 °C, the loss rate was 6.35%; Then,

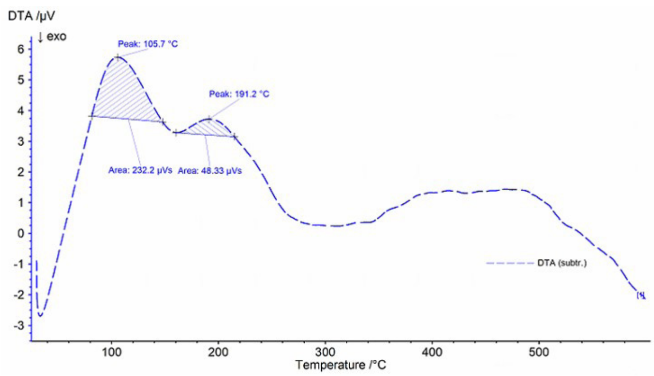

Figure 7. Differential thermal analysis (DTA) curves of clove.

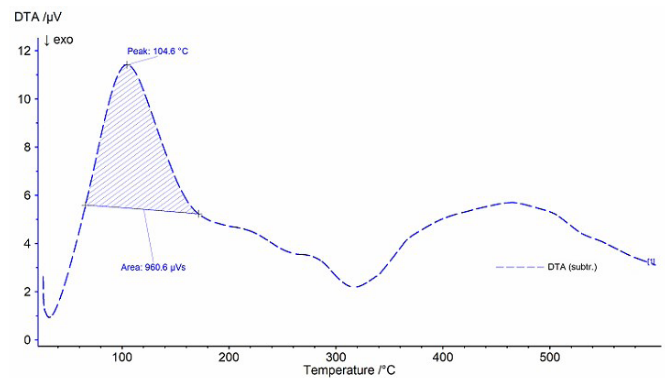

Figure 9. Differential thermal analysis (DTA) curves of licorice.

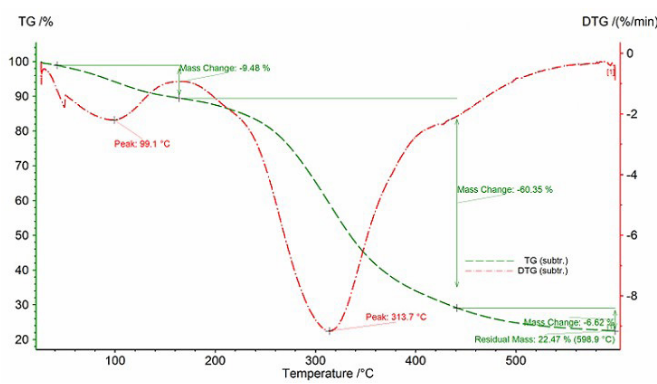

Figure 8. Thermo gravimetric (TG), derivative thermo gravimetric (DTG) curves of licorice.

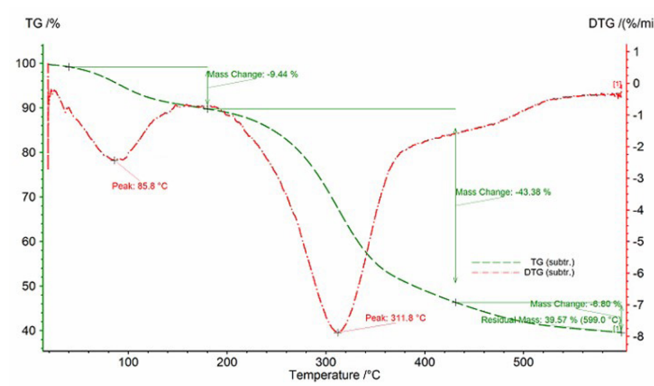

Figure 10. Thermo gravimetric (TG), derivative thermo gravimetric (DTG) curves of amomum.

Table 4. TG-DTG data of clove.

Sample	Project	Temperature range/°C	Percentage weight loss/%	The fastest weight loss temperature/°C
Clove	Peak 1	75.1~427.9	55.03	272.2
	Peak 2	427.9~600	10.93	—

Table 5. TG-DTG data of licorice.

Sample	Project	Temperature range / °C	Percentage weight loss/%	The fastest weight loss temperature/°C
Licorice	Peak 1	42.4~164.1	9.48	99.1
	Peak 2	164.1~414.2	60.35	313.7
	Peak 3	414.2~600	6.62	—

as the temperature continued to rise, the sample was further decomposed, and the remaining sample mass was 22.47%. With the increase of temperature, the DTG curve showed two peaks, and the inflection points of the peak shape were 99.1 °C and 313.7 °C, respectively. In addition, as the temperature rising up, the DTA curve of licorice had a broad exothermic peak, with the peak of 104.6 °C, the temperature range of 65.8 °C-171.3 °C, the peak area of 960.6 J/g.

5)Thermo gravimetric analysis of amomum

The thermo gravimetric data of amomum are shown in Figure 10, Figure 11 and thermo gravimetric analysis data are shown in Table 6. It can be seen from Figure 10 and Figure 11 that the decomposition began at 40 °C, which might be due to the pyrolysis and absorption of the residual small molecular substances in the sample, resulting in a small mass loss of the sample, and the loss rate was 9.44%. After a period of heating up, the temperature reached 179.5 °C, into the second stage of decomposition, the sample began to appear a lot of mass loss, until 431 °C, the loss rate was 43.38%; Then, as the temperature continues to rise, the sample was further decomposed, and the remaining sample mass was 33.36%.

With the increase of temperature, the DTG curve showed two peaks, and the inflection points of the peaks were 85.8 °C and 311.8 °C respectively. In addition, with the increase of temperature, the DTA curve of amomum had a wide exothermic peak, the peak values were 103.2 °C and 222 °C, the temperature ranges were 75.2 °C-151.2 °C and 186.1 °C-256.4 °C, and the peak areas were 331.2 J/g and 61.82 J/g respectively.

The thermogravimetric data shown in Figures 2-11 indicate that the process of thermal decomposition of 5 condiments samples from room temperature to 600 °C at a constant rate. The thermal decomposition stage of deodorization: the temperature corresponds to the range of 164.1 °C-433.8 °C, the weight loss is obvious, and the weight loss rate reaches 22.47%-39.57%. Substances such as sugars, proteins and fats undergo violent thermal decomposition reactions, and the condiment flavor has obviously deteriorated, presenting a burnt taste. Carbonization and combustion stage: the temperature range is 433.8 °C-600 °C, the weight loss rate ranges from 6.62%-7.44%, and the thermal weight loss rate is low, because the residue is gradually oxidized and thermally decomposed and the condiment is finally burned and ashed. Thus, to obtain better quality condiment, the processing temperature should be maintained under 164.1 °C.

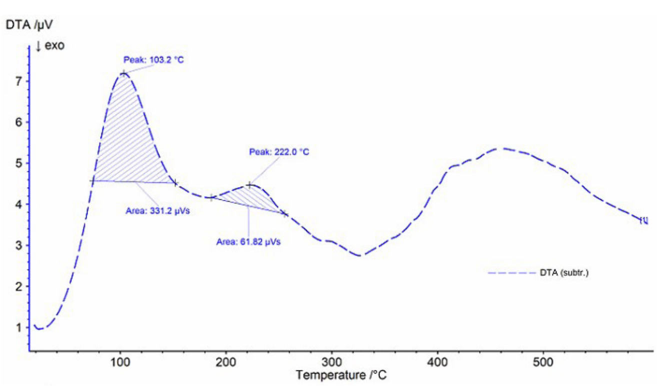

Figure 11. Differential thermal analysis (DTA) curves of amomum.

Combustion stability analysis for 5 kinds of condiments

The thermogravimetric parameters were applied to build combustion stability of 5 kinds of condiments through gray pattern recognition. Based on the thermogravimetric parameter data of 5 kinds of condiments, a multi-index evaluation system for combustion stability was established. Thermo gravimetry is to study the combustion characteristic index of 5 kinds of condiments particles at different heating rates by thermo gravimetry analyzer to judge the combustion stability of condiments. According to the method of grey pattern recognition, this subject calculated the correlation coefficient between each scheme and the ideal scheme composed of the best indicators, obtain the correlation degree from the correlation coefficient, and then sort and analyze the results according to the correlation degree to draw a conclusion. The greater the correlation degree Z is, the better the sample effect is. Finally, compare all the Z values to draw the evaluation conclusion (Zhou et al., 2022e). Calculated by EXCEL, the Z values of 5 condiments in Guangxi, China, including cinnamon, tangerine peel, clove, licorice, amomum, were 0.6786, 0.7293, 0.5049, 0.7237 and 0.6515 respectively. From the analysis of thermogravimetric analysis results and thermogravimetric combustion stability, the order of combustion stability of 5 condiment materials was tangerine peel > licorice > cinnamon > amomum > clove.

3.3 Determination of fat, calcium content, ash and crude fiber

The determination results of fat, calcium content, ash content and crude fiber content for five condiments are shown in Table 7 (n = 3, CV% < 0.20%). Table 7 shows, the order of fat content (%) of cinnamon, tangerine peel, clove, licorice and amomum was clove > licorice > cinnamon > amomum > tangerine peel, the order of calcium content (%) was tangerine peel > licorice > cinnamon > amomum > clove, the order of ash content was amomum > clove > licorice > cinnamon > dried tangerine peel, the order of crude fiber content was cinnamon > amomuml > tangerine peel > licorice > clove. The energy value of condiments can also be reflected by the combustion heat and fat content of condiments to

Table 6. TG-DTG data of amomum.

Sample	Project	Temperature range/°C	Percentage weight loss/%	The fastest weight loss temperature/°C
Amomum	Peak 1	40~179.5	9.44	85.8
	Peak 2	179.5~431	43.38	311.8
	Peak 3	431~600	6.8	—

a certain extent. The contents of ash, fat, crude fiber and calcium were regarded as important physical data to measure the quality of condiments. The quality of condiments was evaluated from the aspect of energy, which can provide a strong scientific basis for the classification of condiments (Gao et al., 2018).

3.4 Determination of trace elements for 5 condiments

Results of trace element determination

A method for the determination of 20 trace elements, including Al, As, Ba, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Na, Ni, Pb, Sc, Se, Sr and Zn, was established by inductively coupled plasma optical emission spectrometer (ICP–OES) based on microwave digestion. The determination data of 20 trace elements in 5 condiments, including cinnamon, tangerine peel, clove, licorice, amomum, from Laibin, Guangxi, China, are shown in Table 8 (μg/g, n = 6, CV% < 2.0%).The content data of the heavy metals Pb and Hg were not detected, and no toxic element As was detected in condiments. The toxic element Cd were very low, which is consistent with international regulations.

Factor analysis of 16 trace elements in 5 kinds of condiments

Through factor analysis, the characteristic roots of the factor correlation coefficient matrix and variance contribution rates of trace elements (Jafari et al., 2021; Zhang et al., 2021), including Al, Ba, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Sc, Se, Sr and Zn, were obtained, as shown in Table 9. According to Table 9, the cumulative contribution rates of the first 4 main factors reached 100.00%, and the eigenvalues of the first 4 main correlation coefficient factors (λ > 0.6) were larger; The first 4 main factors contributed the most to the explanatory variables. It was most appropriate to extract the first 4 main correlation coefficient factors, which represented 100.00% of the information on 16 trace elements in 5 kinds of condiments including cinnamon, tangerine peel, clove, licorice, amomum, from Laibin, Guangxi, China.

The component coefficient matrix after rotation is shown in Table 10. Table 10 shows that the first main factor F_1 of the correlation coefficient mainly contained the original variables Al, Ba, K, Li, and Mn. The second main factor F_2 of the correlation coefficient mainly contained the information for the original variables Fe, Ni, Sc, Sr and Zn. The third main factor F_3 of the correlation coefficient mainly contained the information for the original variable Co, Cr and Se. The fourth main factor F_4 of the correlation coefficient mainly contained the information for the original variable Cu, Mg and Na.

The factor scores and the comprehensive factor scores are shown in Table 11. Table 11 indicates that the order of the contents of 16 trace elements in 5 kinds of condiments was clove > tangerine peel > cinnamon > licorice > amomum. In terms

Table 7. Determination results of fat, calcium, ash and crude fiber of five condiments (n = 3, CV% < 0.20%).

Sample	Fat content/%	Calcium content/%	Ash/%	Crude fiber/%
Cinnamon	2.315446813	6.553694746	3.320215316	23.46078104
Tangerine peel	1.038013747	7.84309484	3.276419012	17.95300077
Clove	6.53216471	2.735551955	6.38585731	10.00620939
Licorice	3.898966994	7.516640396	3.462986198	10.6115784
Amomum	1.425490012	2.771352793	7.072673341	20.24855341

Table 8. 20 trace element data of 5 kinds of condiments (μg/g, n = 6, CV% < 2.0%).

Sample	Cinnamon	Tangerine peel	Clove	Licorice	Amomum
Al	147.2417 ± 0.061	10.5020 ± 0.0005	426.2146 ± 0.0076	47.6048 ± 0.0029	72.8916 ± 0.0005
As	—	—	—	—	—
Ba	2.2066 ± 0.0005	32.5199 ± 0.0008	73.6842 ± 0.0030	3.1936 ± 0.0004	22.3092 ± 0.0002
Cd	0.3511 ± 0.0000	—	0.1012 ± 0.0000	0.1497 ± 0.0001	0.2510 ± 0.0000
Co	0.4012 ± 0.0001	0.2988 ± 0.0000	0.3036 ± 0.0001	0.1497 ± 0.0007	0.2008 ± 0.0000
Cr	14.1926 ± 0.0001	5.2789 ± 0.0000	3.4919 ± 0.0003	4.2415 ± 0.0001	4.6185 ± 0.0028
Cu	13.4905 ± 0.0000	45.0199 ± 0.0010	42.6619 ± 0.0019	71.1078 ± 0.0018	14.7088 ± 0.0000
Fe	544.6339 ± 0.0010	2372.5100 ± 0.0400	1346.1538 ± 0.0090	441.7166 ± 0.0023	213.3032 ± 0.0032
Hg	—	—	—	—	—
K	0.0000 ± 0.0000	5024.9004 ± 0.1800	11280.3644 ± 0.3000	6032.9341 ± 0.0600	0.0000 ± 0.0000
Li	0.1003 ± 0.0000	0.6972 ± 0.0000	0.9109 ± 0.0013	0.4990 ± 0.0000	0.0000 ± 0.0000
Mg	2355.5667 ± 0.0630	1214.1434 ± 0.0060	0.0000 ± 0.0000	2000.4990 ± 0.0290	2047.1888 ± 0.0590
Mn	116.4995 ± 0.0022	49.4024 ± 0.0006	780.3644 ± 0.0100	15.4691 ± 0.0004	233.2831 ± 0.0005
Na	428.5858 ± 0.0149	877.9880 ± 0.0000	0.0000 ± 0.0000	2266.9661 ± 0.0011	1281.1245 ± 0.0170
Ni	27.6329 ± 0.0002	232.5697 ± 0.0004	23.8866 ± 0.0002	18.7126 ± 0.0004	6.9277 ± 0.0004
Pb	—	—	—	—	—
Sc	0.2006 ± 0.0000	0.2490 ± 0.0000	0.0506 ± 0.0000	0.1996 ± 0.0000	0.2510 ± 0.0000
Se	1.8556 ± 0.0007	0.9960 ± 0.0015	1.2652 ± 0.0002	0.6487 ± 0.0011	0.7028 ± 0.0008
Sr	27.3821 ± 0.0006	172.3108 ± 0.0004	49.6964 ± 0.0013	100.6487 ± 0.0018	20.9337 ± 0.0000
Zn	168.6058 ± 0.0597	2298.8048 ± 0.0360	306.6296 ± 0.0092	1225.0499 ± 0.0050	131.2249 ± 0.0093

Table 9. Factor characteristic root and variance contribution rate of 16 trace elements in 5 kinds of condiments.

Principal factor	Characteristic root	Contribution rate %	Cumulative contribution rate %
1	6.5534	40.9590	40.9590
2	5.2690	32.9313	73.8904
3	3.1894	19.9339	93.8243
4	0.9881	6.1757	100.0000
…	…	…	…

Table 10. The component coefficient matrix of 16 trace elements in 5 kinds of condiments.

Element	Component coefficient matrix 1	Component coefficient matrix 2	Component coefficient matrix 3	Component coefficient matrix 4
Al	0.890	-0.368	0.266	0.047
Ba	0.947	0.135	-0.047	-0.286
Co	0.146	0.105	0.975	-0.134
Cr	-0.463	-0.198	0.859	0.096
Cu	0.201	0.395	-0.544	0.712
Fe	0.374	0.905	0.165	-0.116
K	0.863	0.248	-0.227	0.378
Li	0.773	0.534	-0.116	0.322
Mg	-0.961	-0.265	0.058	0.062
Mn	0.931	-0.309	0.068	-0.183
Na	-0.599	-0.001	-0.715	0.359
Ni	-0.066	0.976	0.102	-0.182
Sc	-0.903	0.267	-0.157	-0.298
Se	0.108	-0.129	0.983	0.074
Sr	-0.057	0.952	-0.216	0.212
Zn	-0.150	0.946	-0.226	0.179

Table 11. Factor scores and comprehensive factor scores of 16 trace elements in 5 kinds of condiments.

Sample	F_1	F_2	F_3	F_4	F	Ranking
Cinnamon	-0.65505	-0.52528	1.55661	0.26824	-0.11442	3
Tangerine peel	-0.16047	1.73173	0.07394	-0.41219	0.49383	2
Clove	1.76025	-0.28932	0.1186	0.06135	0.65314	1
Licorice	-0.45754	-0.12621	-0.99218	1.41078	-0.33962	4
Amomum	-0.48719	-0.79093	-0.75697	-1.32819	-0.69293	5

of trace element contents, clove contained the highest levels of trace elements in all samples.

3.5 Construction of multi-index comprehensive evaluation system for condiments

Construction of multi-index analysis and comprehensive evaluation system by entropy analysis

According to the combustion heat, thermo gravimetric analysis parameters, fat, calcium, ash, crude fiber, trace element content data for five condiments, construction of multi-index comprehensive evaluation system for condiments including cinnamon, tangerine peel, clove, licorice, amomum in Guangx, China by entropy method (Aide et al., 2021; Álvarez et al., 2020; Arch-Tirado et al., 2020; Bostian et al., 2020; Chen et al., 2020a; Cho, 2020).

According to the characteristics of entropy, this paper judges the randomness and disorder degree of an event by calculating the entropy value, and judges the dispersion degree of an index by using the entropy value. The greater the dispersion degree of the index is, the greater the influence (weight) of the index on the comprehensive evaluation is, and the smaller the entropy value is. Using entropy method, five kinds of condiments were weighted to calculate the comprehensive score P.

The weighted summation formula was applied to calculate the evaluation value of the sample. The larger the comprehensive score P was, the better the sample effect was. Finally, compare all P values, that is, draw the evaluation conclusion. Using EXCEL calculation, the P values of cinnamon, tangerine peel, clove, licorice, amomum were 0.3660, 0.5255, 0.4899, 0.3184 and 0.2698 respectively.

According to combustion heat, thermogravimetric analysis parameters, fat, calcium, ash, crude fiber, trace element content data, the multi-index evaluation order of 5 condiments produced from Guangxi, China was tangerine peel > clove > cinnamon > licorice > amomum.

Comprehensive evaluation method of grey correlation coefficient multi-index analysis

(Feng et al., 2020; Li et al., 2020; Park et al., 2020; Tikhamarine et al., 2020) The comprehensive evaluation method of grey correlation coefficient multi-index analysis was applied to find the correlation coefficient between each scheme and the ideal scheme composed of the best indexes and draw a conclusion. The multi-index comprehensive evaluation method for the multi-index analysis of heat of combustion, combustibility (combustion stability of condiments), fat content, calcium, ash and crude fiber content of five kinds of condiments in Guangxi was established. Burning heat X1, fat content X2, calcium content X3, ash content X4, crude fiber X5, weight loss percentage of phase I X6, weight loss fastest temperature of phase I X7, weight loss percentage of phase II X8, residual mass percentage X9, peak area of phase I X10.The results of grey correlation coefficient of five kinds of condiments were shown in Table 12.

It can be seen from Table 12 that the first grey correlation coefficient factor had a large grey correlation coefficient on indexes X3, X6 and X9, mainly reflecting the combustion stability of condiments. The calcium content of five kinds of condiments is also very rich, suggesting that although condiments are seasonings and less dosage, they can also be used as one of the sources of calcium supplement. The fastest weight loss temperature was between 311~332 °C. The second grey correlation coefficient factor had a large correlation coefficient in indexes X1, X2, X5, X7 and X10, mainly reflecting the energy of condiments. The energy value of condiments can also be reflected in the combustion heat, fat content and crude fiber content to some extent. The burning heat, fat content and crude fiber content were used as an important physical data to measure the quality of condiments. The nutritional quality of food was evaluated from the aspect of energy, which can provide a strong scientific basis for the classification of condiments. The third gray correlation coefficient factor had a large correlation coefficient in indicator X8, mainly reflecting the percentage of combustion weightlessness of condiments. The fourth grey correlation coefficient factor had a large correlation coefficient in indicator X4, mainly reflecting the ash content of condiments (Zhou, 2017b).

Construction of multi-index analysis and comprehensive evaluation system by grey correlation coefficient cluster analysis

The gray correlation coefficient cluster analysis is based on the many properties of the sample (Abdullahi et al., 2020; Murphy et al., 2020; Varkevisser et al., 2020; Yang et al., 2020), and the cluster analysis diagram is obtained from the correlation coefficient. According to the literature (Zhou, 2017a, 2017c), the classification is carried out according to the degree of affinity of the nature of the sample. All cases are classified into different classes, making the same class Individuals in different classes have greater similarities, and individuals in different classes have greater differences. The multi-index comprehensive cluster analysis system of combustion heat, combustibility (combustion stability of condiments), fat, calcium, ash, crude fiber and trace element content for five kinds of condiments in Guangxi was established. The gray correlation coefficient cluster analysis tree diagram is shown in Figure 12. As can be seen from Figure 12, five kinds of condiments from different producing areas, namely cinnamon, tangerine peel, clove, licorice and amomum, were divided into two categories according to the results of grey system cluster analysis. Clove and tangerine peel constitute

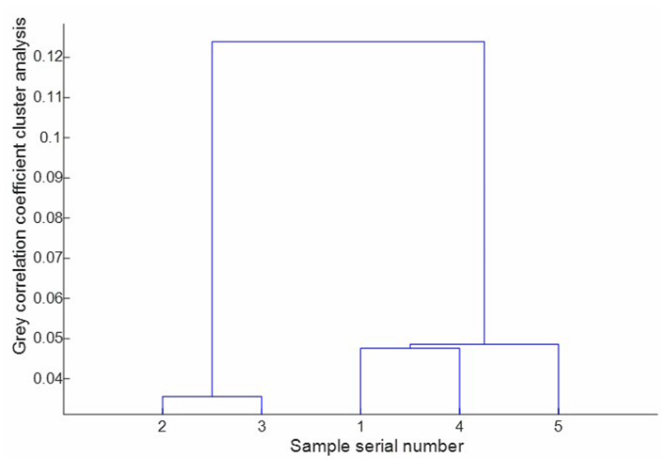

Figure 12. Tree diagram of grey correlation coefficient cluster analysis of multiple indexes of five condiments.

Table 12. Grey correlation coefficient of 5 condiments.

Index	Cinnamon	Tangerine Peel	Clove	Licorice	Amomum
Combustion heat X1	0.9846	0.9781	0.9910	0.9878	0.9804
Fat content X2	0.6719	0.6689	0.6820	0.6757	0.6698
Calcium content X3	0.8572	0.8599	0.8491	0.8592	0.8492
Ash X4	0.4571	0.4571	0.4593	0.4572	0.4598
Crude fiber X5	0.9865	0.9917	0.9993	0.9987	0.9895
The first stage weight loss percentage X6	0.9845	0.9977	0.9866	0.9830	0.9830
First stage weightlessness fastest temperature X7	0.8612	0.8712	0.8745	0.8613	0.8603
Phase II Weight Loss Percentage X8	0.9941	0.9865	0.9792	0.9994	0.9924
Residual mass percentage X9	0.9853	0.9908	0.9859	0.9907	0.9819
The first phase peak area X10	0.9707	0.9863	0.9948	0.9785	0.9925

a class, and cinnamon, amomum and licorice form one class. Through the grey correlation coefficient cluster analysis, we found the similarity degree and genetic relationship between the properties of condiments, which can facilitate investigation of the classification of condiments.

4 Conclusion

Based on the thermogravimetric parameter data of 5 condiments, a multi-index evaluation system for combustion stability was established. The thermogravimetric parameters were applied to build combustion stability of 5 kinds of condiments through gray pattern recognition. The processing temperature should be maintained below 164.1 °C for better quality condiments.

In this paper, the combustion heat, differential thermal-thermogravimetric analysis, fat, crude fiber, calcium, ash and trace element content data of condiments were used to construct a systematic multi-index comprehensive evaluation system using gray pattern recognition, factor analysis, entropy analysis, grey correlation coefficient multi-index analysis and grey correlation coefficient cluster analysis. According to combustion heat, thermogravimetric analysis parameters, fat, calcium, ash, crude fiber, trace element content data, the multi-index evaluation order of 5 condiments produced from Guangxi, China was tangerine peel > clove > cinnamon > licorice > amomum. The multi-index comprehensive evaluation system established by the research provides a new idea for the nutritional evaluation of condiments. This research provides a strong scientific basis for the large-scale development of condiment resources and condiment classification research, and provides basic support for the selection of condiment raw materials.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare no conflict of interest.

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