Journal of Sustainability Science and Management
Volume 19 Number 11, November 2024: 94-103

eISSN: 2672-7226

COMPARATIVE ANALYSIS ON STABILITY OF WHITE, YELLOW, AND PINK OYSTER MUSHROOM EXTRACTS (*P. ostreatus*, *P. citrinopileatus*, AND *P. djamor*)

NURUL IZZATI MEDIHI[1], ZAIBUNNISA ABDUL HAIYEE[1], WAN ABD AL QADR IMAD WAN-MOHTAR[2], RAZIFAH MOHD RAZALI[3], NURUL NADIA ABDULL RASHID[4] AND SIVA RASEETHA[1]*

[1]Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. [2]Functional Omics and Bioprocess Development Laboratory, Institute of Biological Sciences, Faculty of Science, Universiti Malaya, 50603 Kuala Lumpur, Kuala Lumpur, Malaysia. [3]Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [4]Nadiya Agrofarm Enterprise, No. 281, Jalan Ros, FELCRA Bukit Kepong, 85300 Labis, Johor, Malaysia.

**Corresponding author: raseetha@salam.uitm.edu.my*
http://doi.org/10.46754/jssm.2024.11.006
Received: 21 February 2024 *Accepted: 11 July 2024* *Published: 15 November 2024*

Abstract: Various colours of oyster mushrooms are determined by several constituents. Recent scientific studies have highlighted the usage of natural extracts from coloured oyster mushrooms for their potential health benefits and application in the food, cosmetics, and pharmaceutical sectors. Despite growing interest, detailed data on the characteristics of these extracts remain limited. In this research, the stability of extracts from oyster mushroom species with white (*P. ostreatus*), yellow (*P. citrinopileatus*), and pink (*P. djamor*) cap colours was determined by using conventional extraction techniques against heat, light, and pH. The extracts contained melanin based on their characteristics observed during a series of stability tests. The solubility test indicated that the extracts were insoluble in water, HCl, ethanol, and methanol yet dissolved and soluble in NaOH. *P. citrinopileatus* extract was significantly higher at 40°C and 100°C than *P. ostreatus* and *P. djamor* extract. All extracts were relatively stable in sodium metabisulfite compared to citric acid. The current findings provide a beneficial approach to investigate further the mechanism underlying the formation of pigment in oyster mushrooms in the future and assess the potential of these extracts as natural colourants in the food industry, prompting further investigation into their application.

Keywords: Colour, extraction, oyster mushrooms, sustainability, stability.

Introduction

Both wild and cultivated mushrooms comprise a significant part of the human diet due to their unique qualities. *Agaricus bisporus*, *Lentinus edodes*, and *Pleurotus* sp. are among the most widely consumed mushrooms globally (Lesa *et al*., 2022). The cultivation of oyster mushrooms offers numerous benefits over other edible mushrooms. For example, it grows quickly in a wide range of temperatures (10°C to 30°C) and pH (six to eight), possesses great potential for a high nutritional value and medicinal significance and secretes a wide range of enzymes that are capable of breaking down the lingo-cellulosic biomass of substrates (Ejigu *et al*., 2022). Furthermore, oyster mushrooms are a rich source of bioactive compounds such as polysaccharides, terpenoids, and flavonoids that have antiviral, antitumor, antioxidant, anti-inflammatory, and immune-enhancing properties (Barbosa & de Carvalho Junior, 2021). The colour of the cap is a crucial factor in the commercialisation of oyster mushrooms. Oyster mushroom caps come in four primary colour varieties: White, black, yellow, and pink (Zhang *et al*., 2022). Several studies have agreed that pigment from coloured oyster mushrooms can be applied as a natural food colourant to substitute the synthetic food colourant.

Furthermore, there is an increased interest in substituting synthetic colourants with natural counterparts, as the former has been linked to detrimental health consequences such as cancer, low haemoglobin concentrations, and allergic reactions (Malabadi *et al*., 2022). Previous research has also shown the alarming effects of synthetic food dye on human health such as mutagenicity, the possibility of carcinogenicity, and hyperactivity in children (Silva *et al*., 2022). As a result, many food manufacturers have chosen to use natural food colouring as an alternative to synthetic colouring.

Natural food colouring may have nutritional and physiological benefits and provide an appealing and tasty appearance. Anthocyanins, carotenoids, chlorophylls, and curcumin are well-known natural pigments widely used to give food colour and are considered harmless (Japar & Aghwan, 2021). While natural colourants offer various benefits, they also come with certain drawbacks. For example, they can quickly deteriorate due to various elements, including oxidation, light, pH, temperature, and surrounding instability (Barbosa & de Carvalho Junior, 2021; Pandian *et al*., 2021). Melanin has been identified as one of the pigments found in a variety of mushrooms, including *Ganoderma lucidum* (Xu *et al*., 2020), *Pleurotus cornucopiae*, *Pleurotus citrinopileatus*, *Pleurotus djamor* (Zhang *et al*., 2022), *Auricularia auricula* (Agaricomycetes) (Yin *et al*., 2022), and *Lentinula edodes* (Yan *et al*., 2020). Melanins derived from diverse sources usually exhibit comparable physicochemical characteristics such as robust light absorption, distinctive solubility, and exceptional redox characteristics. Furthermore, melanin serves various beneficial purposes, including antioxidants (Ahmad *et al*., 2022). Melanin is produced by oxidative polymerisation of phenolic compounds in fungi, primarily via the 1,8-dihydroxynaphthalene [DHN] or 3,4-dihydroxyphenylalanine [DOPA] pathways. This process produces various forms of melanin, including eumelanin, pheomelanin, allomelanin, pheomelanin, and neuromelanin (Singh *et al.*, 2021).

Research groups have systematically studied and debated the properties and qualities of extracts from coloured oyster mushrooms. However, existing studies have generally overlooked how variations in the stability properties of these extracts may depend on different strains of the mushrooms. Moreover, there is a significant gap in the literature in assessing these extracts as potential natural food dyes. To address these gaps, this study focuses on the extracts obtained from three species of oyster mushrooms: *Pleurotus ostreatus*, *Pleurotus citrinopileatus*, and *Pleurotus djamor*. This research aims to thoroughly evaluate and compare their stability properties; thus, contributing to a deeper understanding of their feasibility as food colours.

Figure 1: Images indicating (A) white oyster mushroom, (B) yellow oyster mushroom, and (C) pink oyster mushroom

Materials and Methods

Raw Materials

The white, yellow, and pink oyster mushrooms (Figure 1) were supplied by Nadiya Agrofarm, Johor, Malaysia. The mushrooms were packed in an icebox during transportation and immediately cleaned from soil and dirt using tissue paper without washing. The mushroom samples were kept in a plastic wrapper and stored at -20°C before extraction.

Extraction of Pigment

Oyster mushrooms were extracted according to an approach described by previous studies (Fu *et al*., 2022; Netravati *et al*., 2022) with minor modifications. First, the mushrooms were cleaned using tissue paper and cut into small pieces. Then, they were suspended in 1.5 mol/L NaOH at a volume ratio of 1:10 (w/v). The suspension was homogenised for one hour and filtered through a filter paper to remove insoluble particles. The filtrate was collected and evaporated using a rotary vacuum evaporator (Heidolph rotary evaporator, Germany) at 60°C and 114 mbar for two to three hours. The concentrated extracts were kept in glass vials and refrigerated until further analysis.

UV-visible Light Absorption Spectra

The extracts were dissolved in a solution of 0.1 mol/L NaOH at a final concentration of 50 mg/L. The absorption properties of the extracts were measured in the wavelength range of 200 nm to 1,000 nm using a UV-visible spectrophotometer (Zhang *et al*., 2022).

Solubility Test

1 mL of extracts was added to test tubes containing 1 mL of distilled water, 3 mol/L HCl, 1 mol/L NaOH, and common organic solvents (ethanol and methanol). The sample was stirred at room temperature for one hour to dissolve thoroughly. The solubility of the samples was measured at the wavelength of 500 nm using a spectrophotometer. The solubility of the extracts is directly proportional to the value of absorbance (Zhang *et al*., 2022).

Stability Test

Heat Stability

5 mL of extracts were dissolved in 50 mL distilled water and heated at different temperatures of 40°C, 60°C, 80°C, and 100°C, respectively. The samples were held at each temperature for two hours and the absorbance was read at 400 nm.

Light Stability

The stability of extracts against light was determined according to the method described by Fu *et al*. (2022) with slight modifications. 1 mL of extract was dissolved in 20 mL 0.1 mol/L NaOH solution. The solution was incubated for two hours and placed under natural light in a dark place. The absorbance was determined at 400 nm to attain the light stability of the extracts.

pH Stability

Extract (1 mL) was dissolved in 10 mL of 0.1 mol/L NaOH and HCl to achieve pH 3.0, 7.0, and 14.0, respectively. The solutions were incubated for two hours and the absorbance was measured at 400 nm (Fu *et al*., 2022).

Preservative Treatment

5 mL of the extracts were diluted in 50 mL water and 10 mg of preservatives sodium metabisulfite and citric acid were added. These solutions were incubated for two hours and the absorbance value was measured at 400 nm.

Antioxidant Treatment

5 mL of the extracts were diluted in 50 mL water and 10 mg of antioxidants ascorbic acid, and butylated hydroxyl anisole (BHA) were added. These solutions were incubated for two hours and the absorbance value was measured at 400 nm.

Statistical Analysis

All the analyses and measurements were done in triplicate for each type of mushroom species. The results were reported as mean value ± standard deviations and the obtained data were statistically analysed using one-way analysis of variance (ANOVA), followed by the post-hoc test of Least Significant Difference (LSD) by using Statistical Package for Social Sciences (SPSS) Version 26 software. Differences between means at a 5% ($p < 0.05$) level are considered significant.

Results and Discussion

UV-visible Light Absorption Spectra

The white, yellow, and pink oyster mushroom extracts showed maximum absorbance in the UV region. Its optical density progressively decreased with an increase in wavelength (Figure 2) consistent with the previous research (Zhang *et al*., 2022). The result also matched the typical profile of melanin absorption. The peak absorbance for pigments in two oyster mushrooms occurred at 235 nm, showing a slight variance compared to the melanin extracted from the fruiting body of wild *A. auricula*, which was at 210 nm (Yin *et al*., 2022). Variations in the melanin source could lead to a slight alteration in the natural structure of melanin, which would explain the variations in maximum absorbance. Furthermore, the absence of visible absorption peaks at 280 nm indicated that the melanin extracted from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* contained no lipids, other proteins, or nucleic acids (Ma *et al*., 2023).

Solubility Test

The solubility of extracts from the three oyster mushroom species was determined by measuring the absorbance of the extract solution at 500 nm in water, 3 mol/L HCl, 1 mol/L NaOH, and common organic solvents (ethanol and methanol). The absorbance values of pigments in HCl, water, and organic solvents were nearly zero, whereas they were more significant than 1.5 in NaOH (Table 1). The findings showed that the extracts were only soluble in NaOH but insoluble in water, HCl, and other organic solvents, which agreed with prior research (Fu *et al*., 2022; Zhang *et al*., 2022). The solubility of the extracts in NaOH was due to their low nitrogen content and the ability to synthesise through the 1,8-dihydroxnapthalene pathway (Suwannarach *et al*., 2019). Based on previous research, the characteristics were also observed in the synthetic melanin and are common in

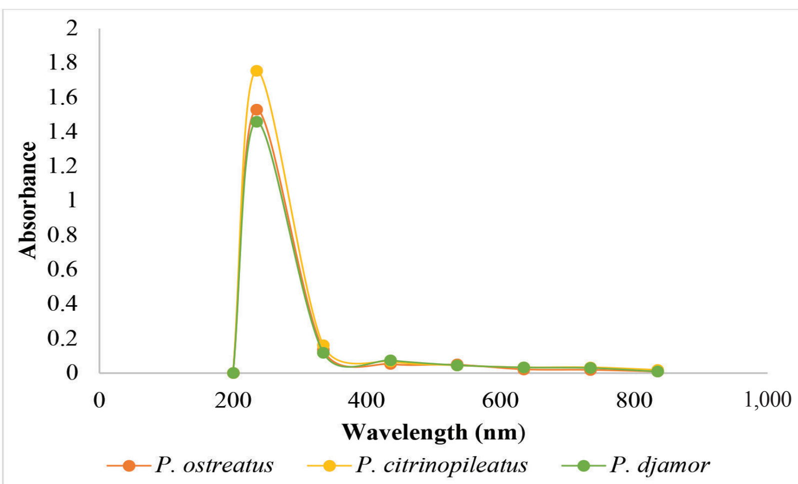

Figure 2: UV-visible spectrum of pigment extracted from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Table 1: Solubility tests of pigments of *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Solvent	Solubility Results		
	P. ostreatus	***P. citrinopileatus***	***P. djamor***
Water	Insoluble	Insoluble	Insoluble
NaOH	Soluble	Soluble	Soluble
HCl	Insoluble	Insoluble	Insoluble
Ethanol	Insoluble	Insoluble	Insoluble
Methanol	Insoluble	Insoluble	Insoluble

many microbial melanins (Suwannarach *et al*., 2019; Fu *et al*., 2022; Zhang *et al*., 2022). Hence, the presence of melanin pigment in *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* extracts was confirmed. Medicinal mushroom dyes are safe organic dyes that can be produced quickly, inexpensively, and in large quantities, contributing to sustainable development objectives (Ahmad *et al*., 2022). However, they also face limitations in their uses. For example, selecting an appropriate extraction method is inevitable, as it can affect the quality and quantity of the pigments (Anugraha & Thomas, 2021). Additionally, the bright brown pigment extracted from *Aspergillus ustus* had attractive colours, stability, safety, and bioactivity but is sensitive to certain metals such as Zn^{2+}, Fe^{3+}, Fe^{2+}, and Cu^{2+} (Zhou *et al*., 2023).

Stability Test

Heat Stability

The effect of temperature on the extract stability of *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* was studied to determine the potential use of the extracts as natural colourants. The extract was heated from 40°C to 100°C for two hours. The results revealed that the extracts of *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* were relatively temperature stable. It was observed that the white, yellow, and pink colour of the solution was almost unchanged throughout the heating process. As presented in Table 2, the quantitative data indicated that the extracts were significantly higher at 60°C for *P. ostreatus* and *P. djamor* than at other temperatures. The extract of *P. citrinopileatus* was substantially higher than *P. ostreatus* and *P. djamor* at temperatures of 40°C, 80°C, and 100°C.

Meanwhile, 100°C treatment resulted in significantly lowest heat stability compared to other temperatures for all mushroom species. Heat stability is essential for natural food dyes since it affects their usability and expands their range of applications in the food industries (Setiowati *et al*., 2020). Melanin maintains its colouring effect in a variety of culinary applications due to its resistance to degradation at high temperatures, which improves the visual appeal of food without running the risk of losing colour.

Table 2: Heat stability of pigments from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Temperature (°C)	Absorbance (Wavelength: 400 nm)		
	P. ostreatus	***P. citrinopileatus***	***P. djamor***
40	0.947 ± 0.002^{Bc}	0.953 ± 0.002^{Ab}	0.947 ± 0.01^{Bc}
60	0.962 ± 0.002^{Aa}	0.959 ± 0.002^{Ba}	0.957 ± 0.01^{Ca}
80	0.957 ± 0.002^{Bb}	0.961 ± 0.001^{Aa}	0.953 ± 0.02^{Cb}
100	0.943 ± 0.002^{Bd}	0.948 ± 0.001^{Ac}	0.942 ± 0.01^{Bd}

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different at ($p < 0.05$) while mean values within a column with different lowercase superscripts are statistically different at ($p < 0.05$).

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different at ($p < 0.05$) while mean values within a column with varying superscripts of lowercase are statistically different at ($p < 0.05$).

Light Stability

The results on light stability of the extracts from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* stored under natural and dark light were presented in Table 3. The extract from three oyster mushroom species was significantly higher after two hours of incubation under natural light. On the other hand, the absorbance of all extracts under dark light after two hours was significantly lower than that of natural light. The increase in absorption value might be the enhancement of the polymerisation of melanin from *Pleurotus* sp. during exposure to light (Fu *et al*., 2022). However, the result was contrary to a previous study of *Auricularia heimuer* fermentation, which reported that the absorbance decreased over time at different light conditions (Ma *et al*., 2022). In addition, it was observed that the colour of pigment solutions had no noticeable change during the incubation period of two hours at room temperature. These indicated that light had less effect on the melanin solutions, which agreed with the results reported by Fu *et al*. (2022). The results were also confirmed by a previous study conducted by Zou *et al*. (2015), which indicated that the *Auricularia auricula* fermentation broths melanin powder had minimal effects when exposed to natural light.

pH Stability

Table 4 shows the effect of pH on the stability of pigment solutions from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*. The findings revealed that the extracts were sensitive to certain pH levels in specific ways. Extracts of all mushroom species were significantly higher at pH 7.0 than pH 3.0 and 14.0 (Table 4). It was noted that *P. citrinopileatus* resulted in higher pH values than other extracts in all pH tests. All oyster mushroom species extract solutions

Table 3: Light stability of pigments from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Light Source	Absorbance (Wavelength: 400 nm)					
	P. ostreatus		*P. citrinopileatus*		*P. djamor*	
	0 hour	2 hours	0 hour	2 hours	0 hour	2 hours
Natural light	0.500 ± 0.001^{B}	0.516 ± 0.002^{Aa}	0.703 ± 0.003^{B}	0.716 ± 0.002^{Aa}	0.505 ± 0.003^{B}	0.516 ± 0.001^{Aa}
Dark light	0.501 ± 0.001^{B}	0.500 ± 0.002^{Bb}	0.704 ± 0.001^{A}	0.704 ± 0.002^{Ab}	0.514 ± 0.002^{B}	0.512 ± 0.001^{Bb}

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different by t-test at ($p < 0.05$) between 0h and 2 hr for each species, respectively. Mean values within a column with different lowercase superscripts are statistically different by t-test at ($p < 0.05$) between natural and dark light for each species, respectively.

Table 4: pH stability of pigments from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

pH	Absorbance (Wavelength: 400 nm)		
	P. ostreatus	*P. citrinopileatus*	*P. djamor*
3.0	0.106 ± 0.001^{Bc}	0.392 ± 0.001^{Ab}	0.108 ± 0.01^{Bb}
7.0	0.332 ± 0.003^{Ca}	0.429 ± 0.001^{Aa}	0.349 ± 0.01^{Ba}
14.0	0.113 ± 0.003^{Bb}	0.234 ± 0.002^{Ac}	0.105 ± 0.01^{Cb}

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different at ($p < 0.05$), while mean values within a column with different lowercase superscripts are statistically different at ($p < 0.05$).

have maximum stability at neutral pH (pH 7.0) compared to alkali or acidic conditions.

Moreover, the medium's pH significantly influenced the colouration of the pigment solution (Fu *et al*., 2022), inducing sometimes a modification in their structures. An alkaline pH quickly promotes melanin's polymerisation (Chen *et al*., 2020), which contributes to its chemical resilience. Additionally, the ionisable groups in melanin, particularly the amino and carboxylic groups are in equilibrium at neutral pH. Since no excess charge encourages solubility or reactivity, this charge balance supports chemical stability and structural integrity (Guo *et al*., 2023).

Preservative Treatment

The extract solution was treated with citric acid and sodium metabisulfite preservatives and the stability of the absorbance value was determined after two hours of incubation. The absorbance value of extract from *P. citrinopileatus* was significantly higher compared to *P. djamor* and *P. ostreatus* in citric acid treatment (Table 5). The absorbance of *P. citrinopileatus* was considerably lower in sodium metabisulphite than in other extracts. However, all extracts showed significantly higher absorbance in the sodium metabisulphite-treated sample than in the citric acid sample. The results indicated that all extract solutions were more stable in sodium metabisulphite than in citric acid. Sodium metabisulfite offers a more stabilising environment for natural pigments, mainly resulting from its less aggressive pH than citric acid. On the other hand, citric acid may promote the hydrolytic and oxidative deterioration of pigments since it is more acidic than other acids (Jurić *et al*., 2022), making it less effective at preserving pigment stability.

Antioxidant Treatment

When an antioxidant such as ascorbic acid and butylated hydroxyl anisole (BHA) was added to the pigment solution, the absorbance values varied from 0.181 to 0.189 (BHA) and 0.174 to 0.180 (ascorbic acid) after incubated for two hours. As presented in Table 6, the ascorbic acid-treated samples were all significantly different. Only extracts from *P. ostreatus* showed significantly lower absorbance in the BHA Treated sample than other extracts. However, BHA extracts result in significantly higher absorbance than ascorbic acid-treated extracts. The findings aligned with previously published reports, which found that the pigment solution had moderate antioxidant stability (Fu *et al.*, 2022). The antioxidant treatment could play a vital role in preserving the stability of

Table 5: Effect of preservatives on pigments from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Preservative	**Absorbance (Wavelength: 400 nm)**		
	P. ostreatus	***P. citrinopileatus***	***P. djamor***
Citric acid	0.039 ± 0.001^{Cb}	0.055 ± 0.001^{Ab}	0.052 ± 0.002^{Bb}
Sodium metabisulphite	0.070 ± 0.001^{Aa}	0.057 ± 0.001^{Ca}	0.064 ± 0.001^{Ba}

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different at ($p < 0.05$) while mean values within a column with different lowercase superscripts are statistically different at ($p < 0.05$).

Table 6: Effect of antioxidants on pigments from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor*

Preservative	**Absorbance (Wavelength: 400 nm)**		
	P. ostreatus	***P. citrinopileatus***	***P. djamor***
Ascorbic acid	0.174 ± 0.001^{Cb}	0.178 ± 0.001^{Bb}	0.180 ± 0.001^{Ab}
BHA	0.181 ± 0.001^{Ba}	0.189 ± 0.001^{Aa}	0.187 ± 0.002^{Aa}

Data are presented as mean ± SD. Mean values within a row with different uppercase superscripts are statistically different at ($p < 0.05$) while mean values within a column with different lowercase superscripts are statistically different at ($p < 0.05$).

natural pigments in oyster mushrooms. For example, they can be utilised in various forms such as coatings to improve the stability and shelf-life of the pigments. Preserving the natural pigment with antioxidants also can help to retard or control oxidation in food products (Chib *et al.*, 2020). Recent studies have shown that ascorbic acid treatment significantly delayed the browning in fresh-cut potato strips during storage (Zhou *et al.*, 2021) and accelerates the ripening in tomato fruits, making it helpful in preventing food product discolouration (Steelheart *et al.*, 2020).

Conclusions

Increasing interest in coloured oyster mushrooms and the advantages of natural food colours has spurred research on mushroom-derived pigments. The characteristics of the extracts from *P. ostreatus*, *P. citrinopileatus*, and *P. djamor* were investigated thoroughly in this research. The results showed that the extracts from all oyster mushroom species demonstrated optical solid absorbance in a broad UV-visible spectral range with maximum absorbance at 235 nm. The pigment had good solubility under alkaline conditions (NaOH) but was insoluble in water, acidic conditions, and common organic solvents. In addition, it also had good thermal stability and light resistance and was most stable at neutral pH (pH 7.0). The data showed that all extracts significantly differed at 60°C and 80°C for heat stability. In particular, the extracts of *P. citrinopileatus* were higher at 40°C and 100°C than those of *P. ostreatus* and *P. djamor*. The absorbance of all extracts was significantly higher after two hours of incubation under natural light. The findings indicated that all extract solutions were more stable in sodium metabisulfite than the citric acid solution for preservative treatment. Additionally, the extracts were relatively stable under antioxidant treatments. The findings in this research provided a basis for future studies to clarify the characteristics of pigment extracted from coloured *Pleurotus* sp. and assess their potential to be used as a natural food colourant.

Acknowledgements

The authors are grateful for the financial support from Universiti Teknologi MARA under the Special Research Grant: 600-RMC/GPK 5/3 (229/2020) funding scheme. The authors also thank UiTM and its laboratory staff for facilities and technical assistance.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

References

Ahmad, N., Vunduk, J., Klaus, A., Dahlan, N. Y., Ghosh, S., Muhammad-Sukki, F., & Wan-Mohtar, W. A. A. Q. I. (2022). Roles of medicinal mushrooms as natural food dyes and dye-sensitised solar cells (DSSC): Synergy of zero hunger and affordable energy for sustainable development. *Sustainability*, *14*(21), 13894.

Anugraha, A. C., & Thomas, T. (2021). A review on pigment-producing soil fungi and its applications. *Asian Journal of Mycology*, *4*(1), 89-112.

Barbosa, J. R., & de Carvalho Junior, R. N. (2021). Polysaccharides obtained from natural edible sources and their role in modulating the immune system: Biologically active potential that can be exploited against COVID-19. *Trends in Food Science & Technology*, *108*, 223-235.

Chen, Y. C., Kendall, T., Yip, P., Davy, A., Sefcik, J., & Sutter, J. U. (2020). Influence of ions and pH on the formation of solid- and liquid-like melanin. *ACS Omega*, *5*(39), 25059-25068.

Chib, A., Gupta, N., Bhat, A., Anjum, N., & Yadav, G. (2020). Role of antioxidants in food. *International Journal of Chemical Studies*, *8*, 2354-2361.

Ejigu, N., Sitotaw, B., Girmay, S., & Assaye, H. (2022). Evaluation of oyster mushroom (*Pleurotus ostreatus*) production using water hyacinth (*Eichhornia crassipes*) biomass supplemented with agricultural wastes. *International Journal of Food Science*, *2022*.

Fu, X., Xie, M., Lu, M., Shi, L., Shi, T., & Yu, M. (2022). Characterization of the physicochemical properties, antioxidant activity, and antiproliferative activity of natural melanin from *S. reiliana*. *Scientific Reports*, *12*(1).

Guo, L., Li, W., Gu, Z., Wang, L., Guo, L., Ma, S., Li, C., Sun, J., Han, B., & Chang, J. (2023). Recent advances and progress on melanin: From source to application. *International Journal of Molecular Sciences*, *24*(5), 4360.

Japar, S. H., & Aghwan, Z. A. (2021). Food colouring issues in the Halal industry. *Enhancing Halal Sustainability: Selected Papers from the 4th International Halal Conference 2019* (pp. 277-286). Springer Singapore.

Jurić, S., Jurić, M., Król-Kilińska, Ż., Vlahoviček-Kahlina, K., Vinceković, M., Dragović-Uzelac, V., & Donsì, F. (2022). Sources, stability, encapsulation and application of natural pigments in foods. *Food Reviews International*, *38*(8), 1735-1790.

Lesa, K. N., Khandaker, M. U., Mohammad Rashed Iqbal, F., Sharma, R., Islam, F., Mitra, S., & Emran, T. B. (2022). Nutritional value, medicinal importance, and health-promoting effects of dietary mushrooms (*Pleurotus ostreatus*). *Journal of Food Quality*, *2022*.

Ma, Y., Zhang, P., Dai, X., Yao, X., Zhou, S., Ma, Q., & Bao, Y. (2023). Extraction, physicochemical properties, and antioxidant activity of natural melanin from *Auricularia heimuer* fermentation. *Frontiers in Nutrition*, *10*, 1131542.

Malabadi, R. B., Kolkar, K., & Chalannavar, R. (2022). Plant natural pigment colorants-health benefits: Toxicity of synthetic or artificial food colorants. *International Journal of Innovativation Scientific Research and Review*, *4*, 3418-3429.

Setiowati, A. D., Wijaya, W., & Van der Meeren, P. (2020). Whey protein-polysaccharide conjugates obtained via dry heat treatment to improve the heat stability of whey protein-stabilized emulsions. *Trends in Food Science & Technology*, *98*, 150-161.

Silva, M. M., Reboredo, F. H., & Lidon, F. C. (2022). Food colour additives: A synoptical overview on their chemical properties, applications in food products, and health side effects. *Foods*, *11*(3), 379.

Singh, S., Nimse, S. B., Mathew, D. E., Dhimmar, A., Sahastrabudhe, H., Gajjar, A., & Shinde, P. B. (2021). Microbial melanin: Recent advances in biosynthesis, extraction, characterization, and applications. *Biotechnology Advances*, *53*, 107773.

Steelheart, C., Alegre, M. L., Baldet, P., Rothan, C., Bres, C., Just, D., Okabe, Y., Ezura, H., Ganganelli, I., Gergoff Grozeff, G. E., & Bartoli, C. G. (2020). The effect of low ascorbic acid content on tomato fruit ripening. *Planta*, *252*, 1-13.

Suwannarach, N., Kumla, J., Watanabe, B., Matsui, K., & Lumyong, S. (2019). Characterization of melanin and optimal conditions for pigment production by an endophytic fungus, Spissiomyces endophytica SDBR-CMU319. *PLOS ONE*, *14*(9), e0222187.

Xu, L., Li, J., Chang, M., Cheng, Y., Geng, X., Meng, J., & Zhu, M. (2020). Comparison of physicochemical and biochemical properties of natural and arginine-modified melanin from medicinal mushroom *Ganoderma lucidum*. *Journal of Basic Microbiology*, *60*(11-12), 1014-1028.

Yan, D., Liu, Y., Rong, C., Song, S., Zhao, S., Qin, L., Wang, S., & Gao, Q. (2020). Characterization of brown film formed by *Lentinula edodes*. *Fungal Biology*, *124*(2), 135-143.

Yin, C. M., Yao, F., Wu, W., Fan, X. Z., Chen, Z., Ma, K., & Gao, H. (2022). Physicochemical properties and antioxidant activity of natural melanin extracted from the wild wood ear mushroom, *Auricularia auricula* (Agaricomycetes). *International Journal of Medicinal Mushrooms*, *24*(1).

Zhang, Y., Wu, X., Huang, C., Zhang, Z., & Gao, W. (2022). Isolation and identification of pigments from oyster mushrooms with black, yellow and pink caps. *Food Chemistry*, *372*.

Zhou, F., Xu, D., Liu, C., Chen, C., Tian, M., & Jiang, A. (2021). Ascorbic acid treatment inhibits wound healing of fresh-cut potato strips by controlling phenylpropanoid metabolism. *Postharvest Biology and Technology*, *181*, 111644.

Zhou, M., Chen, Y., Fang, X., Wu, L., & Zhang, Y. (2023). Isolation and identification of pigment-producing filamentous fungus DBFL05 and its pigment characteristics and chemical structure. *CyTA – Journal of Food*, *21*, 374-385.

Zou, Y., Li, L., & Liu, C. (2015). Physicochemical properties and stability of melanin from *Auricularia auricula* fermentation broths. *Carpathian Journal of Food Science & Technology*, *7*(2).