Research article

Evaluation of different drying methods on the quality of *Cinnamomum cassia* barks by analytic hierarchy process method

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A B S T R A C T

Cinnamomum cassia Presl is a major food spice as well as traditional herbal medicine with anti-inflammatory, analgesic, and stomachic properties, which must be dried to preserve its quality, but mostly by using traditional, ineffective drying method. In order to find a scientific drying method by evaluating different drying methods that could influence the quality of *C. cassia*, ten indices were employed to evaluate different drying methods in *C. cassia* using the Analytic Hierarchy Process (AHP) method though calculating the total scores and ranking the priority. Four quality markers (Q-Markers) (coumarin, cinnamyl alcohol, cinnamaldehyde and *o*-methoxycinnamaldehyde) were isolated from the samples and analyzed by high performance liquid chromatography (HPLC) method under different drying methods. The results showed that various drying methods had multiple effects on the physicochemical qualities, essential oil content, and Q-Marker contents. Compared with other drying methods, oven-drying of 45 °C (45OD) maintained optimal levels of color and aroma, it also significantly shortened the drying time by 225 h than traditionally shade-drying (SHD) method with the drying rate (48.35 %), and obtained the highest essential oil content (3.05 %) and Q-Marker contents (30.23 mg g^{-1}). Furthermore, the ash content (4.22 %) were satisfied with the stipulation of Chinese pharmacopoeia in 45OD samples. Applying AHP allowed us to identify 45OD as the optimal drying method with the highest total score (9.00), followed by the traditional shade-drying (SHD) method (7.88). The present study is the first report to apply the AHP method for quality evaluation of drying processing in *C. cassia*. It can provide the theoretical basis for evaluating an excellent method for *C. cassia* drying processing, as well as the rational use of different drying methods to furtherly develop the high quality *C. cassia* industry.

1. Introduction

Cinnamomum cassia Presl belonging to the family Lauraceae, commonly known as cinnamon, is an evergreen tree widely distributed in southeast Asia, Indonesia, and South America [1]. In China, *C. cassia* is cultivated in tropical and subtropical areas, such as Guangdong, Guangxi, Fujian, Yunnan, and Taiwan provinces [2]. As one of the main producers, the annual output of *C. cassia* in China

have reached the first around the world since 2012 [3]. "Guangxi Cinnamon" is recognized as a national product of geographical indication, and its yield ranks the first in the country with the planting area (over 47,000 ha in 2020) [4]. *C. cassia* has economic values owing to its medicinal properties and characteristic cinnamon aroma, and it is popular in the pharmacy, food, perfumery, cosmetics and flavor industries [5,6]. The bark of *C. cassia* is frequently used in Western countries as a spice and seasoning, but as a drug in Asian countries. In China, it is a common traditional Chinese medicine. More than 500 formulas in Chinese Pharmacopoeia used cinnamon as the main material due to its anti-inflammatory, analgesic, and stomachic properties [7,8]. Pharmacological studies have also found that cinnamon has bacteriostatic, anti-tumor effects, as well as good curative effects on cardiovascular and immune system diseases [9]. To date, over 160 chemical compounds have been identified from *C. cassia*, with a wide range of pharmacological effects [6]. Essential oils are the main chemical components of cinnamon, in which cinnamaldehyde accounts for more than 85 % (v/v) of the total essential oil components [9]. Cinnamaldehyde has been considered as an important index for evaluating the quality of *C. cassia* stipulated in the Chinese pharmacopoeia. In recent years, more and more pharmacological studies have proven that cinnamaldehyde as the main bioactive component of cinnamon had antifungal, antiparasitic, antitumor, antibacterial, and antidiabetic pharmacological activities [10–12]. Except for cinnamaldehyde, cinnamic acid, coumarine, flavonoids, and terpenoids were also isolated from *C. cassia* barks [13,14]. Several compounds, including cinnamaldehyde, coumarin, cinnamyl alcohol, cinnamic acid, and *o*-methoxycinnamaldehyde, were considered as the quality markers (Q-Marker) of *C. cassia* [15]. As the increasing demand of *C. cassia*, its intensive processing has been developed rapidly in the industrial scale.

Primary processing is important for the quality of Chinese medicinal materials, and the initial drying is one of the essential processes for medicinal plants to fix and preserve their constituents [16]. Many researches showed that different drying methods have important effects on the yields and constituents of oil, along with the potency, taste, medicinal properties and efficacy [17–19]. Drying not only prevents the growth of spoilage microorganisms, it would also slow some enzyme activities and many moisture-mediated reactions [20]. Simultaneously, the flavor alterations, nutrient loss, color changes, and oxidation products formation appeared during the drying process [21]. Volatile compounds are the most sensitive compounds in medicinal material drying [22]. The effects of various drying methods on the release or retention of volatile compounds is not predictable. For example, the total volatile content of pericarp varied from 0.70 to 1.55 % under the treatments of twelve different pre-drying and drying methods in *Amomum tsao-ko* [19]. Proper method could improve the quality and increase its economic benefits of the medicinal materials, especially for aromatic plants. At present, sun-drying (SD) and shade-drying (SHD) method are chosen for the frequently used drying methods for *C. cassia* barks in industrial application. SHD is the only method stipulated by Chinese Pharmacopoeia [8], but this method has many drawbacks such as wasting time, vulnerable by natural environment, poor controllability of drying conditions, liable to mildew, and loss of essential oil *etc.* [23]. In recent years, cultivated *C. cassia* is circulated in the market with varying quality. However, few studies are available on the effects of different drying methods on the quality of *C. cassia*. With the development of drying technology, some modern technologies, such as oven-drying (OD), freeze-drying (FD), and microwave-drying (MD), have realized more convenient operation and higher economic benefits, which can greatly reduce the influence of external factors on medicinal materials [24]. However, few studies about

Fig. 1. Fresh sample of cinnamon. (a) The 30-year-old tree. (b) Bark. (c) Bark without periderm.

the modern drying method for the drying of *C. cassia*.

Analytic Hierarchy Process (AHP), a qualitative and quantitative combination of systematic, hierarchical analysis method, was firstly proposed by Saaty [25] and used to evaluate the opinions of those involved in decision-making processes to find the relative importance of each of the criteria. It can fully reflect the mutual influence of each index, through reasonable subjective judgment, mathematical methods to quantify each factor, and the weight consistency ratio and consistency index calculation to judge the acceptability of the matrix, in order to achieve the weight coefficient from qualitative to quantitative transformation [26,27]. To date, AHP method has been widely used in the extraction technology optimization, quality evaluation and variety selection in traditional Chinese medicine plants [28–31]. However, the issue of quality evaluation for different drying methods in *C. cassia* barks is still pending work.

In the current study, the effect of fourteen drying methods on ten evaluation indices at three levels (appearance, internal and efficiency quality) were investigated using AHP method, including SD, SHD, OD at nine different temperatures (30, 40, 45, 50, 55, 60, 65, 70, 75 °C), MD, and FD. Furthermore, the content of four quality markers (Q-Markers) were also determined by high performance liquid chromatography (HPLC) method. The objective of this work was firstly to develop mathematical analytical method to evaluate the comprehensive quality of *C. cassia* barks and select the appropriate drying methods used to process barks in genuine producing area.

2. Materials and methods

2.1. Plant materials

Fresh barks of 20-year-old *C. cassia* were collected from cultivation base of *C. cassia* in Pingnan city of Guangxi Province, China (N 23°42′59″, E 110°25′27″), at an average altitude of 230.6 m. The barks from three individual trees were stripped off from the sections about 50 cm above ground (Fig. 1a–c), then mixed together as one biological replicate. After scraping the surface impurities and cork layer, the samples were cut into strips, and then equally divided into 14 groups (approximately 1.0 kg per group) with 3 replications for analysis. The samples were identified by associate professor Zhonghua Dai from the School of Pharmacy, Guangxi University of Chinese Medicine as *C. cassia* Presl.

2.2. Drying methods

Samples were dried by the following methods: (1) SD: Samples were placed on well-ventilated drying racks and exposed directly to the sunlight, and weighed every 12 h until the moisture content was less than 15 % (the standard level of moisture was prescribed by Chinese pharmacopoeia). (2) SHD: Samples were kept in room at temperature (25 °C), and weighed every 12 h until the moisture content was less than 15 %. (3) (OD: Samples were placed in temperature incubators at nine different temperatures (30, 40, 45, 50, 55, 60, 65, 70, 75 °C) respectively, and weighed every 0.5 h until the moisture content was less than 15 %. (4) MD: Samples were placed in a domestic digital microwave oven (Galanz) at 1200 W, and weighed every 5 mins until the moisture content was less than 15 %. (5) FD: Samples were kept at −20 °C for 1 day, and then transferred into a freeze drier (Scientz, Ningbo, China). The smaples were kept in −40 °C for drying with the rotary pump pressure 2 mbar, and weighted every 2 h until the moisture content was less than 15 %. (6) SD + 50OD: Samples were sun-drying for 2 days firstly, and then oven-drying at 50 °C until the moisture content was less than 15 %. The drying time was recorded, and drying rate was calculated by dry weight minus fresh weight ratios. After drying, all the samples were ground and passed through a 50-mesh sieve (250 μm) to obtain powder. Some characteristics of barks, including colors, amour and features, were also recorded.

2.3. Ash and essential oil quantification

The ash and essential oil content of samples were measured in triplicate using the method of general rule 2302 and 2204b published in Chinese Pharmacopoeia [8], respectively. According to Chinese Pharmacopoeia, the total ash content of cinnamon shall not exceed 5.0 %, as well as the essential oil content shall not be less than 1.2 %.

2.4. Content determination of four quality markers

2.4.1. High-performance liquid chromatography conditions
Chromatographic separation was performed using a LC-40 HPLC system (Shimadzu, Kyoto, Japan), equipped with a ZORBAX Eclipse XDB-C18 (Agilent, Stockport, UK, 250 mm × 4.6 mm,5 μm). Solvent A (water) and solvent B (acetonitrile) were used as mobile phase with the ratio of 65:35. The parameters were programed as follows: Flow rate 1.0 mL min^{-1}, injection volume 10 μL, column temperature 40 °C, and detection wavelength 250 nm. Triplicates were carried out to assess the accuracy of the HPLC system.

2.4.2. Preparation of the standard solution
To prepare the mix standard solution, accurately weighed 10.87 mg coumarin, 29.30 mg cinnamyl alcohol, 104.40 mg cinnamaldehyde and 30.00 mg *o*-methoxycinnamaldehyde respectively, dissolved and diluted to 25 mL volumetric flasks to final volume with methanol. The final concentration of coumarin, cinnamyl alcohol, cinnamaldehyde and *o*-methoxycinnamaldehyde were 0.018 mg/mL, 0.04 mg/mL, 0.6 mg/mL, 0.1 mg/mL respectively. All standard solutions were stored at 4 °C.

2.4.3. Preparation of the herbal extracts

500 mg of powder was accurately weighed, and placed into a 50 mL dry corked conical bottle with 25 mL methanol, then sonicated at 350 W and 35 kHz for 30 min. After twice supersonic extraction, the supernatant was transferred and diluted with methanol in a ratio of 1:1 (v/v) followed by the suspension was centrifuged at 5000 r/min for 10 min. The extracted samples were removed and filtered (0.22 μm pore size) to be used for analysis. The contents of four quality markers were calculated by their corresponding retention time and peak areas with the corresponding reference standards of coumarin, o-methoxycinnamaldehyde, cinnamaldehyde, and cinnamyl alcohol under the same conditions.

2.5. Comprehensive quality evaluation

An Analytic Hierarchy Process (AHP) method [32,33] is adopted to obtain weighted vector for every index and for the evaluation model, and divide the results into multiple indexes as the weight index to make comprehensive weighted evaluation, so as to determine the weight of each evaluation index. The hierarchical structure model of each evaluation index was shown in (Fig. 2). Among appearance traits, color and aroma were selected as evaluation factors. Ash content, essential oil content and cinnamaldehyde content were the important evaluation factors for internal quality stipulated by Chinese Pharmacopoeia. In addition, the content of four quality markers (coumarin, cinnamyl alcohol and o-methoxycinnamaldehyde) were also chosen as evaluation factors for internal quality. Drying time and drying rate were added as evaluation indexes of drying efficiency.In the AHP method, a 1–9 ratio scale method was employed to assign relative score, and the judgment matrix, weight (W), maximum eigenvalue (λ_{max}), consistency ratio (CR) value were calculated. To make sure the accuracy of evaluation, the original index was normalized by equalization method [31]. The 10-point scale and grade for each indicator with normalized weight score were scored according to W values, which included four grading points with progressive increase of 10 %, 30 %, 70 % and 90 % in the change interval.

Two indexes (ash content and drying time) were negative scoring indexes, and the score value (Ri) of these index was calculated as follows:

$$R_i = \left[(x_i\text{-}p_{i,min}) / (p_{i,max}\text{-}p_{i,min}) \right] *2 + (n*2) \tag{1}$$

where x_i is the measured value; $p_{i,min}$ and $p_{i,max}$ are the minimum and maximum value of x_i, respectively; n is the grade (n = 0, 1, 2, 3, 4).

For other indexes, the Ri of those index was calculated as follows:

$$R_i = \left[(p_{i,min}\text{-}x_i) / (p_{i,min}\text{-}p_{i,max}) \right] *2 + (n*2) \tag{2}$$

where x_i is the measured value; $p_{i,min}$ and $p_{i,max}$ are the minimum and maximum value of x_i, respectively; n is the grade (n = 0, 1, 2, 3, 4).

The weighted scoring value (WSV) was calculated as follows:

$$WSV = (R_1 \times WC_1 + R_2 \times WC_2) \times WB_1 + (R_3 \times WC_3 + \ldots + R_8 \times WC_8) \times WB_2 + (R_9 \times WC_9 + R_{10} \times WC_{10}) \times WB_3 \tag{3}$$
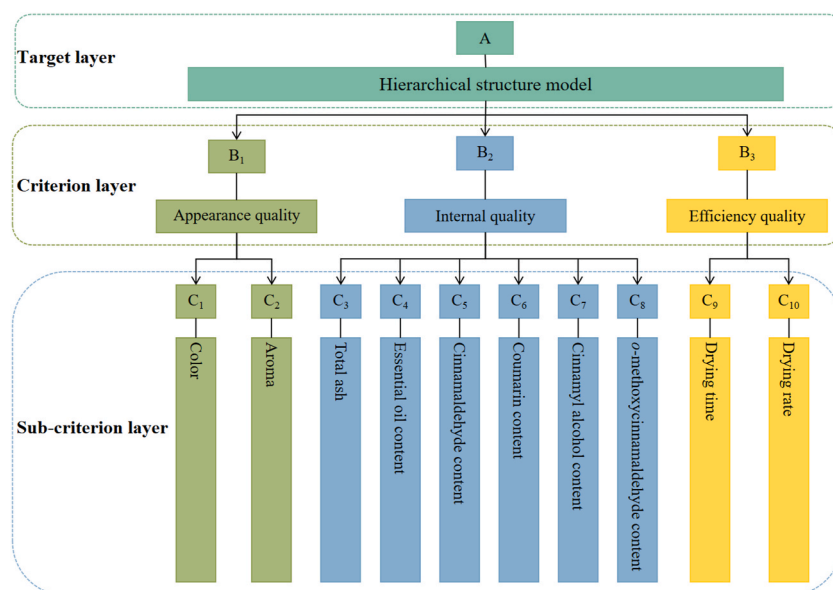

Fig. 2. Weighted hierarchy structure of *C. asiatica* under different drying methods.

In this formula, *Ri* is the score value of each index, *WBi* and *WCi* are the corresponding weight score value. The final score values and rank were generated by calculating the total scores of each method.

2.6. Statistical analysis

Significance was tested by ANOVA and multiple comparisons were performed using IBM SPSS Statistics 24.0 software. Graphpad prism 5.0 software was used to create figures and values marked with different lowercase letters are significantly different ($p < 0.05$).

3. Results

3.1. Effect of different drying methods on external characteristics of C. cassia

The effects of drying methods on the external characteristics are crucial for the quality of medicinal materials, such as color, shape, and aroma. In OD treatment, the samples showed dark reddish brown color, and there was no obvious difference in the color of *C. cassia* under different temperatures. The color in SHD samples was the similar with that in OD samples, but darker reddish brown color appeared in SD, SD + 50OD and MD samples. Compared with OD, the color was significantly different after applying FD drying method. Excepting for FD treatment, the samples under different drying methods rolled into a circle or semi-circle. The samples dried by MD methods produced a smell of burning, but other-treated samples had a pleasant fragrance (Fig. 3).

3.2. Effect of different drying methods on drying rate and time of C. cassia

The drying time of *C. cassia* varied under different drying methods. The drying time of OD treatment under 30, 40, 45, 50, 55, 60, 65, 70, 75 °C were 24, 18, 15, 12, 11, 10.5, 9.0, 7.5, and 6.5 h, respectively. The drying time decreases obviously along with the temperature increase in OD method, from 24 h to 6.5 h. In SD method, it needed 120 h to reach the moisture content was less than 15 %, while SD + 50OD treatment only needed 58 h. The SHD treatment exhibited the lengthiest duration for drying (240 h), whereas the MD treatment demonstrated the shortest drying interval (0.42 h). Compared with traditionally SHD method, 45OD method significantly shortened the drying time by 225 h (Table 1).

The drying rate of *C. cassia* varied under different drying methods, with an average value of 46.02 %, ranging from 39.09 % to 49.44 %. The highest drying rate (49.44 %) appeared in SHD treated samples, and the lowest was in 65OD treated samples. In OD method, 50OD obtained the highest drying rate (48.50 %) when the samples reach constant weight, followed by 45OD (48.35 %) and 70OD (48.34 % (Fig. 4a). Overall, the drying rate changed unstable along with the temperature increase.

3.3. Effects of different drying methods on moisture content, ash and essential oil content of C. cassia

The moisture content of *C. cassia* varied under different drying methods, with an average value of 9.85 %, ranging from 8.46 % to 11.50 %. All the moisture content treated by different drying methods met the limit standard of Chinese Pharmacopoeia (below 15 %) (Fig. 4b).

The total ash content significantly varied when the samples reached a constant weight treated by different drying methods, with the range of 4.09 %–5.99 %. Excepting for MD method (5.99 %), all the total ash content treated by different drying methods met the limit standard of Chinese Pharmacopoeia (below 5 %) (Fig. 4c).

Essential oil is one of the main chemical components of *C. cassia*, which can directly reflect the quality of *C. cassia*. As shown in Fig. 4d, all the essential oil content treated by different drying methods met the standard of Chinese Pharmacopoeia (above 1.2 %). Essential oil content ranged from 1.62 % to 3.05 %, the average essential oil content was 2.32 %. Among them, the essential oil content of 45OD method (3.05 %) was superior to other drying methods. Along with the increasing of temperature, the essential oil content significantly decreased to 1.62 % (75OD), so high temperature was not suitable for drying *C. cassia*. Compared with the traditional SHD method, treatment of FD method produced obviously higher essential oil content, but the essential oil content in MD and SD samples
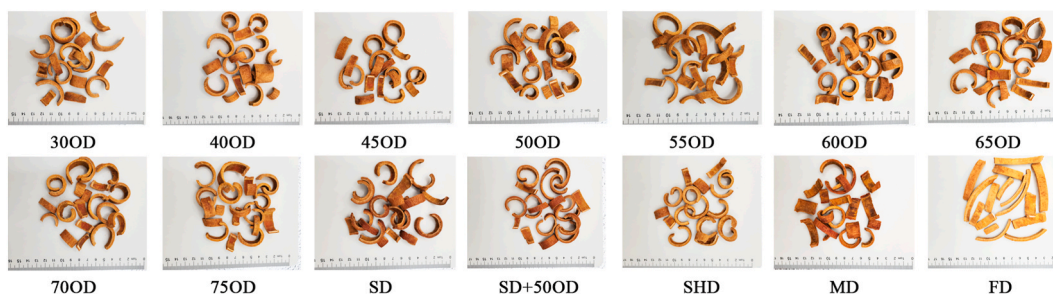

Fig. 3. Color of *C. cassia* under different drying methods. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Drying time of *C. cassia* dried using different drying methods.

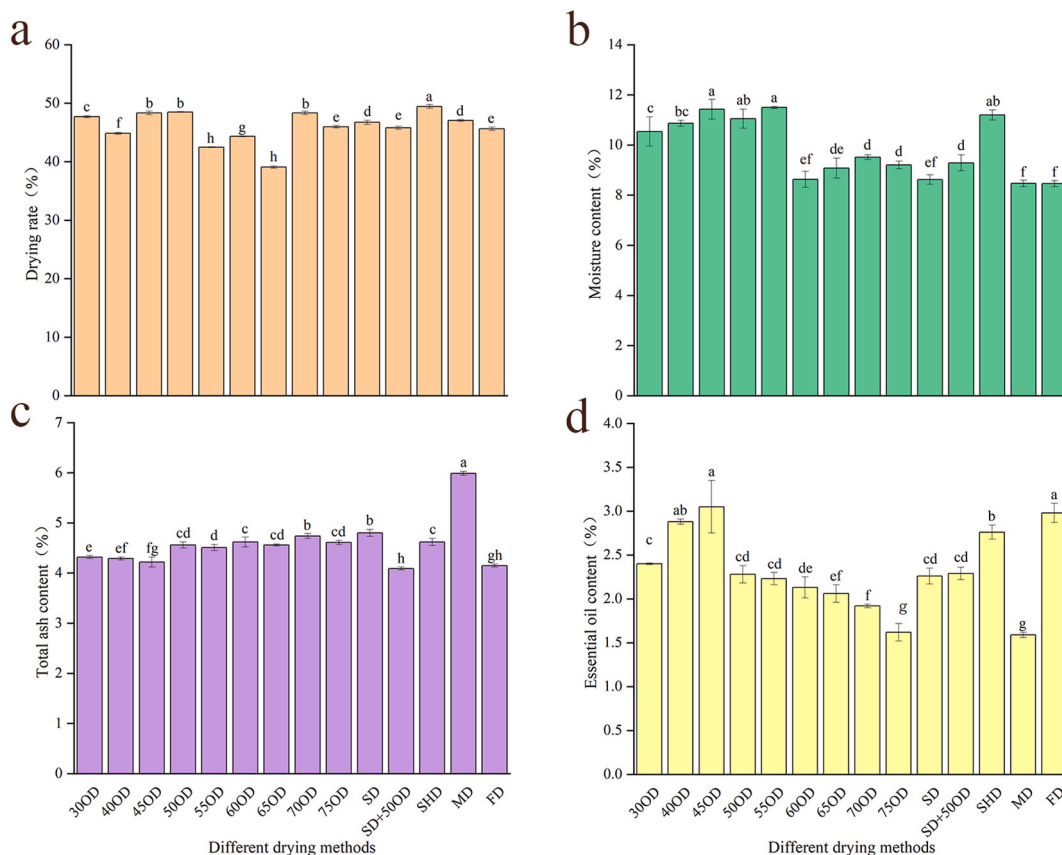| Drying method	Drying time (h)	Drying Methods	Drying time (h)
30OD	24.00 ± 0.35[d]	70OD	7.50 ± 0.09[j]
40OD	18.00 ± 0.20[e]	75OD	6.50 ± 0.13[k]
45OD	15.00 ± 0.26[f]	SD	120.00 ± 0.53[b]
50OD	12.00 ± 0.20[g]	SD + 50OD	58.00 ± 0.36[c]
55OD	11.00 ± 0.10[h]	SHD	240.00 ± 0.87[a]
60OD	10.50 ± 0.20[h]	MD	0.42 ± 0.01[l]
65OD	9.00 ± 0.10[i]	FD	24.00 ± 0.17[d]

Fig. 4. The drying rate (a), moisture content (b), total ash content (c), and essential oil content (d) of *C. cassia* barks dried by different drying methods.

significant decreased due to more active ingredients miss. Therefore, 45OD might be the optimal drying method of *C. cassia* due to it could obtain higher essential oil.

3.4. Effects of different drying methods on the content of four Q markers

The effects of different drying methods on four quality markers, including cinnamaldehyde, coumarin, cinnamyl alcohol, and *o*-methoxycinnamaldehyde, were also determined. Good HPLC chromatogram map peak shape and good separation between each adjacent peaks (separation degree≥1.5) of the standards and samples were shown in Fig. 5a–d, and the linear regression equations were satisfied. There were significant total content differences in different samples. The HPLC chromatograms of the standard compounds and samples are given in Fig. 5e–f, respectively. Total Q-Markers' content ranged from 11.19 mg g^{-1} to 30.23 mg g^{-1}, the maximum content was recorded in 45OD samples (30.23 mg g^{-1}), followed by 55OD (29.36 mg g^{-1}), 30OD (29.23 mg g^{-1}) and 50OD (29.00 mg g^{-1}). There were no significant difference in the total content among the methods mentioned above, indicating that lower temperature benefited for maintaining a higher Q-Markers' content. Furthermore, the OD method at an appropriate temperature range (below 55 °C) produced significantly higher content than other methods such as SHD, FD, and SD.

The content of cinnamaldehyde was much higher than the other Q-Markers. The highest content of cinnamaldehyde was found in
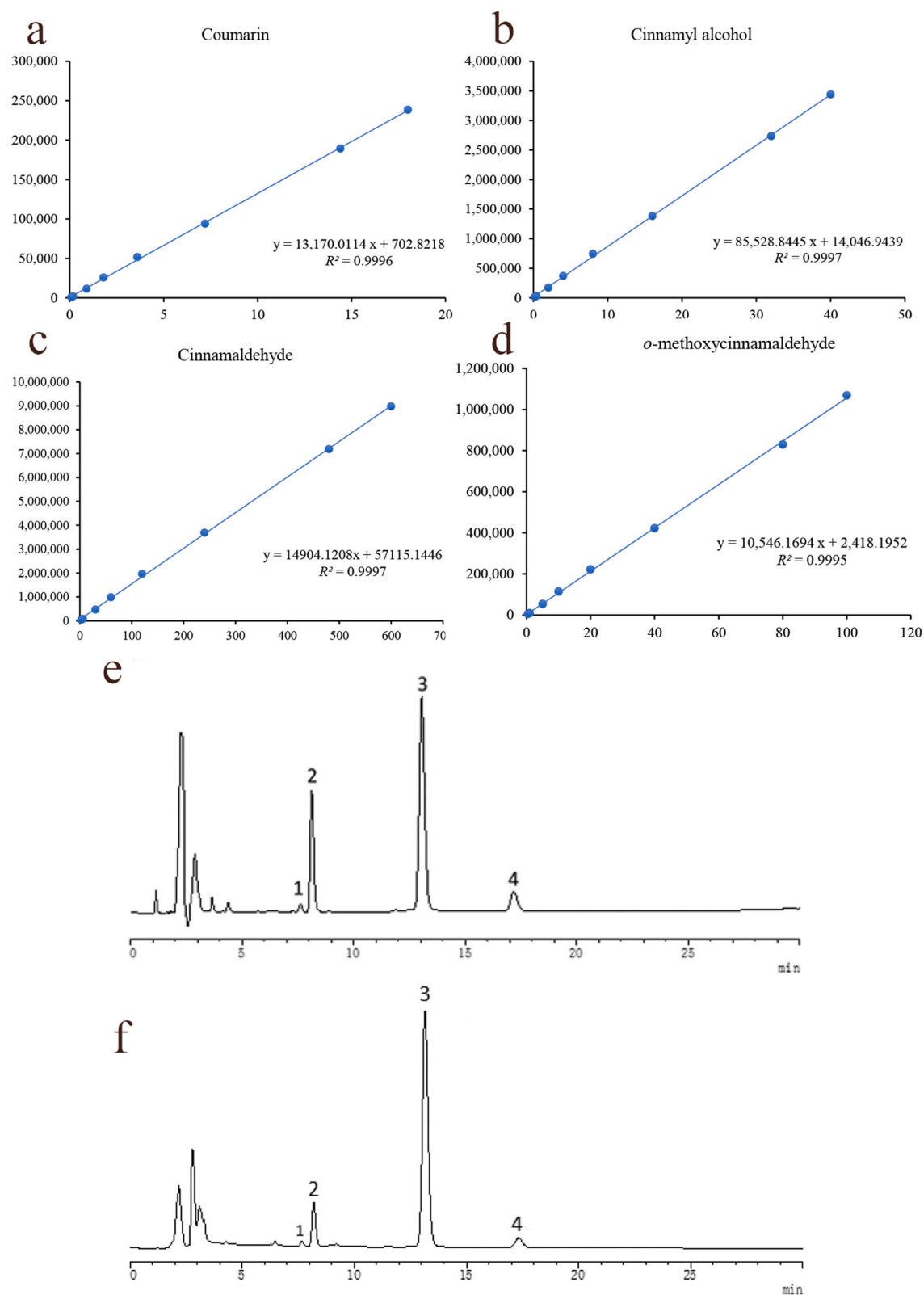
Fig. 5. Linear regression equations of four Q markers and HPLC chromatograms. (a–d) Linear regression equations of coumarin, cinnamic alcohol, cinnamic aldehyde, and 2-methoxy cinnamaldehyde, respectively. (e) HPLC chromatogram of reference substances. (f) HPLC chromatogram of samples. 1, coumarin; 2, cinnamic alcohol; 3, cinnamic aldehyde; 4, *o*-methoxycinnamaldehyde.

the 45OD method (25.73 mg g^{-1}), whereas the lowest was reported in the MD method (9.08 mg g^{-1}). Similarly, we found that the content of cinnamaldehyde significantly decreased in OD samples along with an increasing of temperature. However, SHD method exhibited the maximum coumarin content (0.06 mg g^{-1}), followed by 45OD (0.05 mg g^{-1}). The highest content of cinnamyl alcohol (0.22 mg g^{-1}) appeared in FD samples, whereas coumarin and *o*-methoxycinnamaldehyde (0.02 mg g^{-1} and 2.03 mg g^{-1}) were at a lower level, respectively (Table 1).

3.5. Comprehensive quality evaluation by AHP method

The results showed that the consistency ratios (*CR*) of A-(B$_1$ ~ B$_3$), B$_1$-(C$_1$ ~ C$_2$), B$_2$-(C$_3$ ~ C$_8$) and B$_3$- (C$_9$ ~ C$_{10}$) were 0.00, 0.00, 0.02 and 0.00, which were all less than 0.1, indicating that the judgment matrix had a good consistency. According to the ranking of *W*, appearance quality (B$_1$) (42.86 %) = internal quality (B$_2$) (42.86 %) > efficiency quality (B$_3$) (14.29 %), indicated that appearance index B$_1$ and internal index B$_2$ played more crucial roles in the quality evaluation of *C. cassia*. In the third layer structure, the *W* values of color (C$_1$) and drying rate (C$_{10}$) were 75.00 % and 83.33 % respectively, indicating that they were more important to appearance and efficiency quality respectively. In B$_2$ index, the *W* values of essential oil content (C$_4$) and cinnamaldehyde content (C$_5$) were equal (36.18 %), which was significantly higher than other indexes at the same level (Table 2). The 10-point scale and grade for each indicator with *W* values were scored (Table 3), which could transform index values with different units to the united scores of five different grades. The results of weighted scoring value (*WSV*) revealed that 45OD drying method was the optimal method with the highest total score (9.00), in which color (C$_1$), aroma (C$_2$), essential oil content (C$_4$), cinnamaldehyde content (C$_5$), and *o*-methoxycinnamaldehyde content (C$_8$) were all at the top level. Meanwhile, the following method was the traditional drying method SHD, in which color (C$_1$), aroma (C$_2$), coumarin content (C$_6$) and drying rate (C$_{10}$) was higher than other methods. However, MD method ranked the lowest because of the lowest content of internal quality, such as C$_4$~C$_6$, and C$_8$ (Table 4).

4. Discussion

Many medicinal plants need to process by drying after harvesting due to their high moisture. Drying could maintain the quality characteristics of Chinese medicinal materials by inhibiting the growth of spoilage microorganisms and moisture-mediated chemical alterations [20]. In decades, a great deal of drying methods were investigated in different medical plants to improve the quality characteristics, showing an improvement in quality, better energy conservation and higher process efficiency [34]. In spite of these progresses, comprehensive and objective quality evaluation Chinese herbal medicine in terms of drying methods has been one of the most important issues during drying process as each specific drying method was different for each plants.

AHP method is one of the most widely applied in various fields, such as management, agriculture and pharmacy, to make strategic decisions of significant importance and responsibility when both quantitative and qualitative aspects of a decision need to be assessed [33]. So far, the AHP-comprehensive scoring method has been used in assessing the quality of many dried herbs, such as Raw Moutan Cortex [31], Polygonati Rhizoma [35], and Centellae Herba [32]. In this work, the *W* values of color, drying rate, essential oil content and cinnamaldehyde content were higher than other indexes using the AHP-comprehensive scoring method, indicating that they might play crucial roles in the quality evaluation of cinnamon. In general, a reasonable drying method can not only maintain the color seen of herbs but also increase the content of active ingredients [36]. In rosselle (*Hibiscus sabdariffa*) calyx, color and volatile compounds are probably the most important quality characteristics among all the quality properties during different drying methods [37]. Similarly, color and aromatic compounds were also deemed to be crucial indexes for the quality during sweet basil leaves drying [38].

Increasing studies have demonstrated that cinnamaldehyde was the most plentiful metabolite in the essential oil of *C. cassia* [7, 39–42] The GC/MS analysis of *Cinnamomum cassia* also showed that cinnamaldehyde was the major component in the extract (50.79

Table 2
Judgment matrix, weight, maximum eigenvalue, consistency ratio value.

Indicator	Judgment matrices						*W* (%)	Maximum eigenvalue (λ_{max})	Consistency ratio (*CR*)
A(B$_1$~B$_3$)	B$_1$	B$_2$	B$_3$					3.00	0.00
B$_1$	1	1	3				42.86		
B$_2$	1	1	3				42.86		
B$_3$	1/3	1/3	1				14.29		
B$_1$-(C$_1$–C$_2$)	C$_1$		C$_2$					2.17	0.00
C$_1$	1		3				75.00		
C$_2$	1/3		1				25.00		
B$_2$-(C$_3$–C$_8$)	C$_3$	C$_4$	C$_5$	C$_6$	C$_7$	C$_8$		7.15	0.02
C$_3$	1/2	1	1/8	1/8	1/3	1/3	2.97		
C$_4$	8	8	1	1	5	5	36.18		
C$_5$	8	8	1	1	5	5	36.18		
C$_6$	3	3	1/5	1/5	1	1	8.23		
C$_7$	3	3	1/5	1/5	1	1	8.23		
C$_8$	3	3	1/5	1/5	1	1	8.23		
B$_3$-(C$_9$–C$_{10}$)	C$_9$		C$_{10}$					2.00	0.00
C$_9$	1		1/5				16.67		
C$_{10}$	5		1				83.33		

Table 3
The 10-point scale and grade for each index with comprehensive weight score.

Index			Ranking and score (R)				
Appearance quality B_1	C_1	Degree	Dark reddish brown		Reddish brown		Yellow
		Score	8–10		5–7		0–4
	C_2	Degree	sweet and spicy perfume				sweet and spicy perfume with flavor and aroma of baking
		Score	6–10				0–5
	C_3	Content/%	[4.09, 4.12)	[4.12, 4.31)	[4.31, 4.62)	[4.62, 5.40)	[5.40, 5.99]
		Score	8–10	6–7	4–5	2–3	0–1
	C_4	Content/%	[3.05, 2.90)	[2.90, 2.61)	[2.61, 2.03)	[2.03, 1.74)	[1.74, 1.59]
		Score	8–10	6–7	4–5	2–3	0–1
	C_5	Content mg/g	[25.73, 24.07)	[24.07, 20.74)	[20.74, 14.08)	[14.08, 10.84)	[10.84, 9.08]
		Score	8–10	6–7	4–5	2–3	0–1
	C_6	Content mg/g	[0.06, 0.056)	[0.056, 0.048)	[0.048, 0.032)	[0.032, 0.024)	[0.024, 0.02]
		Score	8–10	6–7	4–5	2–3	0–1
	C_7	Content mg/g	[0.22, 0.20)	[0.20, 0.16)	[0.16, 0.09)	[0.09, 0.06)	[0.06, 0.04]
		Score	8–10	6–7	4–5	2–3	0–1
	C_8	Content mg/g	[3.72, 3.52)	[3.52,3.12)	[3.12 2.31)	[2.31, 1.91)	[1.91, 1.71]
		Score	8–10	6–7	4–5	2–3	0–1
Efficiency quality B_3	C_9	Time/h	[0.42, 3.46)	[3.46, 9.75)	[9.75, 24.0)	[24.0, 180)	[180, 240]
		Score	8–10	6–7	4–5	2–3	0–1
	C_{10}	Content/%	[49.4, 49.0)	[49.0, 48.0)	[48.0, 45.2)	[45.2, 40.8)	[40.8, 39.1]
		Score	8–10	6–7	4–5	2–3	0–1
		Grade	4	3	2	1	0

Table 4
Results of comprehensive weight score for different drying method.

Drying method	30OD	40OD	45OD	50OD	55OD	60OD	65OD	70OD	75OD	SD	SD + 50OD	SHD	MD	FD
C_1	10	10	10	10	10	10	10	10	10	6	7	10	6	3
C_2	10	10	10	10	10	10	10	10	10	10	10	10	5	10
C_3	5.76	7.79	7.86	5.51	5.56	5.44	5.51	3.32	5.45	3.25	10.0	5.44	0.00	7.94
C_4	5.11	7.77	10.0	4.95	4.88	4.74	2.64	0.45	4.04	4.92	6.96	5.60	0.00	9.90
C_5	9.99	7.89	10.0	9.98	9.97	7.76	9.65	4.74	2.43	7.69	5.48	7.70	0.00	9.96
C_6	2.50	2.50	7.50	2.50	5.00	2.50	2.50	5.00	5.00	2.50	5.00	10.0	0.00	0.00
C_7	0.00	4.84	7.33	2.44	4.69	7.36	5.04	7.54	7.62	7.44	7.43	0.00	7.76	10.0
C_8	7.50	5.18	10.0	7.32	9.68	4.86	7.32	7.41	5.05	4.69	5.08	9.76	0.00	2.32
C_9	3.80	5.85	5.88	5.90	5.91	5.92	7.93	7.94	7.95	3.00	3.52	0.00	10.0	5.80
C_{10}	5.67	3.11	7.79	7.82	2.66	3.01	0.00	7.79	5.33	5.48	5.30	10.0	5.54	5.27
Score	7.39	7.34	9.00	7.75	7.37	6.88	6.55	6.52	6.38	5.81	6.28	7.88	3.42	5.99
Ranking	4	6	1	3	5	7	8	9	10	13	11	2	14	12

%) and essential oil (89.95 %) [43]. Cinnamaldehyde was considered as the indicator component stipulated in the Chinese pharmacopoeia and the main bioactive component of cinnamon with antifungal, antiparasitic, antitumor, antibacterial, and antidiabetic pharmacological activities [10–12].Our previous study found that the most abundant volatile organic compounds, cinnamaldehyde, peaked at 120 months after planting of *C. cassia* barks, and dominated the aroma qualities [42]. In this study, cinnamaldehyde content had higher weight value in the AHP-comprehensive scoring method, indicating its importance for quality evaluation of *C. cassia*. Besides cinnamaldehyde, four other major active ingredients were also considered as the quality markers (Q-Marker) of *C. cassia*, including coumarin, cinnamyl alcohol, cinnamic acid, and *o*-methoxycinnamaldehyde [15,44]. For instant, cinnamaldehyde and *o*-methoxycinnamaldehyde in cinnamon are the main effective components of its anti-inflammatory, hypoglycemic and immunomodulatory effects. Cinnamyl alcohol is the main effective component of its antibacterial action and the main material basis for the effectiveness of cinnamon [15]. Wang et al. simultaneously determined their concentrations and differentiated capacities of them in Cinnamomi ramulus (CR, *Guizhi* in Chinese) and Cinnamomi cortex (CC, *Rougui* in Chinese) using HPLC method, and found that *trans*-cinnamaldehyde and cinnamyl alcohol could be used as markers to successfully distinguish CR and CC [44]. Due to the content of cinnamic acid was below the limit of detection, we successfully established a HPLC method for content determination of four quality markers in current study. There were significant differences of the total content of four quality markers in different drying methods, and the maximum appeared in 45OD samples (30.23 mg g^{-1}). Additionally, SHD method exhibited the maximum coumarin content (0.06 mg g^{-1}), while the highest content of cinnamyl alcohol (0.22 mg g^{-1}) appeared in FD samples. These results suggested that the clinical efficacy of Cinnamomi cortex produced by different drying methods might exhibit certain differences. It is necessary to maintain the natural color during drying process due to the color seen of dried products was important for the first judgment made by the consumers. Long-duration drying and high temperatures cause color degradation of the original product [45]. The variations in visual appearance under different drying methods have already been established for various plants, such as rose [46], asparagus [45], and sweet basil [38]. The color seen of both OD and SHD drying methods was dark reddish brown color, which was consistent with the color stipulated in the Chinese pharmacopoeia. Considering the consumption of drying time, OD method showed a potential in

maintaining the color characteristics, which may be in line with the high content of active ingredients.

The drying parameters including drying methods, temperature, vacuum level (in case of processes such as freeze drying) played important roles on the preservation of volatile compounds of products during drying process [15]. In asparagus roots, several indexes varied under various drying processes, including color, odor, and volatile compounds [45]. In *Amomum tsao-ko*, the total volatile content, oxygenated monoterpenes content, and the main components showed remarkable variations in pre-drying and drying methods [19]. Similarly, we found that the various drying methods had multiple effects on the color, drying rate and time, ash content, essential oil content, as well as Q-Marker contents. In SHD method, the drying time was the longest (240 h), while the drying rate, essential oil and Q-Marker compounds content were at a high level. Compared with other drying methods, 45OD maintained optimal levels of color and aroma, it also significantly shortened the drying time by 225 h than traditionally shade-drying (SHD) method with the drying rate (48.35 %), and obtained the highest essential oil content (3.05 %) and Q-Marker contents (30.23 mg g^{-1}). Furthermore, the ash content (4.22 %) were satisfied with the stipulation of Chinese pharmacopoeia in 45OD samples [45].

Many research have reported that OD at higher temperatures resulted in a considerable decrease in essential oil content through evaporation [34,47]. Peanut should be dried by hot air below 45 °C for quality maintenance through not only reducing the percentage of damaged red testa and broken kernel, but also increasing the acid value and peroxide value of the extracted oil [48]. Many volatile compounds in the dried products lost when drying temperatures higher than 60 °C in sweet basil [49], peppermint [50], and lime [51]. Our results also revealed that elevated temperature (above 60 °C) could decrease the total Q-Markers' content, this phenomenon illustrates that Q-Markers are unstable at high temperature in *C. cassia*. We suggest that the temperature for drying *C. cassia* barks was below 50 °C, of which 45OD was optimal with the highest total score (9.00).

5. Conclusions

Sun-drying (SD) and shade-drying (SHD) method are chosen for the frequently used drying methods for *C. cassia* barks in industrial application. SHD is the only drying method stipulated by Chinese Pharmacopoeia. However, they were usually susceptible to weather, which indirectly affected the drying efficiency and quality. With the development of drying technology, some modern technologies could be utilized in the processing of *C. cassia* drying process. Results revealed that fourteen different drying methods had multiple effects on the physicochemical qualities, essential oil content, and Q-Marker contents in the current study. Compared with other drying methods, 45 OD maintained optimal levels of color and aroma, it also significantly shortened the drying time by 225 h than traditionally SHD method with the drying rate (48.35 %), and obtained the highest essential oil content (3.05 %) and Q-Marker contents (30.23 mg g^{-1}). Furthermore, the ash content (4.22 %) were satisfied with the stipulation of Chinese pharmacopoeia in 45OD samples. Taking into account the appearance characteristics, internal quality and efficiency, 45OD is an efficient technique for the industrial drying production of high quality *C. cassia* barks recommended by AHP method with the highest total score (9.00).

The present study is the first report to apply the AHP method for quality evaluation of drying processing in *C. cassia*. It can provide the theoretical basis for evaluating an excellent method for *C. cassia* drying processing, as well as the rational use of different drying methods to furtherly develop the high quality *C. cassia* industry.

Data availability

Data associated with the study has not been deposited into a publicly available repository. Data are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The collection of plant materials used in our study complied with permission of related institutions, and complied with national or international guidelines and legislation. The experiments did not involve endangered or protected species.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Linshuang Li: Writing – original draft, Methodology, Investigation, Formal analysis. **Liuping Chen:** Writing – original draft, Methodology, Investigation, Formal analysis. **Dongjin Pan:** Writing – review & editing. **Ying Zhu:** Methodology, Investigation, Formal analysis. **Rongshao Huang:** Supervision, Funding acquisition, Conceptualization. **Jing Chen:** Writing – original draft. **Chenying Ye:** Writing – original draft. **Shaochang Yao:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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