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The nutrients, flavour, and antioxidant analysis of different parts of *Dictyophora rubrovalvata*

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Abstract: This study evaluated the nutrients, flavour and antioxidant capacity in the embryo, colloid and fruiting body of *Dictyophora rubrovalvata*. The embryo had the highest protein [2.91 ± 0.39 g·(100 g)$^{-1}$] and polysaccharides (17.44 ± 1.49 mg·g^{-1}), the fruiting body had the highest total phenol content (0.87 ± 0.17 mg·g^{-1}), the colloid was rich in minerals [1.57 ± 0.16 g·(100 g)$^{-1}$]. The antioxidant capacity of the embryo was higher than that of the other parts, in terms of different solvents, the antioxidant capacity of *D. rubrovalvata* extracted with ethanol was higher than that of water. 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and reducing capacity were positively correlated with polysaccharides, proteins and polyphenols. The free amino acid content ranged from 7.44 to 11.52 mg·g^{-1}, the distribution was fruiting body > embryo > colloid, of which glutamic acid content was the highest, and the flavour characteristics were mainly umami and sweetness. The nucleotide content of fruiting body and embryo was higher than in the colloid. In addition, the compositions of volatile flavour compounds were identified by headspace solid-phase microextraction gas chromatography-mass spectrometry (HS-SPME-GC-MS), mainly alcohols, aldehydes and ketones, their distributions varied greatly among the three samples. These results indicated that different parts of *D. rubrovalvata* have different nutritional characteristics, the fruiting body has a high content of volatile and non-volatile components, the embryo and the colloid have good functional activity, laying a foundation for the functional development and comprehensive utilisation of *D. rubrovalvata*.

Keywords: component analysis; biological activity; non-volatile compound; volatile compound; quality

Dictyophora rubrovalvata belongs to the fungi of the genus *Dictyophora* in the family Phallaceae, and it is a very precious dual-purpose edible and medicinal fungus variety in China (Ker et al. 2011). In recent years, it has been reported that *D. rubrovalvata* produced 186 400 t of fresh products in China every year, large-scale artificial cultivation has been achieved in Guizhou, Sichuan, and Yunnan (Dai et al. 2021). *D. rubrovalvata* has a beautiful appearance, a fragrant flavour, a crispy and tender taste. It is rich in protein, polysaccharides, flavonoids, vitamins, amino acids (Zeng et al. 2023), and has biological activities such as antioxidant, anti-hyperlipidaemic, anti-tumor, immune regulation, and liver and kidney protection (Deng et al. 2016; Liu et al. 2017; Wang et al. 2019; Bai et al. 2021). It is known as the 'queen of mushrooms'.

The whole plant of *D. rubrovalvata* is composed of three parts: hyphae, stipes (fruiting bodies) and cap. The primary areas of current research on the utilisation of *D. rubrovalvata* include cultivation, nu-

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Figure 1. (A) Embryo, (B) fruiting body, and (C) colloid of *Dictyophora rubrovalvata*

tritional analysis, polysaccharide functional components and processed products (Liang et al. 2020; Wang et al. 2020; Yao et al. 2022). However, the growth stage of *D. rubrovalvata* includes embryo, fruiting body and colloid, as shown in Figure 1. The embryo, which possessed a rich colloid matrix encasing spores, was the pre-morphology of *D. rubrovalvata*. Early on, the fruiting body was spherical in shape and it develops in closed mushroom buds. The fruiting body will break and protrude as it ages. The colloid becomes flowing and fragrant after the fruiting body sprouts, however it was usually thrown away once the fruiting body was picked, wasting resources. Relevant studies have shown that all parts of *D. rubrovalvata* contain active ingredients such as polysaccharides, phenols, amino acids and other active ingredients (Liang et al. 2020), so its postharvest by-products also have a great development value. Zhuang et al. (2011) revealed that the volva and pileus can also be used as a high-quality plant protein resource. The industry took edible parts of *D. rubrovalvata* as processing objects, there have been no development and utilisation of the different parts, especially the post-harvest waste such as the large amount of the colloid. The nutritional components and flavour system analysis of embryo, fruiting body and colloid in *D. rubrovalvata* throughout growth have received comparatively less attention. This study evaluates the quality differences in the three growth stages based on essential nutritional components, antioxidant capacity, amino acid content and flavour characteristics, and volatile flavour substances in order to lay the theoretical foundation for the comprehensive development and utilisation of *D. rubrovalvata*. This has significant economic and social benefits for the efficient utilisation of *D. rubrovalvata* resources, laying a foundation for the comprehensive processing and utilisation of *D. rubrovalvata*.

MATERIAL AND METHODS

Material

Fresh, disease-free, and similarly sized fruiting bodies and embryos of *D. rubrovalvata* were collected from the cultivation site in Zhijin County, Bijie City, Guizhou Province. The by-products of the fruiting body were retrieved after harvesting, and the capsule peel was immediately removed to obtain fresh colloids.

Nutrient components

The nutrient composition of the three sites, including moisture, protein, ash and polysaccharide, was determined in triplicate according to the methods of the Association of Official Analytical Chemists (1995). The protein content was determined by the Kashi nitrogen method [protein (%) = N (%) × 6.25]. The ash content is determined by weighing the residue obtained after incineration at 550 °C to a constant weight. The polysaccharide content was determined by the phenol-sulphuric acid method, and the curve was prepared with glucose standard solution ($Y = 1.0594x + 0.0603$; $R^2 = 0.9992$). All other chemicals and solvents were of analytical grade and were purchased from Sinopharm Chemical Reagent Co., Ltd. (China).

Total phenolic content (TPC) analysis

Triple extraction of 1.0 g sample was performed with 30 mL of 60% (*v*/*v*) ethanol in an ultrasound bath (100 W) for 30 min. TPC was determined by the Folin-Ciocalteu method. Prepare the calibration curve using gallic acid standard solution ($Y = 0.6749x + 0.0711$; $R^2 = 0.9994$).

Antioxidant assays

Preparation of ethanol extract. Ultrasonic-assisted extraction of 1.0 g sample was done with 30 mL of 60% ethanol at room temperature for 30 min, followed

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by centrifugation at 6 000 rpm for 15 min and dilution of the supernatant to 50 mL.

Preparation of distilled water extract. In accordance with the above ethanol extraction method, ethanol was replaced with distilled water.

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity. The DPPH radical scavenging capacity of the extract was determined by the improved method of Kumla et al. (2021).

The 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) scavenging activity. The ABTS radical scavenging capacity of the extract was determined by the improved method of Wang et al. (2021).

Reducing power. The reducing power of extracts was determined by a modified method of Reis et al. (2014).

Non-volatile compound analysis

The acquired samples were dried in a vacuum freeze dryer (Sciente-18N; Ningbo Xinzhi Biotechnology, China) at 0–100 Pa for 48 h after being frozen at –20 °C for 12 h.

Free amino acid analysis. Referring to Beluhan et al. (2010) the amino acid composition was analysed. An amount of 1.0 g sample powder was mixed with 5% (*v*/*v*) trichloroacetic acid for 20 min at room temperature with an ultrasonic power of 100 W, and centrifuged for 30 min at 10 000 rpm. The supernatant was passed through a 0.22 μm filter (Shanghai Xingya Purification Materials Co., Ltd., China) prior to analysis.

Nucleotide assay. Using high-performance liquid chromatography (WondaSil C18; 4.6 × 250 mm, 5 μm), the mobile phase was 0.01 M KH_2PO_4 buffer solution and methanol at a flow rate of 1 mL·min^{-1}. The column temperature was 25 °C and equal gradient elution was performed (Manninen et al. 2018; Zhou et al. 2022).

Volatile compound analysis

The volatile compounds were determined according to a previous study with minor modifications (Li et al. 2019; Zhou et al. 2022). The volatiles were extracted by headspace solid-phase microextraction (HS-SPME), placing 2.0 g of the sample in a 20 mL headspace glass sampling vial. An SPME fibre divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) (Supelco, USA) was used to extract the volatiles at 60 °C for 30 min. Afterward, an HS-SPME fibre was inserted into the injection port of the gas chromatography-mass spectrometry (GC/MS) system for thermal desorption.

The GC/MS was performed using a Trace GC and a Trace MS (Finnigan Trace GC/MS; Finnigan, USA) equipped with a 3DB-624 Ultra Inert column (30 m × 250 μm × 1.4 μm; J&W Scientific, USA). The injector port was heated to 240 °C. The initial temperature was set to 38 °C for 5 min, then raised at 6 °C min^{-1} to 140 °C, elevated to 240 °C at 10 °C·min^{-1} and held there for 10 min. The carrier gas was helium and it had a flow rate of 1 mL·min^{-1}, and the split ratio was 1 : 10. Mass spectra were acquired in electron impact mode. The MS was taken at 70 eV, and the ion source temperature was 230 °C; the mass scanning range was 25–500 u. The data were retrieved by the mass spectrometry computer system and checked with the NIST 2017 and Wiley 275 standard mass spectra. The volatile chemical components were identified, and the peak area normalisation method was used for qualitative and relative quantitative analyses.

Statistical analysis

The results are expressed as mean value ± standard deviation (SD). The SPSS software (version 22.0) was used for statistical data analysis. The statistical significance of the data was tested by one-way analysis of variance (ANOVA), followed by Duncan's test to compare the means that showed significant variation. A value of $P < 0.05$ was considered to be statistically significant.

RESULTS AND DISCUSSION

Nutrient components

As shown in Table 1, the polysaccharide content was the highest ($P < 0.05$) in the embryo, it was

Table 1. Nutritional indicators of different parts of *Dictyophora rubrovalvata*

Sample	Polysaccharide (mg·g^{-1})	Total phenols (mg·g^{-1})	Protein [g·(100 g^{-1})]	Ash content [g·(100 g^{-1})]
Embryo	17.44 ± 1.49^{a}	0.65 ± 0.09^{b}	2.91 ± 0.39^{a}	1.32 ± 0.32^{a}
Fruiting body	12.59 ± 3.18^{b}	0.87 ± 0.17^{a}	1.87 ± 0.21^{b}	1.37 ± 0.08^{a}
Colloid	6.39 ± 0.19^{c}	0.58 ± 0.20^{b}	0.79 ± 0.25^{c}	1.57 ± 0.16^{a}

$^{a–c}$ Letters in the same column indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$

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higher than that of *Pleurotus ostreatus*, *Flammulina velutipes*, *Tremella fuciformis*, and *Pholiota nameko* reported in Li et al. (2023). The content of TPC was the highest in the fruiting body, that means plant phenols are mainly found in the stems and skins of plants (Dai et al. 2015). There was no significant difference in TPC between the colloid and the embryo ($P < 0.05$), indicating that there were also available active substances in the colloid and embryo. However, the colloid has a high moisture content, which may lead to a relatively low nutrient concentration. The mineral content of the three parts was similar. This indicated that *D. rubrovalvata* had a certain nutritional value at various stages, and the colloid accounts for a large proportion of the waste; if it is utilised, it will reduce the waste of *D. rubrovalvata* resources and also improve the nutritional and economic value of products.

Analysis of antioxidant capacity of *D. rubrovalvata*

Because of different solubility of polysaccharides and phenols, this study was conducted to determine the antioxidant capacity of different parts of *D. rubrovalvata* by using ethanol and water extract to lay the foundation for efficient utilisation. As shown in Figures 2, 3, and 4, the antioxidant capacity of ethanol extract was higher than that of the water extract, which is in agreement with the findings of Wickramasinghe et al. (2023), the differences in extraction methods may have led to these variations, and they indicated that active substances like polyphenols in ethanol extraction have stronger antioxidant contributions. In the three growth stages, the embryo had the strongest antioxidant capacity; this is related to the highest content of polysaccharides and protein, which provides a theoretical basis for the development of functional foods in the embryo. The ethanol extract of the fruiting body exhibits better ABTS+ radical scavenging ability than the colloid, which may be related to its high TPC content. Moreover, the colloid contains relatively high moisture,

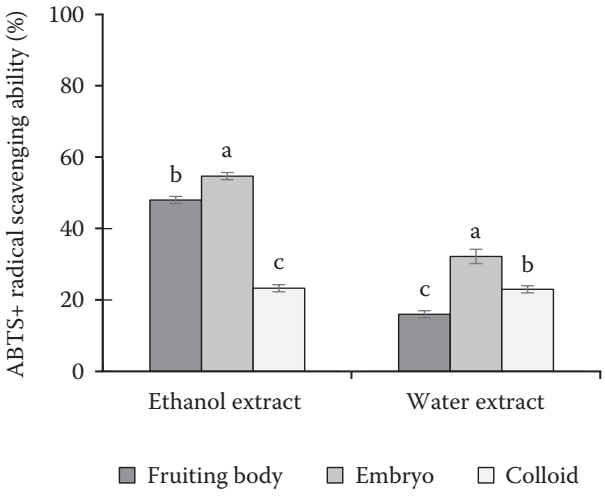

Figure 3. ABTS+ radical scavenging ability in different parts of *Dictyophora rubrovalvata*

a–c – different letters indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$; ABTS – 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)

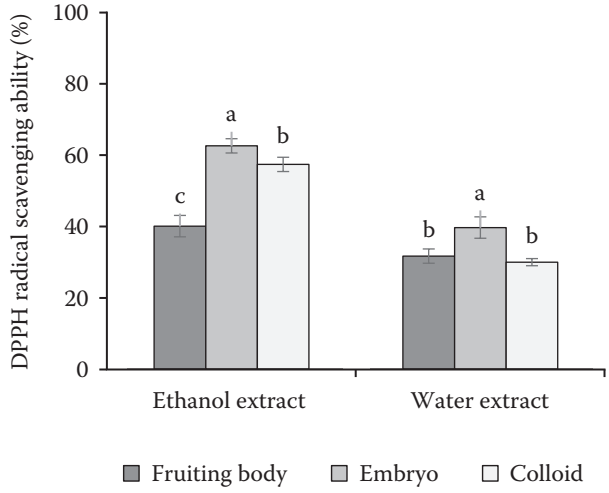

Figure 2. DPPH radical scavenging ability in different parts of *Dictyophora rubrovalvata*

a–c – different letters indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$; DPPH – 2,2-diphenyl-1-picrylhydrazyl

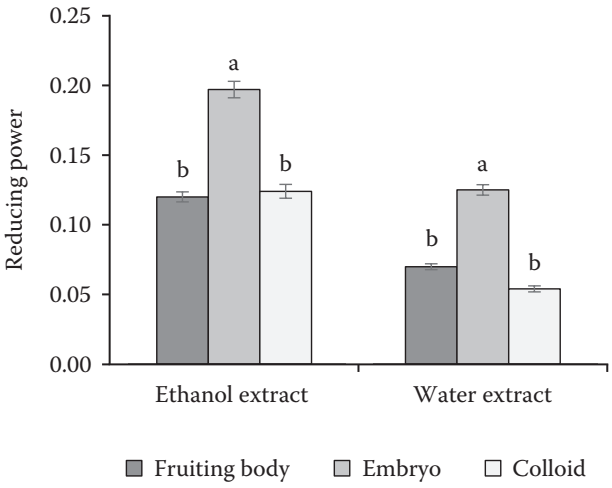

Figure 4. Reducing ability of different parts of *Dictyophora rubrovalvata*

a–b – different letters indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$

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which weakens its antioxidant capacity. However, there was no significant difference in the reducing power of the fruiting body and colloid, indicating that there were also available substances in the colloid which laid the foundation for the high-value processing of various parts of *D. rubrovalvata*. In addition, as shown in Tables 2 and 3, protein and polysaccharides were significantly positively correlated with DPPH radical scavenging capacity and reducing power of water extracts, and ABTS+ radical scavenging capacity of ethanol extracts was significantly positively correlated with TPC, polysaccharides and protein. This suggests that antioxidants embody different antioxidant pathways in different solvents.

Analysis of flavouring substance content and composition

Free amino acids. Free amino acids as important non-volatile flavour substances in edible fungi are important nutrients required by humans (Tian et al. 2016). Table 4 shows seven essential amino acids and 10 non-essential amino acids in *D. rubrovalvata*, when the content of free amino acids was the highest in the fruiting body, mainly umami and sweet amino acids, indicating that the fruiting body was the most suitable for food processing. The sweet amino acids in the fruiting body were 1.70 times higher than in the embryo and 2.20 times higher than in the colloid, which is in agreement with the study of Mau et al. (2021). Whether it was *D. rubrovalvata* or shiitake mushroom, the fruiting body had a much higher sweet amino acid content than the other sections. The umami amino acids also had similar results. The embryo and the colloid also had available amino acids, suggesting that processed by-products had a high utilisation value. Glutamic acid and alanine were the highest among the free amino acids, which can synergistically produce umami and sweetness for *D. rubrovalvata* (Xiao et al. 2022; Yang et al. 2016). They are important substances involved in various physiological activities (Katsutaka et al. 2023), which can not only enrich the flavour but also provide support for expanding the research of functional food. These two amino acids are mainly concentrated in the fruiting body, enhancing the sweetness and umami of the product. Colloids also have a certain flavour and they have a certain value in the development and utilisation of flavour products.

Flavoured nucleotides. Inosine monophosphate (5'-IMP), cytosine monophosphate (5'-CMP), and adenosine monophosphate (5'-AMP) were detected, and the results are shown in Table 5. The fruiting body and embryo contained the highest nucleotides, and they are much higher than the three nucleotides reported by Mau et al. (2021) in shiitake mushrooms. This suggests that the fruiting body and embryo can be used in the processing of flavour enhancers. The colloid has a high mineral content and a certain concentration of polysaccharides and amino acids despite having low nucleotides, which means that discarding it would be a waste of resources. Combined with Table 4, this indicates that fruiting bodies contain the highest concentration of non-volatile compounds, making them ideal for the development of flavourings. However, the

Table 2. Correlation analysis between antioxidant activity and components in ethanol extraction

Antioxidant method	Polysaccharide	TPC	Protein
DPPH	0.241	–0.278	0.198
ABTS	0.825**	0.981**	0.921**
Reducing power	0.817**	0.419	0.695*

*, ** Significant at $P \leq 0.05$ and 0.01, respectively; the values are the means of three replicates; TPC – total phenolic content; DPPH – 2,2-diphenyl-1-picrylhydrazyl; ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

Table 3. Correlation analysis between antioxidant activity and components in water extraction

Antioxidant method	Polysaccharide	TPC	Protein
DPPH	0.673*	0.190	0.904**
ABTS	0.504	–0.356	0.561
Reducing power	0.830**	0.027	0.778*

*, ** Significant at $P \leq 0.05$ and 0.01, respectively; the values are the means of three replicates; TPC – total phenolic content; DPPH – 2,2-diphenyl-1-picrylhydrazyl; ABTS – 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

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Table 4. Free amino acid content and composition of *Dictyophora rubrovalvata* in different parts (mg·g^{-1})

Amino acids	Colloid	Embryo	Fruiting body
Glycine	0.15 ± 0.00^{c}	0.10 ± 90.01^{b}	0.25 ± 0.01^{a}
Alanine	1.21 ± 0.03^{b}	1.61 ± 0.02^{b}	2.91 ± 0.27^{a}
Proline	0.07 ± 0.01^{c}	0.18 ± 0.00^{b}	0.23 ± 0.01^{a}
Serine	0.09 ± 0.01^{b}	0.12 ± 0.00^{b}	0.22 ± 0.01^{a}
Threonine	0.42 ± 0.02^{b}	0.44 ± 0.02^{b}	0.68 ± 0.04^{a}
Sweetness	1.95 ± 0.03^{c}	2.53 ± 0.03^{b}	4.29 ± 0.20^{a}
Glutamic acid	1.21 ± 0.01^{a}	1.79 ± 0.10^{b}	3.74 ± 0.09^{c}
Aspartic acid	0.63 ± 0.01^{a}	0.64 ± 0.01^{a}	0.46 ± 0.01^{b}
Umami	1.85 ± 0.01^{c}	2.43 ± 0.06^{b}	4.20 ± 0.05^{a}
Methionine	0.38 ± 0.02^{a}	0.03 ± 0.02^{b}	0.05 ± 0.00^{c}
Arginine	0.72 ± 0.09^{a}	0.49 ± 0.01^{b}	0.04 ± 0.01^{c}
Histidine	0.05 ± 0.00^{b}	0.06 ± 0.00^{b}	0.12 ± 0.01^{a}
Tyrosine	0.40 ± 0.02^{b}	0.36 ± 0.00^{b}	0.75 ± 0.07^{a}
Valine	0.65 ± 0.02^{a}	0.69 ± 0.02^{a}	0.69 ± 0.01^{a}
Leucine	0.31 ± 0.01^{b}	0.42 ± 0.02^{a}	0.33 ± 0.01^{b}
Lysine	0.21 ± 0.01^{b}	0.26 ± 0.01^{a}	0.23 ± 0.01^{a,b}
Phenylalanine	0.52 ± 0.01^{a}	0.41 ± 0.02^{b}	0.34 ± 0.00^{c}
Isoleucine	0.38 ± 0.02^{b}	0.18 ± 0.01^{c}	0.44 ± 0.01^{a}
Bitterness	3.62 ± 0.08^{a}	3.15 ± 0.08^{b}	2.99 ± 0.08^{c}
Cysteine	0.03 ± 0.00^{b}	0.05 ± 0.00^{a}	0.04 ± 0.00^{a}
Tasteless	0.03 ± 0.00^{b}	0.05 ± 0.00^{a}	0.04 ± 0.00^{a}
Sum	7.44 ± 0.17^{c}	8.16 ± 0.02^{b}	11.52 ± 0.32^{a}

$^{a–c}$ Letters in the same column indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$

colloid also has other useful properties that should not be disregarded, like the ability to thicken food by adding thickening agents and replacing some of the water, thus increasing its functional value.

Volatile compound analysis. The volatile compounds were detected and analysed by HS-SPME-GC-MS, when a total of 58 volatile compounds were identified in *D. rubrovalvata*, including 17 aldehydes, 11 ketones, 14 alcohols, 6 acids, and 10 other compounds, among them ketones, aldehydes and alcohols were the main volatile components (Tables 6 and 7). Specifically, 36.25% of all volatile compounds in the fruiting body, 29.95% in the embryo and 29.22% in the colloid were ketones. Among the ketones, piperitone was the highest in the fruiting body; these ketones were formed by the oxidative degradation of unsaturated fatty acids (Shi et al. 2020). Aldehydes accounted for 30.63% of the total volatile compounds in the embryo, 9.08% and 28.46% in the fruiting body and colloid, respec-

Table 5. Different parts of *Dictyophora rubrovalvata* showed flavor nucleotide content (mg·g^{-1})

Part	5'-IMP	5'-CMP	5'-AMP	Sum
Embryo	1.14 ± 0.06^{a}	2.25 ± 0.04^{a}	5.35 ± 0.30^{a}	8.74 ± 0.28^{a}
Fruiting body	1.19 ± 0.24^{a}	2.21 ± 0.18^{a}	6.32 ± 1.66^{a}	9.72 ± 2.07^{a}
Colloid	0.02 ± 0.01^{b}	1.36 ± 0.06^{b}	1.96 ± 0.02^{b}	3.35 ± 0.09^{b}

$^{a–b}$ Letters in the same column indicate significant differences at $P < 0.05$; values are means ± SD; $n = 3$; 5'-IMP – inosine monophosphate; 5'-CMP – cytosine monophosphate; 5'-AMP – adenosine monophosphate

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Table 6. The relative content of volatile flavor compounds of *Dictyophora rubrovalvata* (%)

Category	Volatile compounds	Molecular formula	Fruiting body	Embryo	Colloid
Alcohols	ethanol	C_2H_6O	0.04	0.04	0.02
	phenethyl alcohol	$C_8H_{10}O$	1.84	4.85	2.58
	1-pentanol	$C_5H_{12}O$	–	1.02	0.54
	linalool	$C_{10}H_{18}O$	4.94	–	–
	2-methyl-1-propanol	$C_4H_{10}O$	–	–	0.23
	furfuryl alcohol	$C_5H_6O_2$	–	–	0.80
	2-ethylhexanol	$C_8H_{18}O$	2.53	6.69	3.56
	1-hexanol	$C_6H_{14}O$	–	2.15	1.14
	1-octanol	$C_8H_{18}O$	–	–	3.56
	2-methyl-1-pentanol	$C_5H_{12}O$	–	–	0.55
	3-methyl-1-butanol	$C_5H_{12}O$	–	–	0.55
	2,3-butanediol	$C_4H_{10}O_2$	0.42	1.12	0.59
	1-octen-3-ol	$C_8H_{16}O$	–	6.1	3.25
	hexanal	$C_6H_{12}O$	0.70	1.84	0.98
Aldehydes	acetaldehyde	C_2H_4O	0.01	–	0.02
	2-methylbutyraldehyde	$C_5H_{10}O$	–	0.85	–
	furfural	$C_5H_4O_2$	–	1.33	0.71
	benzaldehyde	C_7H_6O	0.93	2.47	1.31
	gamma-nonanolactone	$C_9H_{16}O_2$	–	14.27	7.60
	acrylaldehyde	$C_9H_{16}O$	–	–	0.04
	valeraldehyde	$C_5H_{10}O$	–	0.83	–
	heptaldehyde	$C_7H_{14}O$	–	3.62	–
	decyl aldehyde	$C_{10}H_{20}O$	5.24	–	–
	phenylacetaldehyde	C_8H_8O	–	4.57	2.43
	octanal	$C_8H_{16}O$	–	–	3.24
	1-nonanal	$C_9H_{18}O$	–	–	5.19
	2-methylbutyraldehyde	$C_5H_{10}O$	–	0.85	–
	(e)-2-octenal	$C_8H_{14}O$	2.10	–	2.96
	crotonaldehyde	C_4H_6O	0.10	–	–
	2,4-dimethylbenzaldehyde	C_4H_8OS	–	–	3.98
	piperitone	$C_{10}H_{16}O$	35.31	–	–
	2-pentanone	$C_5H_{10}O$	–	0.84	0.44
	2-heptanone	$C_7H_{14}O$	–	3.62	–
	2-undecanone	$C_{11}H_{22}O$	–	18.96	10.10
	2,3-butanedione	$C_4H_6O_2$	0.31	–	–
	acetoin	$C_4H_8O_2$	0.37	0.98	0.52
Ketones	2-pentanone	$C_5H_{10}O$	–	0.84	0.44
	2-decanone	$C_{10}H_{20}O$	–	–	7.37
	3-octen-2-one	$C_8H_{14}O$	–	5.55	–
	2h-pyran-2,6(3h)-dione	$C_5H_4O_3$	–	–	1.62
	6-pentyl-2h-pyran-2-one	$C_{10}H_{14}O_2$	–	–	9.17

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Table 6. To be continued

Category	Volatile compounds	Molecular formula	Fruiting body	Embryo	Colloid
Acids	acetic acid	$C_2H_4O_2$	0.05	0.13	0.07
	isobutyric acid	$C_4H_8O_2$	0.38	–	0.54
	isovaleric acid	$C_5H_{10}O_2$	0.79	2.08	–
	2-methyl butyric acid	$C_5H_{10}O_2$	0.79	–	1.11
	hexanoic acid	$C_6H_{12}O_2$	1.49	3.93	2.09
	isovaleric acid	$C_5H_{10}O_2$	0.79	2.08	–
Others	ethyl acetate	$C_8H_{16}O_2$	0.37	–	–
	tulipalin A	$C_5H_6O_2$	–	1.52	–
	delta-hexalactone	$C_6H_{10}O_2$	–	–	1.89
	n, n-dimethylformamide	C_3H_7NO	–	–	0.20
	phenol	C_6H_6O	0.48	–	–
	3-picoline	C_6H_7N	0.46	1.22	–
	alpha-bisabolol	$C_{15}H_{26}O$	15.58	–	–
	1-pentadecyne	$C_{15}H_{28}$	–	–	18.52
	tetramethylpyrazine	$C_8H_{12}N_2$	3.00	–	–
	2-pentylfuran	$C_9H_{14}O$	3.21	8.57	–
	(-)-alpha-bisabolol	$C_{30}H_{52}O_4$	18.30	–	–

tively. Aldehydes vary greatly in percentage and type, which might also be an important factor affecting the flavour of *D. rubrovalvata*. Alcohols accounted for 25.35% of the total volatile compounds in the fruiting body, and the relative content of alcohols was the lowest in the colloid (17.37%). The relative content of 2-ethylhexanol in alcohols was the highest, which is inconsistent with the results reported by Liu et al. (2021). They detected the highest relative content of 1-octen-3-ol in shiitake mushrooms, which may be a difference due to the species of the fungus. The relative content of heterocyclic compounds was the highest in the fruiting body (25.82%), with the highest content of alpha-bisabolol and its oxides being the most abundant (15.58% and 18.30%, respectively), while it has good anti-inflammatory and anti-bacterial properties (Wu et al. 2020). And they were present only in the fruiting body, which is a reproductive organ that produces spores. It is possible that the entities contained high expression of terpene synthases, which were present in the reproductive organs of the plant (Li et al. 2021). Moreover, alpha-bisabolol has good anti-inflammatory effects, indicating that in addition to having good flavour characteristics, the fruiting body can also play a certain active role.

Figure 5 shows the heat map of volatile compounds in different part of *D. rubrovalvata*, when volatile compounds in the embryo were one group and volatile compounds in the fruiting body and colloid were another group, indicating that there were differences in volatile compounds between different parts of *D. rubrovalvata*. The flavour of the fruiting body is similar to that of the colloid, which could mean that certain components experience oxidation and deterioration when the fruiting body germinates and is exposed to air. (Li et al. 2018).

Table 7. Analysis of volatile components of different parts of *Dictyophora rubrovalvata* (%)

Volatile components	Fruiting body	Embryo	Colloid
Alcohols	25.35	21.97	17.37
Aldehydes	9.08	30.63	28.46
Ketones	36.25	29.95	29.22
Acids	3.50	6.14	4.34
Others	25.82	11.31	20.61

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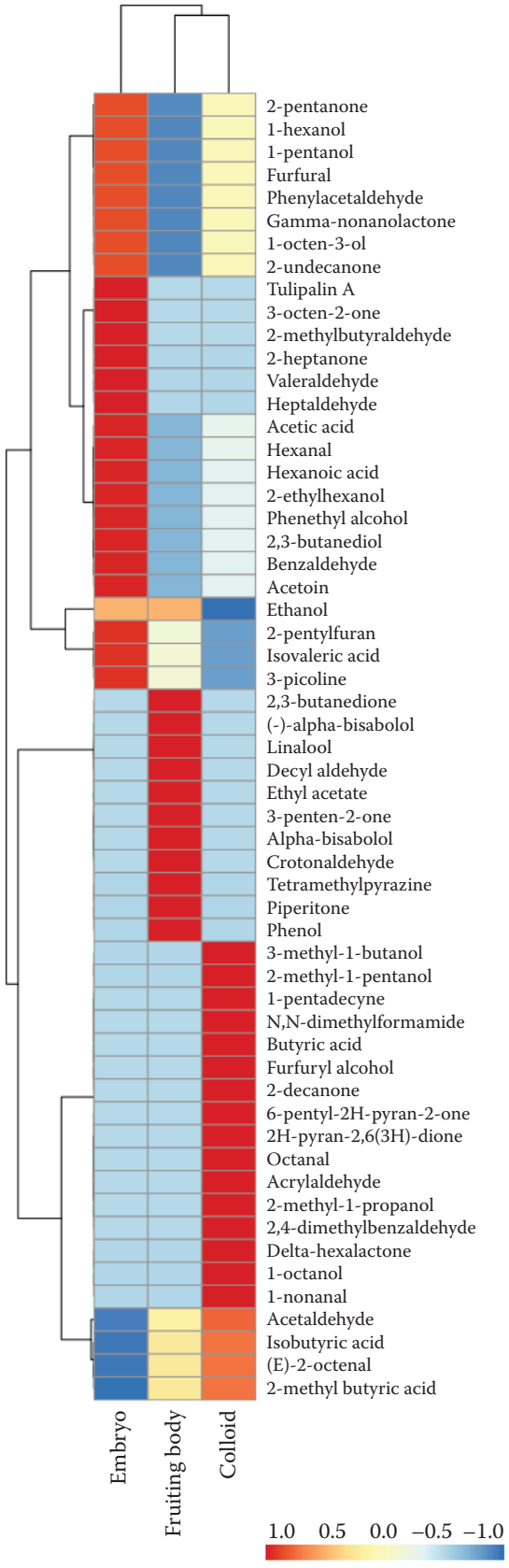

Figure 5. Heat map clustering analysis of different parts of *Dictyophora rubrovalvata*

CONCLUSION

In this paper, we investigated the nutritional, flavour and antioxidant properties of three parts (embryo, fruiting body, and colloid) of *D. rubrovalvata*. The fruiting body has a high content of volatile and non-volatile components, which is suitable for the development of condiments such as soup, while the embryo has the strongest antioxidant capacity, which can be used for the development of antioxidant functional foods in addition to the germination of fruiting body. The colloid has protein, polyphenol and mineral content as well as good antioxidant activity, so it can be used as a dietary additive to enhance the nutrition of other foods. However, they are usually discarded as waste during the harvesting of the fruiting body, which not only causes environmental pollution but also results in huge resource waste. If we can further develop the flavour and the active ingredients of fungi and their by-products, and conduct in-depth research on the resources of *D. rubrovalvata*, it can not only increase the added value of agricultural products, but also reduce development costs, thereby driving the development of the *D. rubrovalvata* industry.

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