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Research article

Evaluation of the phytochemical, bioactive compounds and descriptive sensory of encapsulated lingzhi (*Ganoderma lucidum*) extracts with combined wall materials for masking effect on the perception of off-flavour and bitterness

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ABSTRACT

Lingzhi mushroom (*Ganoderma lucidum*) is known as a medicinal mushroom that can be utilized in various functional foods available in the market, including powders, dietary supplements, and tea. However, its use is limited due to factors such as bitterness, flavour, and astringency. The objective of this study is to characterize and quantify the sensory profile of Lingzhi mushroom samples (fresh, dried and Lingzhi extracts) using quantitative descriptive analysis and investigate the physicochemical and sensory properties of encapsulated Lingzhi extracts using different ratios of wall material (maltodextrin, gum Arabic and modified starch from rice flour). The optimal ratio for encapsulation involved 32.75 % maltodextrin, 42.25 % gum Arabic, and 25 % modified starch w/w. Three parallel experiments were performed under practical conditions, resulting in average encapsulation efficiencies of 88.39 ± 0.09 % for flavonoids 89.53 ± 0.06 % for polysaccharides and 0.31 ± 0.01 of water activity. The sensory descriptive analysis indicated the following ratings: brown sugar aroma (4.36 ± 0.17), earthy aroma (22.04 ± 0.12), nutty aroma (2.00 ± 0.01), fresh mushroom aroma (11.18 ± 0.19), dried Lingzhi aroma (3.08 ± 0.13), black tea aroma (4.50 ± 0.19), salty taste (1.00 ± 0.01), earthy flavour (23.14 ± 0.22) and Mushroomy (after taste) (2.06 ± 0.09), respectively. The flavour identified of Lingzhi extracts and encapsulated by gas chromatography electronic nose (GC-E-Nose). The result showed ten flavour compounds (Acetaldehyde, Methanethiol, Propanal, propane-2-one, Methyl acetate, 2-methyl propanal, Ethyl Acetate, Heptane, 1-Butanamine, 2-methyl butanal, Thiophene). Optimizing the encapsulation conditions has a significant impact on reducing off-flavours and bitterness. Comparing the flavour profiles of Lingzhi extracts with encapsulated Lingzhi extracts using gas chromatography electronic nose (GC-E-Nose). Encapsulation technology represents a burgeoning field that holds immense potential in ensuring the stability of functional ingredients and facilitating their incorporation into instant beverage products.

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1. INTRODUCTION

Mushrooms have been valued for both their culinary and medicinal properties for thousands of years, as recognized by the global community. It is estimated that there are approximately 1.5 million species of fungi worldwide, of which only 82,000 species have been described. Among these, 5000 species are edible, but only 2000 species are considered safe for consumption. In ancient Chinese medicine, the Reishi mushroom (also known as Lingzhi) was highly regarded as the most beneficial medicinal mushroom. Herbalists, ethnobotanists, scientists, and traditional practitioners claim that Lingzhi has the potential to alleviate or even cure a wide range of diseases [1]. Although *Ganoderma* species are classified as non-edible mushrooms due to their woody fruiting body and bitter taste, they contain several health-promoting and biologically active compounds that justify their application in functional foods and supplements. Lingzhi, in particular, has been found to contain various bioactive molecules such as polysaccharides (primarily β-glucans), terpenoids, phenolic compounds, steroids, saturated, unsaturated (monounsaturated) fatty acid and flavonoids. These compounds have established health benefits. Numerous studies and scientific reviews have documented the anti-obesity, anti-inflammatory, and prebiotic properties of Lingzhi. The main constituents of mushroom polysaccharides, the non-digestible and prebiotic β-glucans, contribute to enhancing the microbiota in the large intestine, making Lingzhi a functional or nutraceutical ingredient worth considering [2].

Encapsulation in the food industry has multiple purposes, such as masking undesirable colour, flavour, or taste, preserving unstable components, incorporating additional functional and nutritional elements, and achieving controlled release of encapsulated ingredients. Encapsulation techniques can be categorized into three types: chemical, physicochemical, and physicomechanical methods. Various techniques fall under these categories, including spray drying, freeze-drying, electrospinning, coacervation, extrusion, co-precipitation, gelation, emulsion formation, layer-by-layer deposition, fluidized bed coating, and sol-gel encapsulation. Among these techniques, fluidized bed coating, spray drying, coacervation, and pan coating are commonly employed as commercially used encapsulation methods [3]. Therefore, the encapsulation of Lingzhi extracts is necessary to safeguard their stability during handling, processing, and storage, protecting them against adverse conditions [4].

The selection of carrier materials plays a crucial role in the process of encapsulation. Among the commonly used carrier materials are gum Arabic, maltodextrins, modified starches, and certain proteins [5]. Gum Arabic, derived as an exudate from Acacia trees, is an edible biopolymer with a complex chemical composition. It primarily consists of a group of macromolecules characterized by high carbohydrate content (approximately 97 %) and low protein content (<3 %). One of the reasons for the widespread use of gum Arabic in food encapsulation is its beneficial properties. Gum Arabic exhibits a low viscosity and excellent emulsifying ability when dissolved in water-based solutions. Furthermore, it is non-toxic, odourless, and tasteless, making it highly suitable for various food applications. These favourable attributes have positioned gum Arabic as the preferred agent for food encapsulation purposes, and it has maintained this status for many years [6]. Maltodextrins are starches that have undergone hydrolysis and are derived from sources such as wheat, potato, and corn. They possess varying degrees of dextrose equivalence. Maltodextrins with a dextrose equivalence ranging from 10 to 20 are commonly utilized due to their desirable properties. These maltodextrins are highly soluble in water, exhibit low viscosity, and have a neutral flavour profile. Additionally, they are readily biodegradable and offer excellent encapsulation capabilities. As a result, maltodextrins within this dextrose equivalence range are widely employed in food encapsulation applications [5]. In recent times, starch microgels from modified starch have gained popularity due to their proven safety in gastrointestinal environments [7]. In a previous study, it was demonstrated that modifying starch can improve the adsorption and release properties of microgels on lysozyme [9]. Additionally, modified starch can serve as a carrier material for the efficient uptake and transportation of bioactive compounds.

Freeze drying is widely employed to dry heat-sensitive food products and bioactive components, creating high-quality dried food with low temperatures and vacuum conditions. Additionally, freeze-drying is commonly utilized for encapsulating fragile biomaterials within amorphous carbohydrate microstructure matrices. Besides that, freeze-drying is generally used to encapsulate delicate biomaterials in amorphous carbohydrate microstructure matrices. Freeze drying is a way to reduce or slow down the loss of antioxidant and antimicrobial properties in plants [10]. In their 2020 study, Liew et al. [10] explored the potential of utilizing the gelatine encapsulation technique to preserve antioxidant compounds in gelatine-encapsulated C. *ternatea* flowers. The research focused on evaluating the total flavonoid contents of the encapsulated samples. Notably, the study revealed that freeze-dried powders exhibited the highest encapsulation efficiency among the tested methods.

Sensory descriptive analysis encompasses the discrimination and description of both qualitative and quantitative sensory aspects of products by trained panels. Various methods, such as the Flavor Profile, Texture Profile, Spectrum™ method, and Quantitative Descriptive Analysis (QDA®), can be employed for sensory descriptive analysis. These methods enable the identification of differences among product variants or conditions, the determination of drivers of consumer hedonic responses, and the exploration of relationships between sensory and chemical characteristics [11].

This study has three objectives (1) to investigate the descriptive sensory profile of Lingzhi mushrooms in various forms (fresh, dried, and extracts), (2) to examine the impact of encapsulation techniques on the expression of off-flavours and bitterness. The study employed a Simplex-centroid mixture design to determine the optimal ratio of wall materials for encapsulation, which included maltodextrin, Arabic gum, and modified starch from rice flour. The aim is to maximize the percentage yield of bioactive compound encapsulation efficiency and refine the descriptive sensory profile by optimizing encapsulation conditions. Additionally, (3) to compare the flavour and taste of the encapsulated Lingzhi extracts with unencapsulated Lingzhi extracts using descriptive sensory analysis and gas chromatography electronic nose (GC-E-Nose).

2. Material and methods

2.1. Material

The mature fruiting body of Lingzhi (*Ganoderma lucidum*) was supplied by Lingzhi from the Royal project (Mae Teang, Chiang Mai province, Thailand). Harvesting period: 60 days. The dried Lingzhi was subjected to heating at 80 °C until its moisture content reached 10 %, which was then utilized for the study. The glucose standard was procured from Sigma-Aldrich (St. Louis, MO, USA). Vanillin was procured from Merck (Darmstadt, Germany). We obtained food-grade ethanol from Apex Alco Co., Ltd (Bangkok, Thailand). We purchased the chemicals aluminium chloride and phenol from Laboratory Reagent & Fine Chemicals (Mumbai, India). Potassium acetate, sulfuric acid, and glacial acetic acid were acquired from RCI Lab Scan Limited (Bangkok, Thailand), and perchloric acid was sourced from QReC (New Zealand).

2.2. Method

2.2.1. Sensory properties of fresh, dried lingzhi mushroom and lingzhi extracts

2.2.1.1. Preparation of fresh Lingzhi tea. Consumers cannot directly consume fresh Lingzhi due to several reasons. Firstly, fresh Lingzhi has a glossy exterior and a woody texture, making it unsuitable for direct consumption. Additionally, LZ species, as reported by Hapuarachchi et al. [12], are not classified as edible mushrooms. This is because they possess a bitter taste and a hard texture in their fruiting bodies, lacking the fleshy texture typically found in edible mushrooms. Therefore, it is not recommended to consume fresh Lingzhi directly. To test the mushroom in the form of tea, an established amount of mushroom was added to purified boiling water for 5 min. Two grams of fresh Lingzhi to 100 mL of water.

2.2.1.2. Preparation of dried Lingzhi tea. To test the mushroom, a specified amount of dried Lingzhi (0.67g per 100 mL of water) was added to hot purified water to create Lingzhi tea. The Lingzhi mushrooms have a high dietary fibre content of approximately 70.06 % [12]. Due to the drying process, Lingzhi mushrooms acquire a very hard texture. As a polypore mushroom, Lingzhi is not consumed whole but rather cut into pieces and used for making tea [13]. Furthermore, Lingzhi cannot be ground into a powder as it has a fibrous appearance.

2.2.1.3. Preparation of Lingzhi extract tea. The Lingzhi mushroom was dried and 1 g of it was extracted using 65.35 % ethanol (20 mL). The mixture was then placed in the centre of a microwave oven (LG, model MS2022D, Korea) operating at a frequency of 800 W for 1 min and 30 s. The crude extract was subsequently evaporated under vacuum conditions using a Buchi rotary evaporator (model Rotavapor® R-300, Flawil, Switzerland) until dry. The resulting precipitate was dissolved in distilled water, freeze-dried using a Labconco Stoppering tray dryer and Freezone 6 freeze dryer (USA), and stored in aluminium foil bags at 4 °C until analysis [14]. Then, to evaluate Lingzhi extract as a tea, Lingzhi extract powder was added to purified boiling water. The ratio used was 0.03 g of Lingzhi extracts per 100 mL of water.

2.2.1.4. Sensory descriptive analysis (DA). Ten trained panelists, consisting of nine females and one male, took part in the descriptive analysis of Lingzhi mushroom samples. Panelists were chosen based on the following criteria: (1) individuals with natural teeth, (2) those without food allergies, (3) non-smokers, (4) individuals aged 18 to 64, (5) those who consume mushrooms or mushroom-based products at least once a month, (6) availability for all sessions, (7) interest in participating, and (8) the ability to verbally express their observations about the product [15]. Prior to selection, all panelists achieved a perfect score on a taste sensitivity test and demonstrated the ability to distinguish five of the seven common food flavors—sweet, sour, salty, bitter, and umami [16]. Upon arriving at the laboratory, participants were welcomed, provided with a briefing, and requested to sign a written consent form. Prior to commencing the experiment, participants completed the sensory evaluation.

The panelists employed a consensus-based descriptive sensory method, similar to those used in other studies for lexicon development. Initially, each panelist assessed a variety of mushroom samples to observe and note their sensory characteristics. The panel leader then facilitated group discussions to reach a consensus on the descriptors identified. As more samples were evaluated, the team refined the lexicon by agreeing on descriptors, precisely defining flavor notes, proposing definitions, and suggesting potential references (such as foods or chemicals) that could represent these characteristics. Care was taken to avoid overlapping descriptors for the same flavor. Discussions and tastings continued until the lexicon was fully developed. Product or chemical references were selected to illustrate the flavors and were scored on a 0–150 mm scale [17].

The scale used for evaluation was divided into half-point increments, ranging from 0 (no intensity) to 150 mm (extremely strong). The initial development of the lexicon and identification of reference points required four sessions, each lasting 1.5 h. Once the basic lexicon was established, testing commenced on various Lingzhi samples, including fresh, dried, and Lingzhi extract. Each sample was tested individually and in a random order within three replications, using the 0–150 mm scale. During testing, participants were provided with purified water, unsalted crackers, and carrots to cleanse their palate between samples.

2.2.2. Encapsulation experiment

2.2.2.1. Preparation of encapsulation of Lingzhi extracts by freeze-dryer. The emulsion was prepared by adding 90 g of wall materials and 10 g of Lingzhi extract to 900 mL of distilled water. The respective wall materials were dissolved in distilled water at 60–70 °C. Then, modified starch was added at 80 °C, maintaining homogeneity until the complete dissolution of the wall materials [18]. After the complete dissolution of the encapsulants at around 40 °C, the Lingzhi extract was added with a full rotation of 10,000 rpm for 5 min. The resulting solutions were frozen overnight at −30 °C and lyophilized in a freeze dryer for 48 h. The freeze-dried encapsulated extracts were converted into powder with the help of a pestle and mortar (Fig. 1). The powder was frozen at −20 °C in an aluminium foil bag, shielded from light and water vapour, to prevent any potential changes, agglomeration, or oxidation until further analysis.

The study focused on developing encapsulated Lingzhi extracts using a composite blend formulation that involved a range of different wall materials. These materials included maltodextrin (X_1: 25–50 %), Arabic gum (X_2: 25–50 %), and modified starch from rice flour (X_3: 25–50 %). To achieve desirable quality in the encapsulated extracts, the formulation of the composite blend was conducted using a Simplex-centroid mixture design with the assistance of Design-Expert software V.6.0.10.

Several dependent variables were considered to assess the quality of the encapsulated Lingzhi extracts. These variables included encapsulation efficiency (%EE) and the reduction of off-flavours and bitter taste in terms of sensory properties.

The mixture design involving 8 runs was conducted to investigate the combined effects of three independent variables: percentage of maltodextrin, Arabic gum, and modified starch at their low and high levels. The study aimed to examine the impact of these variables on physical-chemical and sensorial properties, which served as the dependent variables. The mixture design aimed to optimize the encapsulation conditions by studying the interactions between these variables (Table 1).

2.2.2.2. Determination of encapsulation efficiency (%EE) and loading capacity (%LC). The encapsulation efficiency was determined using the methods described and modified by Liew et al. [10]. The effectiveness of encapsulation was evaluated by measuring the total flavonoids, polysaccharides, and triterpene content, as well as the surface flavonoids, polysaccharides, and triterpene content of the encapsulated powder after drying. For determination, 100 mg of samples were added to 10 mL of distilled water and ground to destroy the encapsulated powder before extraction for 5 min. In the determination of the surface, 100 mg of samples were directly extracted with 10 mL of distilled water, vortexed for 30 s, and centrifuged at 3000 rpm for 10 min. After separation, the clear supernatant was collected and filtered. A rapid spectroscopic (GENESYS 10S UV VIS Dual Beam, Thermo Scientific, USA) method determined the total and surface values of flavonoids (at 415 nm), polysaccharides (at 490 nm), and triterpene content (at 548 nm). Encapsulation efficiency (Eq. (1)) and the loading capacity were determined according to Muhammad et al. [19], (Eq. (2)) and were calculated using the following equation:

$$\%EE = [(\text{Total bioactive compound contents} - \text{surface bioactive compound contents}) / \text{Total bioactive compound contents}) \times 100] \quad \text{(Eq. 1)}$$

$$\%LC = [(\text{Total bioactive compound contents} - \text{surface bioactive compound contents} / \text{Total sample amount}) \times 100] \quad \text{(Eq. 2)}$$

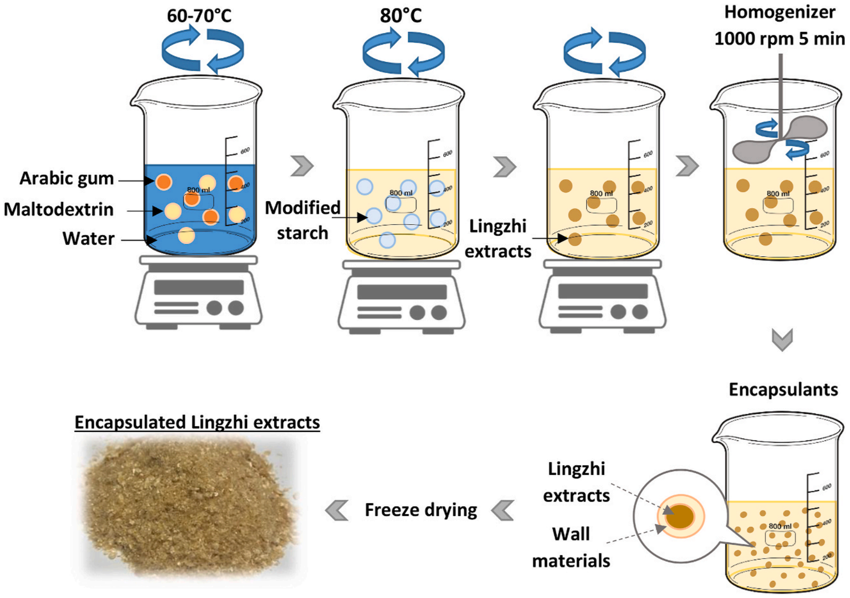


Fig. 1. A schematic diagram, illustrating the process of producing encapsulated powder that contains Lingzhi extracts. This production method involves freeze-drying emulsions, which are immobilized using varying ratios of wall materials, including maltodextrin, Arabic gum, and modified starch derived from rice flour.

Table 1
Simplex-centroid mixture design for encapsulated Lingzhi extracts.

Treatment	Maltodextrin (%)	Gum Arabic (%)	Modified starch (%)
1	25.00	50.00	25.00
2	37.50	37.50	25.00
3	25.00	25.00	50.00
4	25.00	37.50	37.50
5	50.00	25.00	25.00
6	37.50	25.00	37.50
7	33.33	33.33	33.33
8	25.00	50.00	25.00

2.2.3. Comparison of flavour between lingzhi extracts with the optimum condition of encapsulated lingzhi extracts

2.2.3.1. Gas chromatography electronic nose (GC E-nose). A Heracles II gas chromatography electronic nose (Alpha M.O.S., Toulouse, France) was employed for tea sample analysis. It was equipped with an automatic sample pre-treatment unit, an ultra-fast gas chromatography unit and two flame ionization detectors (FIDs). In brief, an accurate aliquot of Lingzhi extracts (5 mg) and encapsulated Lingzhi extracts (50 mg) were placed into a 20 mL headspace vial, and sealed with a threaded cap. After incubating at 80 °C for 5 min with an agitation speed of 500 rpm, 5000 μL of headspace gas was injected into the injector with an inlet temperature of 200 °C. Several amplification ranges are available typically, ranging from about 1 pA (input)/mV at the highest output sensitivity to about 10 nA ($10^{-10} \times 10^{-12}$ A)/mV at the lowest output sensitivity. The volatile compounds were concentrated with a Tenax TA tube at 20 °C for 27 s, and then thermal desorption was carried out at 240 °C for 30 s. Helium was employed as a carrier gas, with a flow speed of 0.8 mL/min. Two parallel chromatographic columns including MXT-5 and MXT-1701 (20 m × 0.18 mm I.D. × 0.4 μm; Restek, Beijing, China) were used to separate the volatile compounds. The initial column temperature was held at 50 °C for 5 s, increased to 100 °C at a rate of 0.1 °C/s, then raised to 120 °C at 0.2 °C/s, and finally raised to 250 °C at 0.4 °C/s after a 10 s hold time. The detector temperature was 260 °C. Each sample was analysed in triplicate. The volatile compounds were identified using the library in the GC-E-Nose program. Hexanal was employed as an external standard to avoid interference in the samples. Quantification of the volatile compounds was conducted using calibration curves from authentic hexanal standards [20]. Furthermore, the concentrations of volatile compounds, for which pure standards were available, were quantified using external standard curves constructed from a series of solutions at five different concentrations containing the corresponding standards. The use of external standards is prevalent in GC analysis, as evidenced by numerous studies [21,22]. Some important compounds were further certified amount of volatile compounds by standards, and the volatile components were quantified using the following formula [23]:

$$C_i = (C_{is} * A_i)/A_{is} \tag{Eq. 3}$$

Where:

C_i: the concentration of volatile components to be measured, measured in μg/g,
C_{is}: the concentration of hexanal (standard), measured in μg/g,
A_i: the peak area of the volatile components to be measured,
A_{is}: the peak area of hexanal (standard).

2.2.3.2. Sensory descriptive analysis (DA). The method employed for the Sensory Descriptive Analysis (DA) is described in section 2.2.1.4.

2.2.3.3. Preparation of encapsulated Lingzhi extracts tea. To assess the potential of encapsulated Lingzhi extracts as a tea, the powdered encapsulated Lingzhi extract was introduced into purified boiling water. The specified ratio for this evaluation was 0.34 g of encapsulated Lingzhi extract per 100 mL of water.

2.2.4. Statistical analysis

The optimal mixture ratio of wall materials for encapsulated Lingzhi extracts was determined using a Simplex-centroid mixture design. This specific experimental design method allows for the evaluation of various mixture combinations to identify the optimal ratio of the wall materials. Multiple regression analysis was conducted on the experimental data, resulting in the formulation of the following equation to represent the model [24]:

$$Y = b1.x1 + b2.x2 + b3.x3 + b12.x1.x2 + b13.x1.x3 + b23.x2.x3 + b123.x1.x2.x3 \tag{Eq. 4}$$

In the statistical analysis, the response variable is represented by Y, while b denotes the regression coefficients and x represents the independent variables. To determine the optimal mixture ratio of wall materials for encapsulated Lingzhi extracts, which maximizes the percentage of encapsulation efficiency while minimizing off-flavour and bitterness, an optimization utilizing multiple response variables was performed using Design Expert software V.6.0.2 (Stat-Ease Co., USA).

3. Results and discussion

3.1. Sensory properties of fresh, dried Lingzhi mushroom and Lingzhi extracts

3.1.1. Sensory descriptive analysis (DA)

The panel has determined the final lexicon, which is presented in Table 2. It comprises a total of 28 attributes, including 2 related to appearance (brown and yellow colour), 16 associated with aroma (earthy, nutty, woody, fermented, fresh Lingzhi, fresh mushroom, dried Lingzhi, brown sugar, sweet malt, sweet and sour fruity, cardboard, yeast, caramelized, vanilla, black tea, and umami), 6 concerning flavour and tastes (bitterness, salty, earthy flavour, black tea flavour, mushroomy flavour, and umami flavour), 1 representing the feeling factor (jpungent), and 3 for aftertaste (pungent, bitterness, and mushroomy). These attributes were utilized to identify various characteristics in multiple variations of Lingzhi. The panel generated the attributes of appearance, aroma, flavour, and aftertaste. However, for the reference standard, the basic tastes and feeling factors of bitterness, saltiness, and astringency were adopted based on Chun et al.'s study [25].

The many other aromas and flavours contained in Lingzhi mushrooms samples. Some of the notes such as woody, nutty, brown, bitter, salty, and pungent are common to a number of different mushrooms, but at varying intensities in Table 3 and Fig. 2.

Sensory evaluation was conducted on six different Lingzhi samples, including fresh Lingzhi, dried Lingzhi, Lingzhi extracts, fresh Lingzhi tea, dried Lingzhi tea, and Lingzhi extracts tea. Fig. 2(a and b) illustrates that dried Lingzhi and Lingzhi extracts exhibited a pleasing aroma reminiscent of brown sugar, sweet malt, sweet and sour fruits, caramelization, and vanilla. The sweet and caramel-like aroma, which arises from the process of caramelization, emerges when carbohydrates undergo high-temperature conditions during the drying process for dried Lingzhi tea and the extraction process for Lingzhi extracts tea. This phenomenon involves the removal of water [26]. This process leads to the isomerization and polymerization of sugars into various complex compounds [27]. For instance, the loss of water from monosaccharides can yield compounds like di-fructose anhydride. As caramelization progresses, degradation reactions occur, resulting in non-enzymatic browning and colour changes [28]. Polymerization reactions give rise to higher-molecular-weight compounds that contribute to the dark-brown colour, visual appearance, and flavour of the final caramel product [29]. Furthermore, it was observed that Lingzhi extract tea had the most pronounced bitter taste, which limited its use in larger quantities. In the published research by Chun et al. [13], the bitterness of the standard was determined using a caffeine solution at concentrations of 0.05 % (65 out of 150 participants perceived bitterness) and 0.06 % (85 out of 150 participants perceived bitterness). In comparison to the caffeine standards, the bitterness of the Lingzhi drinks was evaluated. It was found that the dried Lingzhi and Lingzhi extracts tea exhibited bitterness levels equivalent to 0.022 % and 0.073 % of the caffeine standards, respectively.

3.2. Encapsulation experiment

Consequently, the study aimed to determine the optimal encapsulation conditions for Lingzhi extraction, including the concentration of maltodextrin, Arabic gum, and modified starch, in order to mask the bitter taste and achieve a high encapsulation efficiency of bioactive compounds such as flavonoids, polysaccharides, and triterpenes.

3.2.1. Sensory descriptive analysis (DA)

Sensory evaluation of encapsulation of Lingzhi mushroom extracts powder and tea was undertaken in this work. The results showed that the encapsulated Lingzhi has a masked flvour and its bad aroma, off-flavour, taste (bitterness), feeling factor (pungent) and aftertaste are reduced. The intensity of the woody aroma, fermented aroma, fresh Lingzhi aroma, fresh mushroom aroma cardboard aroma, bitterness, earthy, mushroomy, pungent, pungent, bitterness and mushroomy after taste are less than for the Lingzi extract. Moreover, compared with Lingzhi extracts the encapsulated has greater water solubility efficiency (Fig. 3a–b).

Fig. 3a presents the results for the intensity of encapsulated Lingzhi extracts powder in terms of the appearance attribute (yellow colour) and various aroma attributes (nutty, dried Lingzhi, sweet and sour, cardboard, and umami aroma), excluding the brown sugar aroma. The study found that the lowest intensity was observed in Treatment 6, which used a combination of 37.50 % maltodextrin, 25 % gum Arabic, and 37.50 % modified starch. Treatment 7, which employed 33.33 % maltodextrin, 33.33 % gum Arabic, and 33.33 % modified starch, also exhibited low intensity. On the other hand, Treatments 2 (37.50 % maltodextrin, 37.50 % gum Arabic, and 25 % modified starch) and 3 (25 % maltodextrin, 25 % gum Arabic, and 50 % modified starch) displayed high intensity in all aroma attributes.

Fig. 3b illustrates the intensity scores for the encapsulated Lingzhi extracts tea for various attributes, including appearance (yellow colour), aroma (earthy, nutty, woody, fermented, fresh Lingzhi, fresh mushroom, dried Lingzhi, cardboard, and black tea), tastes and flavour (bitter, salty, earthy, black tea, and mushroomy), feeling factor (pungent), and aftertaste (pungent, bitter, and mushroomy). The results indicate that Treatments 2 (37.50 % maltodextrin, 37.50 % gum Arabic, and 25 % modified starch) and 3 (25 % maltodextrin, 25 % gum Arabic, and 50 % modified starch) exhibited high intensity in all aroma attributes. These treatments demonstrated a strong impact on enhancing the sensory attributes of the encapsulated Lingzhi extracts tea. Meanwhile, Treatment 6, which utilized a combination of 37.50 % maltodextrin, 25 % gum Arabic, and 37.50 % modified starch, and Treatment 7, involving 33.33 % maltodextrin, 33.33 % gum Arabic, and 33.33 % modified starch, displayed lower intensity scores for the various aroma attributes.

These findings suggest that higher concentrations of maltodextrin and modified starch significantly impact the intensity of aroma characteristics in the encapsulated Lingzhi extracts powder and tea. The results indicate that a higher proportion of modified starch has a more pronounced effect on enhancing the aroma attributes compared to treatments with higher amounts of maltodextrin or Arabic gum. The findings of the research conducted by Mehran et al. [30] support the notion that maltodextrin and modified starch exhibit

Table 2
Definitions of attributes and standard references by the trained panel to describe Lingzhi.

Attribute[a]	Definition	Reference	Intensity[b]
Appearance			
Brown colour	The appearance associated with the brown colour	Munsell book (red yellow) hue 5 YR 2 value 4 chroma hue 5 YR 3 value 4 chroma hue 2.5 YR 2 value 4 chroma hue 10 YR 4 value 6 chroma hue 7.5 YR 5 value 10 chroma	120 95 130 50 70
Yellow colour	The appearance associated with the yellow colour	hue 2.5Y 8 value 4 chroma hue 2.5Y 8 value 2 chroma hue 5Y 9 value 2 chroma	50 30 20
Aroma			
Earthy	Aromatics were characteristic of damp soil, wet foliage, or slightly undercooked boiled potato.	Fresh potato	30
Nutty	Aromatic associated with nuts or nut meats.	Pecan (Heritage – Snacks And Foods Co., ltd, Thailand).	70
Woody	The flat, dark, dry aromatics associated with the bark of a tree.	Dried rice straw	40
Fermented	Aromatic associated with fermented fruits, vegetables (can be yeasty) or grains.	Fresh eringii mushroom	75
Fresh Lingzhi	Aromatics associated with fresh Linngzhi.	Fresh Lingzhi	120
Fresh Mushroom	Aromatics are generally associated with fresh raw mushrooms, with some characteristics described as damp earthy and musty.	Fresh white shimeji mushroom	70
Dried Lingzhi	Aromatics associated with dried Lingzhi.	Dried Lingzhi	100
Brown sugar	A rich full-bodied brown sweet aromatic	Brown sugar (Mitrphol, Mitr Phol Group, Thailand)	70
Sweet malt	Sweet malts aroma	Malt powder (Ovaltine, Thailand)	80
Sweet and sour fruity	Chinese date aroma	Dried Chinese date	120
Cardboard	Aromatics associated with cardboard may include a stale character.	Cardboard pieces size 1 × 1 inch 3 sheets with water 10 mL.	50
Yeast	A sour, fermented aromatic commonly associated with yeast.	White bread (Farmhouse, President bakery Co., ltd, Thailand)	75
Caramelized	The browned character associated with Maillard reaction products, starches, and sugars	Maple syrup (Imperial Maple Syrup, KCG Corporation Co., Ltd., Thailand) 5 % maple syrup solution 15 % maple syrup solution	25 70
Vanilla	The aromatic blend of sweet, vanillin, woody, browned notes, sometimes having chocolate, tobacco, floral or spicy components.	Vanilla butter flavour (Winner Group Enterprise Plc., Thailand) 0.1 % vanilla butter flavour solution 0.5 % vanilla butter flavour solution	20 70
Black tea	Aroma and flavour characteristics associated with black tea	Black tea solution (Lipton yellow label, PT Unilever Indonesia, Indonesia) 3 % Black tea solution 10 % Black tea solution	60 130
Umami	Flat, salty flavour enhancers naturally occur in some mushrooms.	Mushroom flavour seasoning powder (FaThai, F-plus, Thailand)	70
Flavour and Taste			
Bitterness	The fundamental taste sensation of which caffeine is typical	0.05 % Caffeine solution 0.06 % Caffeine solution	65 85
Salty	The fundamental taste sensation of which sodium chloride is typical.	0.15 % Sodium chloride solution 0.2 % Sodium chloride solution	15 25
Earthy flavour	Aromatics were characteristic of damp soil, wet foliage, or slightly undercooked boiled potato.	5 % Cooked potato solution 10 % Cooked potato solution	15 100
Black tea flavour	Aroma and flavour characteristics associated with black tea	0.5 % Black tea solution 1 % Black tea solution	56 130
Mushroomy flavour	Slightly musty, and earthy.	1 % Cooked white shimeji mushroom 10 % Cooked white shimeji mushroom	27 100
Umami flavour	Flat, salty flavour enhancers naturally occur in some mushrooms.	0.15 % Accent Salt Solution 0.35 % Accent Salt Solution	15 80
Feeling factor			
Pungent	The complex of drying, puckering, and shrinking sensations in the oral cavity.	0.05 % Alum Solution 0.1 % Alum Solution	40 80
After taste (AT)			
Pungent	The complex of drying, puckering, and shrinking sensations in the oral cavity.	0.05 % Alum Solution 0.1 % Alum Solution	25 50
Bitter	The fundamental taste sensation of which caffeine is typical	0.05 % Caffeine Solution 0.06 % Caffeine Solution	40 70
Mushroomy	Slightly musty, and earthy.	1 % Cooked white shimeji mushroom 10 % Cooked white shimeji mushroom	15 50

[a] Attributes listed in order as perceived by panellists.

[b] Intensity ratings are based on 150 mm unstructured line scales.

Table 3
Mean intensity of all attributes in Lingzhi mushroom 6 samples (0 = none to 150 = extremely high).

Attribute	Fresh Lingzhi	Dried Lingzhi	Lingzhi extracts	Tea		
				Fresh Lingzhi	Dried Lingzhi	Lingzhi extracts
Appearance						
Brown colour (inside)	93.00 ± 3.85	55.71 ± 4.70	53.00 ± 4.38			
Brown colour (outside)	108.13 ± 3.72	112.86 ± 2.67	53.00 ± 4.38			
Yellow colour				40.83 ± 2.04	23.71 ± 1.89	55.13 ± 5.22
Aroma						
Earthy	55.00 ± 4.63	50.33 ± 0.82	4.83 ± 0.41	57.86 ± 3.93	63.14 ± 4.18	42.50 ± 3.78
Nutty	29.17 ± 2.04	47.14 ± 3.93	59.38 ± 1.77	ND	20.67 ± 1.63	ND
Woody	10.00 ± 0.01	59.71 ± 2.44	2.13 ± 0.35	ND	5.00 ± 0.01	56.25 ± 3.54
Fermented	86.25 ± 5.18	5.00 ± 0.01	ND	41.25 ± 3.54	ND	20.00 ± 0.01
Fresh Lingzhi	111.67 ± 2.58	81.43 ± 3.78	75.00 ± 5.35	55.00 ± 5.00	15.00 ± 0.01	25.00 ± 001
Fresh Mushroom	77.50 ± 2.74	20.00 ± 0.01	ND	30.83 ± 2.04	5.00 ± 0.01	30.00 ± 2.67
Dried Lingzhi	102.86 ± 9.06	98.14 ± 8.71	88.75 ± 3.54	ND	ND	25.00 ± 0.01
Brown sugar	32.50 ± 3.78	53.29 ± 3.73	56.88 ± 4.58	ND	10.17 ± 0.41	ND
Sweet malt	ND	75.43 ± 6.92	35.00 ± 4.63	ND	ND	ND
Sweet and sour fruity	ND	69.14 ± 4.14	108.00 ± 5.26	ND	2.00 ± 0.01	10.00 ± 0.01
Cardboard	29.29 ± 1.89	57.14 ± 3.93	ND	5.00 ± 0.01	18.57 ± 2.44	ND
Yeast	55.00 ± 5.35	10.00 ± 0.01	ND	ND	ND	ND
Caramelized	ND	45.43 ± 4.16	78.38 ± 2.33	ND	ND	ND
Vanilla	ND	39.25 ± 1.50	20.83 ± 2.04	ND	ND	2.00 ± 0.01
Black tea	7.50 ± 2.67	95.71 ± 5.35	30.00 ± 0.01	ND	20.00 ± 0.01	8.17 ± 0.41
Umami	36.25 ± 3.54	41.25 ± 2.50	73.75 ± 4.43	ND	8.33 ± 0.58	5.00 ± 0.01
Flavour and taste						
Bitter				73.13 ± 4.58	31.00 ± 2.24	103.13 ± 4.58
Salty				ND	5.20 ± 0.45	2.00 ± 0.01
Earthy flavour				106.25 ± 5.18	52.86 ± 4.88	31.88 ± 2.59
Black tea flavour				35.00 ± 0.01	10.00 ± 0.01	3.00 ± 0.01
Mushroomy flavour				77.14 ± 4.88	38.33 ± 2.58	52.86 ± 4.96
Umami flavour					12.20 ± 0.45	
Feeling factor						
Pungent				72.50 ± 4.63	48.14 ± 4.74	65.63 ± 4.96
After-taste(AT)						
Pungent AT				9.71 ± 0.76	9.6 ± 0.890	50.63 ± 1.77
Bitter AT				56.25 ± 5.18	35.00 ± 0.01	84.293 ± 5.35
Mushroomy AT				64.00 ± 5.01	10.00 ± 0.01	10.00 ± 0.01

Note: The average ± standard deviation.

higher encapsulation efficiency compared to pure modified starch, gum Arabic, and a mixture of maltodextrin and gum Arabic. This suggests that the combination of maltodextrin and modified starch may have synergistic effects in enhancing the encapsulation efficiency of bioactive compounds.

3.2.2. Determination of encapsulation efficiency (%EE) and loading capacity (%LC)

The results of the encapsulation efficiency exhibited a significant difference, which was attributed to the wall materials ratio. These findings are summarized in Fig. 4.

The study revealed that the highest %EE of flavonoid, at 89.96 ± 0.12 %, was achieved using a combination of 25 % maltodextrin, 50 % Arabic gum, and 25 % modified starch. This was followed by Treatment 6 (37.50 % maltodextrin, 25 % Arabic gum, and 37.50 % modified starch), Treatment 1 (25 % maltodextrin, 50 % Arabic gum, and 25 % modified starch), and Treatment 7 (33.33 % maltodextrin, 33.33 % Arabic gum, and 33.33 % modified starch), with %EE values of flavonoid of 89.17 ± 0.14, 88.95 ± 0.07, and 88.37 ± 0.19, respectively. Meanwhile, the %LC for flavonoids revealed that treatment 8 exhibited the highest percentage, followed by treatments 1 and 6, registering values of 16.12 ± 0.02, 15.94 ± 0.01, and 15.98 ± 0.02, respectively (Fig. 5). The utilization of a carrier system comprising maltodextrin and gum Arabic proved to be the most effective for encapsulating anthocyanins in microcapsules. This particular carrier system exhibited exceptional antioxidant content and encapsulation efficiency. The combination of maltodextrin and Arabic gum demonstrated remarkable solubility and superior emulsion properties, facilitating the creation of hollow particles during the drying process. The resulting powder comprised these hollow particles, with the carrier matrix efficiently encapsulating the anthocyanin extracts [31]. Moreover, as compared to native starch [32].

The highest %EE of polysaccharide was observed in Treatment 3 (92.57 ± 0.01 %), which consisted of 25 % maltodextrin, 25 % gum Arabic, and 50 % modified starch. Treatment 1 (25 % maltodextrin, 50 % gum Arabic, and 25 % modified starch) and Treatment 4 (25 % maltodextrin, 37.50 % gum Arabic, and 37.50 % modified starch) also exhibited high %EE values, at 92.38 ± 0.04 % and 92.35 ± 0.18 %, respectively (Fig. 4). Similar results were obtained in other studies about using different encapsulating methods and the

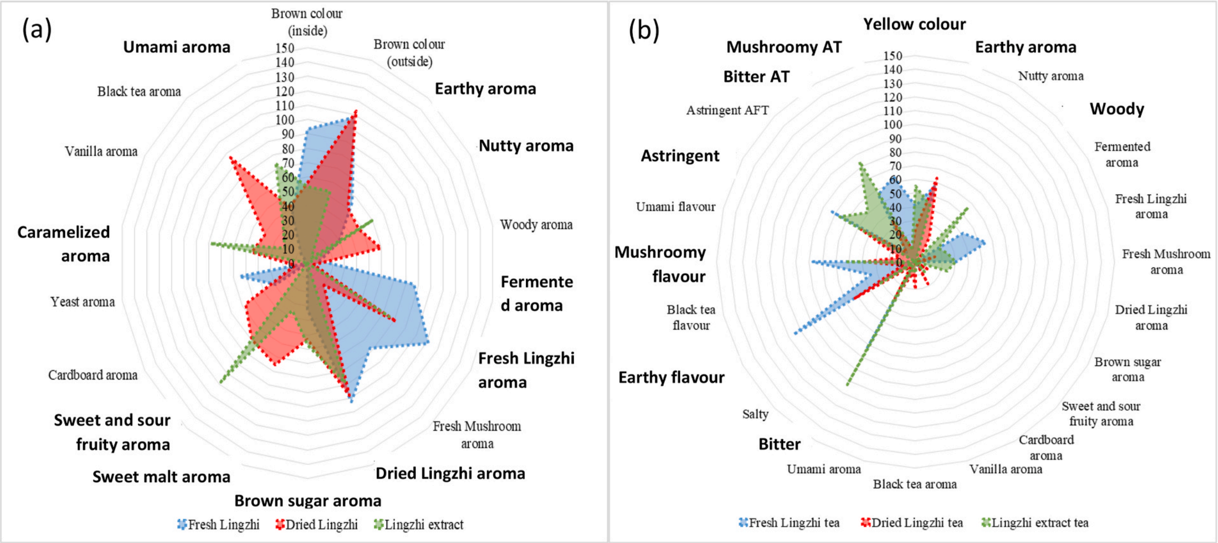


Fig. 2. Spider-web diagram of the sensory descriptors profile for the 6 Lingzhi samples (a) fresh Lingzhi, dried Lingzhi and Lingzhi extracts (b) fresh Lingzhi, dried Lingzhi and Lingzhi extracts tea.

microbiological properties of the best encapsulating methods for C. *ternatea* flowers. The highest encapsulation efficiency based on anthocyanin contents was found in freeze-dried powders (95.75 ± 0.24 %) [10] and %EE of 99.2 % and an encapsulation yield of 89.71 % was previously reported for maltodextrin Arabic gum microparticles encapsulating grape seed extract [32]. Corresponding to the %LC values of polysaccharides, Treatments 4, 3, and 1 exhibited the highest values, measuring 19.40 ± 0.13, 19.38 ± 0.01, and 19.32 ± 0.01, respectively.

The study found that the highest %EE of triterpene, at 91.21 ± 0.26 %, was achieved using a combination of 33.33 % maltodextrin, 33.33 % gum Arabic, and 33.33 % modified starch. This was followed by Treatment 1 (25 % maltodextrin, 50 % Arabic gum, and 25 % modified starch), Treatment 8 (25 % maltodextrin, 50 % gum Arabic, and 25 % modified starch), and Treatment 5 (50 % maltodextrin, 25 % gum Arabic, and 25 % modified starch), with %EE values of triterpene of 91.14 ± 0.37, 91.07 ± 0.44, and 91.00 ± 0.70, respectively. An increase in the concentration of maltodextrin and gum Arabic resulted in an increase in solid content in the feed solution. In this study, the concentration of the core material was found to have an impact on the %EE of the microparticles. It was observed that the maltodextrin-gum Arabic microparticles exhibited higher loading capacity and EE compared to those made with native starch. This difference could be attributed to the structural variations between the wall materials. It is possible that the maltodextrin-gum Arabic combination had a higher binding capacity, leading to improved encapsulation efficiency [33]. The %LC values for triterpenes in treatments 1, 7, 8, and 5 displayed the highest values, measuring 16.70 ± 0.07, 16.69 ± 0.05, 16.69 ± 0.08, and 16.67 ± 0.13, respectively (Fig. 5).

3.2.3. Optimization condition for encapsulated lingzhi extracts

The experimental data were subjected to multiple regression analysis, resulting in a predictive equation for the percentage of encapsulation efficiency (flavonoid and polysaccharide) and sensory attributes such as aroma (brown sugar, earthy, nutty, fresh mushroom, dried Lingzhi, and black tea), taste (salty), flavour (earthy), and aftertaste (mushroomy). The equation, expressed in terms of coded values, is shown in Table 4.

Table 4 shows the multiple regression results and the significance of regression coefficients for the %EE of flavonoid, polysaccharide, brown sugar aroma, earthy aroma, nutty aroma, fresh mushroom, dried Lingzhi aroma, black tea aroma, salty taste, earthy flavour and mushroomy (after taste) model. The smaller the P-value, the more significant the corresponding coefficient. It can be observed from the table that both the linear and quadratic terms of all parameters (maltodextrin: X_1, gum Arabic: X_2 and modified starch: X_3) had a significant (at least at $P \leq 0.05$) effect on %EE flavonoid and polysaccharide. In addition, it was also significantly influenced by the interactions between the amount of gum Arabic, X_2 and modified starch, X_3 ($P \leq 0.05$), respectively. Among all the three encapsulating wall materials studied, maltodextrin has the most critical role in the percentage of encapsulation flavonoid and polysaccharide encapsulation efficiency followed by gum Arabic and modified starch from rice flour.

The relationship between the independent and dependent variables was visually depicted through 2D contour plots generated by the model (Fig. 6a–k). The contour plots exhibited different shapes, which indicated the nature of interactions between the variables. An elliptical contour plot suggested significant interactions between the variables, whereas a circular contour plot indicated the absence of significant interactions. These contour plots provided valuable insights into the relationships and interactions between the variables in the study.

In Fig. 7, the interaction between the encapsulating wall materials, namely maltodextrin (X_1), gum Arabic (X_2), and modified starch (X_3), was analysed in relation to the percentage of encapsulation efficiency and sensorial attributes. The results indicated that an

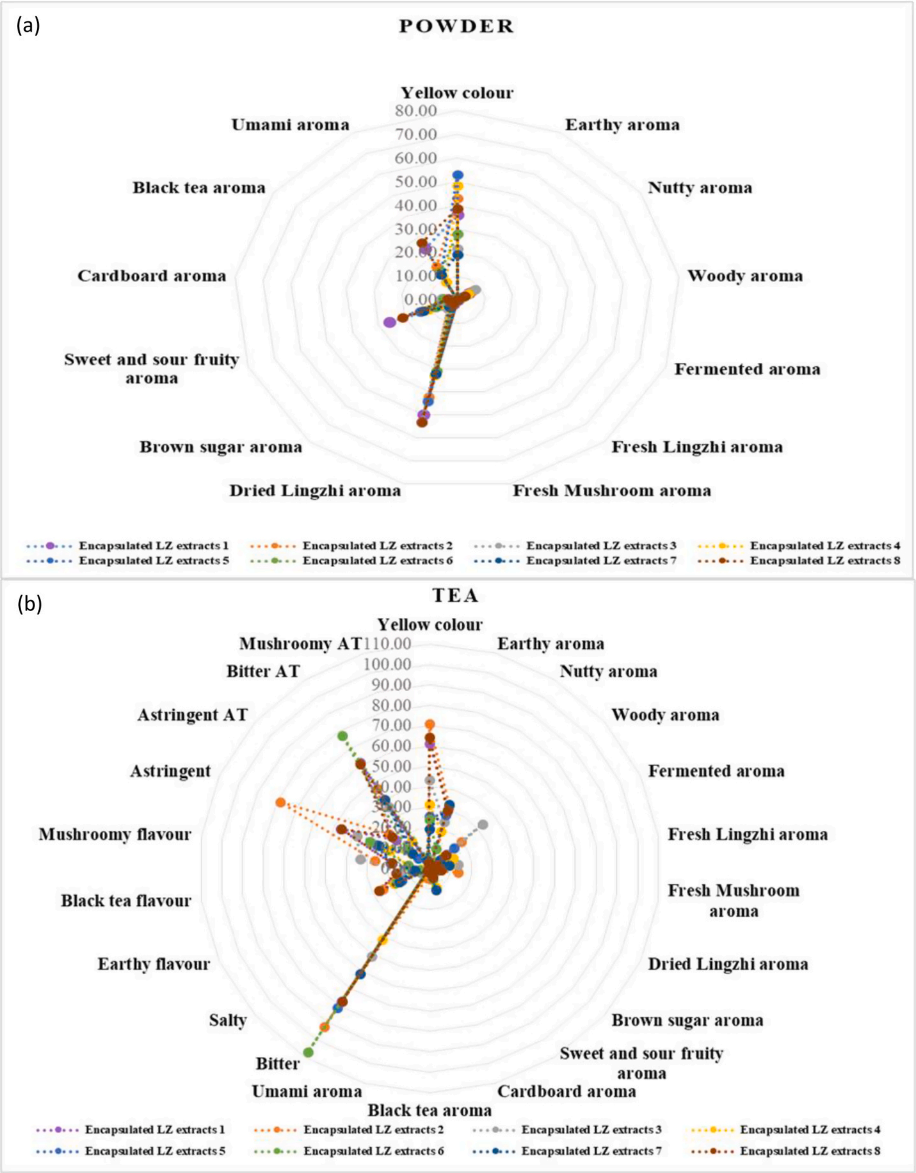


Fig. 3. Sensory Descriptors Analysis Spider-Web Diagram for the 16 Encapsulated Lingzhi Mushroom Samples: (a) Powder of Encapsulated Lingzhi extracts - 8 samples, (b) Encapsulated Lingzhi Extracts Tea - 8 samples. All the details of the treatments are provided in Table 1.

increase in maltodextrin, gum Arabic, and modified starch had an impact on the response variables. Specifically, an increase in maltodextrin and gum Arabic led to a decrease in all sensory attributes, except for earthy flavour and mushroomy aftertaste. Conversely, an increase in modified starch was associated with an improvement in these sensory attributes. The optimization of this study was to maximize the percentage of encapsulation efficiency for flavonoid and polysaccharide contents. Additionally, Fig. 7 highlights the desirable sensory attributes of brown sugar aroma, nutty aroma, and black tea aroma, which were considered indicators of good aroma.

The optimization in this study aimed to maximize the percentage of encapsulation efficiency for flavonoid and polysaccharide contents. Moreover, the sensory attributes associated with good aroma include brown sugar aroma, nutty aroma, and black tea aroma. The optimal flavonoid content (%EE = 88.31 %) and polysaccharide content (%EE = 89.62 %) align closely with results obtained in other studies involving microcapsules loaded with phenolic compounds (e.g., 76.56–86.74 %) [34]. The predicted encapsulation condition for achieving these optimal contents was 32.75 % maltodextrin, 42.25 % Arabic gum, and 25.00 % modified starch (Fig. 7).

The accuracy of the prediction of the optimum response values, which indicate the suitability of the optimized encapsulation conditions, was evaluated by comparing the obtained experimental results with the post-analysis of the optimization procedure. As presented in Table 5.

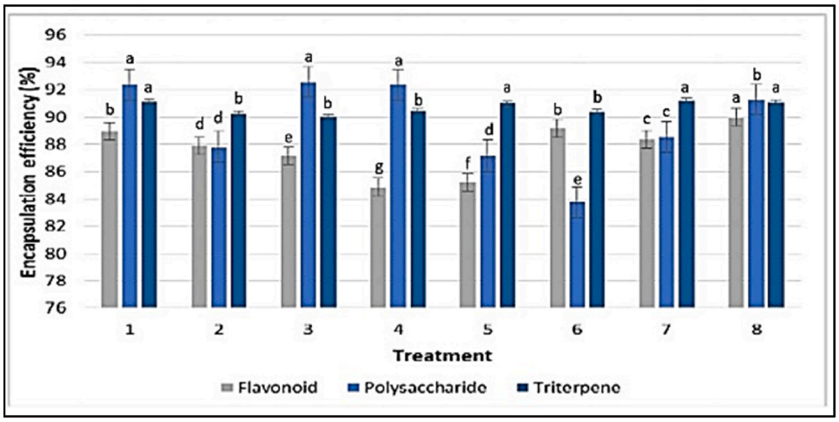


Fig. 4. The experimental design for encapsulation of Lingzhi mushroom extracts with a percentage of encapsulation efficiency of flavonoid, polysaccharide and triterpene. a, b, c, …means with the same letter are not significantly different according to the Duncan Test ($P \leq 0.05$); Values are average of three replicates; SE: Standard error. All the details of the treatments are provided in Table 1.

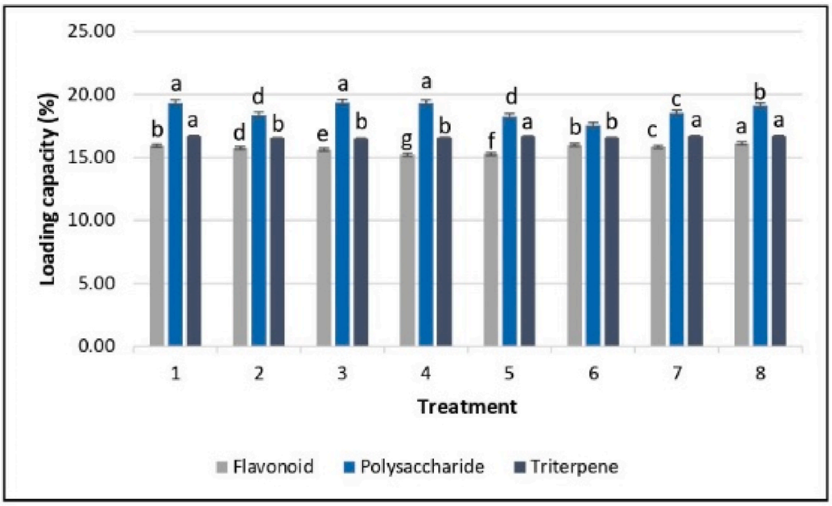


Fig. 5. The experimental design for encapsulation of Lingzhi mushroom extracts with a percentage of loading capacity of flavonoid, polysaccharide and triterpene. ^{a}, ^{b}, ^{c}, …means with the same letter are not significantly different according to the Duncan Test ($P \leq 0.05$); Values are average of three replicates; SE: Standard error. All the details of the treatments are provided in Table 1.

The optimal encapsulation condition for the Lingzhi mushroom extracts was determined using Design-Expert software, resulting in the following composition: 32.75 % maltodextrin, 42.25 % Arabic gum, and 25 % modified starch. To validate the practical applicability, three parallel experiments were conducted under these conditions. The average percentage of encapsulation efficiency for flavonoid, polysaccharide, brown sugar aroma, nutty aroma, and black tea aroma was found to be 88.39 ± 0.09, 89.53 ± 0.06, 4.36 ± 0.17, 2.00 ± 0.01, and 4.50 ± 0.19, respectively, as shown in Table 5. It is noteworthy that the mean values closely align with the predicted values, indicating the reliability of the model.

3.2.4. Comparison between lingzhi extracts with the optimum condition of encapsulated lingzhi extracts

3.2.4.1. Gas chromatography electronic nose (GC E-nose). The volatile compounds present in the Lingzhi extracts and encapsulated Lingzhi extracts were analysed using GC-E-Nose, and the results are presented in Table 6. In total, eleven aroma compounds were identified across the two samples of Lingzhi. These volatile compounds were categorized into different groups, including aldehydes,

Table 4
The models for the effects and interactions of the percentage of maltodextrin, Arabic gum, and modified starch, using chemical and sensory attributes in conjunction with variable combinations.

Response	Regression model	R^2
Flavonoid (%EE)	$+0.28*X_1+1.46*X_2+0.83*X_3+0.021*X_1X_3-0.02*X_2X_3$	0.92
Polysaccharide (%EE)	$+1.44*X_1+0.70*X_2+1.69*X_3-0.04*X_1X_3$	0.90
Brown sugar aroma (P)	$-0.24*X_1-0.43*X_2+0.23*X_3+0.02*X_1X_2-4.09*X_1X_3+3.20\times10^{-3}*X_2X_3$	0.99
Earthy aroma (T)	$+16.66*X_1+14.19*X_2+18.00*X_3-0.76*X_1X_2-0.89*X_1X_3-0.89*X_2X_3+0.03*X_1X_2X_3$	0.99
Nutty aroma (T)	$-0.08*X_1-0.68*X_2+0.08*X_3+0.03*X_1X_2+4.48\times10^{-3}*X_1X_3+0.02*X_2X_3-1.09\times10^{-3}*X_1X_2X_3$	1.00
Fresh mushroom aroma (T)	$-0.04*X_1-0.78*X_2+1.06*X_3+0.03*X_1X_2-0.3*X_1X_3$	0.90
Dried Lingzhi aroma (T)	$-0.20*X_1-0.07*X_2+0.10*X_3+9.28\times10^{-3}*X_1X_2+4.24\times10^{-4}*X_1X_3-2.88\times10^{-3}*X_2X_3$	0.99
Black tea aroma (T)	$-0.28*X_1-0.25*X_2+0.08*X_3+0.02*X_1X_2$	0.87
Salty (T)	$-2.29*X_1-1.40*X_2-2{,}28*X_3+0.09*X_1X_2+0.12*X_1X_3+0.09*X_2X_3-3.51\times10^{-3}*X_1X_2X_3$	1.00
Earthy flavour (T)	$+0.20*X_1+0.52X_2-0.21*X_3$	0.82
Mushroomy (AT) (T)	$+0.51X_1+1.28*X_2+1.03*X_3-0.05*X_1X_2-0.04*X_1X_3-0.06*X_2X_3+2.08\times10^{-3}*X_1X_2X_3$	1.00

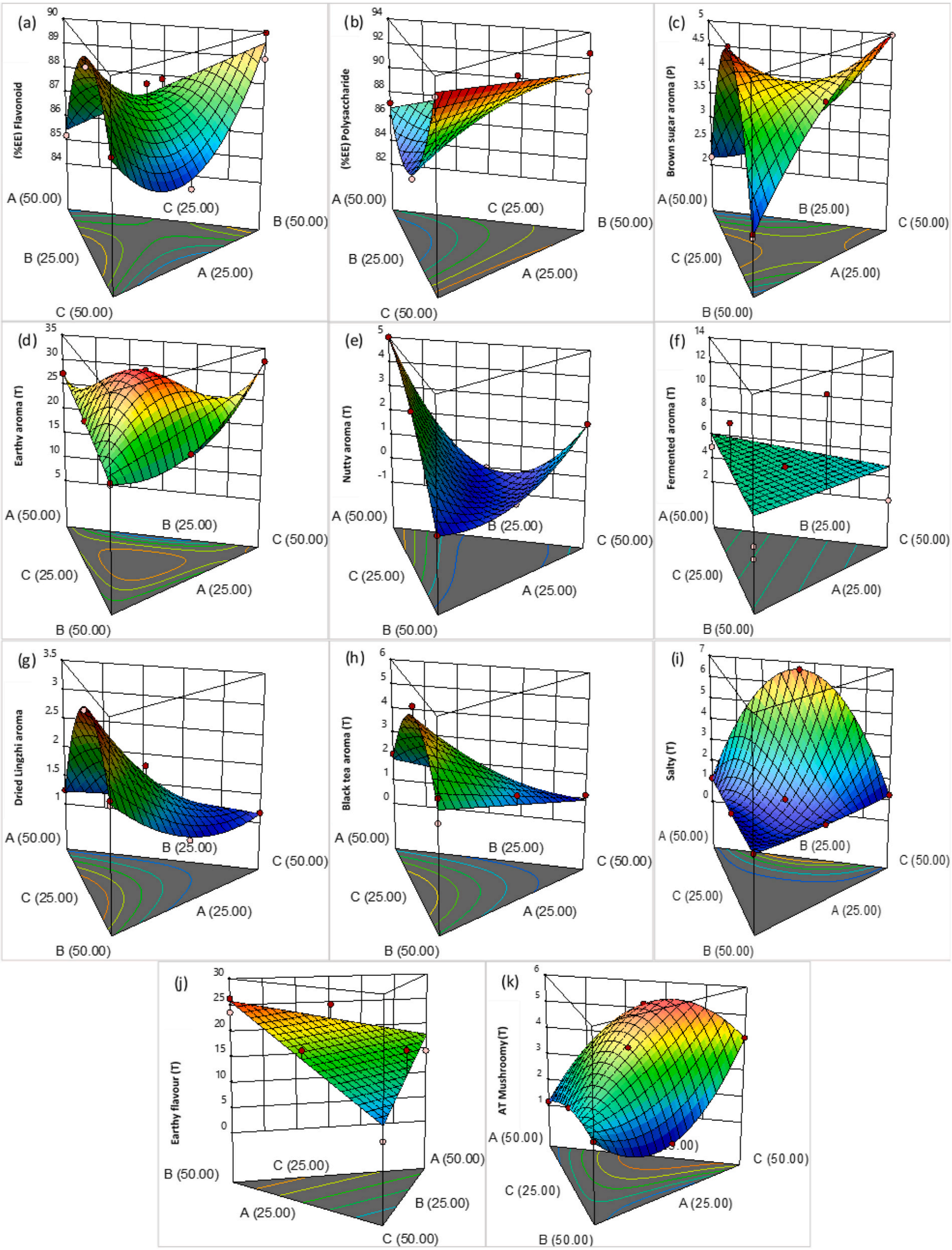
Note: X_1: Maltodextrin, X_2: Arabic gum, X_3: Modified starch, P: Encapsulated Lingzhi mushroom powder and T: Encapsulated Lingzhi mushroom tea.

thiol, ketones, esters, alkanes, amines, and aromatic compounds. The number of volatile compounds varied between the Lingzhi samples, with ten aroma compounds identified in the Lingzhi extracts and nine aroma compounds identified in the encapsulated Lingzhi extracts. The results suggest that the Lingzhi extracts exhibit a more pungent aroma compared to the encapsulated Lingzhi extracts. Furthermore, the aroma profile, as indicated by the relative concentration, demonstrates varying quantities of volatile compounds, resulting in different levels of abundance of these compounds in each sample.

The reactivity of linear chain aldehydes (C_6-C_{12}) was tested on samples, showing a decrease in conversion with increasing chain length from C_6 to C_{12} [35]. This study detected several aldehydes, four of which were identified as key volatile compounds: acetaldehyde, propanal, 2-methylpropanal, and 2-methylbutanal, all imparting a green odor profile. The sensory descriptors in Table 6 were determined through human sensory tests using the program's library. Acetaldehyde and propanal were associated with a pungent, green note [36,37]. Both 2-methylpropanal and 2-methylbutanal were also noted to have green sensory descriptors. Ma et al. [38] reported that aldehydes were the dominant chemical group in fresh Tuber indicum, identifying acetaldehyde, propanal, 2-methylpropanal, and 2-methylbutanal. Among the identified aldehyde compounds in samples, hexanal was classified as an aldehyde [36]. Consistent with Guo et al. [39], hexanal was found in all samples, suggesting its role as a key aroma component in pine mushrooms. Additionally, aromatic components were detected in southwest pine mushrooms from Southwest China, typically considered oxidized products [38]. In Lingzhi samples, ketones were identified as the most abundant volatile organic compounds (VOCs). The presence of ketones indicates autoxidation of fatty acids and Maillard reactions, contributing to the rich aroma in dried mushrooms [40,41]. Specifically, propane-2-one was detected in Lingzhi extracts at a concentration of 41.71 ± 3.76 μg/g.

3.2.4.2. *Sensory descriptive analysis.*

Lingzhi mushrooms contain a wide range of other aromas and flavours. In Table 7 and Fig. 8a-b, various notes such as woody, nutty, brown, bitter, salty, and pungent are common attributes found in different mushrooms. However, the intensities of these notes may vary among different mushroom varieties. Sensory evaluation was performed on four distinct Lingzhi samples, which consisted of Lingzhi extract powder, encapsulated Lingzhi extracts powder, Lingzhi extract tea, and encapsulated Lingzhi extract tea. Table 7 and Fig. 8a demonstrate that the encapsulated Lingzhi extract powder exhibits a variety of aromas, including earthy, woody, fresh Lingzhi, sweet malt, caramelized, vanilla, and black tea. Additionally, a cardboard aroma was detected in the encapsulated Lingzhi extract powder. Hence, the aroma perceived by the trained panel during sensory evaluation can be correlated with the volatile compounds identified by GC-E-Nose, as presented in Table 6. The volatile compounds related to aroma can be categorized into four groups, including earthy aroma (propanal and propane-2-one), pungent aroma (acetaldehyde, methanethiol, and 1-butanamine), sweet aroma (methyl acetate and ethyl acetate), and burnt aroma (2-methylpropanal and 2-methylbutanal). Indeed, it is observed that Lingzhi extract powder has a brown colour, while the encapsulated Lingzhi extracts exhibit a yellow colour. Additionally, when comparing the attributes of the encapsulated Lingzhi extract tea to the Lingzhi extract tea in Table 7 and Fig. 8b, it is apparent that all attributes in the encapsulated Lingzhi extract tea are lower in intensity compared to the Lingzhi extract tea. Maltodextrin, gum Arabic, and modified starch from rice flour are examples of carbohydrates [42,43]. It is known that carbohydrates can contribute to aromas such as the cardboard aroma [44].



(caption on next page)

Fig. 6. Contour plots showing the effect of encapsulated wall material; A: maltodextrin, B: Arabic gum and C: modified starch on encapsulation efficiency (a) flavonoid and (b) polysaccharide and sensorial attributes (c) brown sugar aroma (P), (d) earthy aroma (T), (e) nutty aroma (T), (f) fresh mushroom aroma (T), (g) dried Lingzhi aroma (T), (h) black tea aroma (T), (i) salty (T), (l) earthy flavour (T) and (k) mushroomy after taste (T) (P: Encapsulated Lingzhi mushroom powder and T: Encapsulated Lingzhi mushroom tea). (P: Powder and T: Tea).

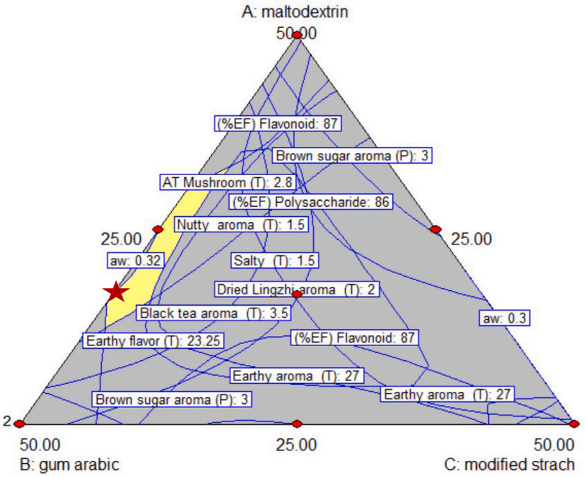


Fig. 7. Overlay plot of optimum encapsulation condition.

Table 5

Compares the percentage of physicochemical and descriptive analysis sensory of encapsulated Lingzhi extracts of predicted value with the observed value.

Respond	Predicted value	Observed value	% Error
Physicochemical			
Flavonoid (%EE)	88.31	88.39 ± 0.09	0.09
Polysaccharide (%EE)	89.62	89.53 ± 0.06	0.10
Sensorial attributes			
Brown sugar aroma (P)	4.54	4.36 ± 0.17	3.96
Earthy aroma (T)	22.20	22.04 ± 0.12	0.72
Nutty aroma (T)	2.15	2.00 ± 0.01	6.98
Fresh mushroom (T)	11.27	11.18 ± 0.19	0.80
Dried Lingzhi aroma (T)	3.16	3.08 ± 0.13	2.53
Black tea aroma	4.64	4.50 ± 0.19	3.02
Salty	1.19	1.00 ± 0.01	15.97
Earthy flavour	23.29	23.14 ± 0.22	0.64
Mushroomy (after taste)	2.27	2.06 ± 0.09	9.25

Note: The average ± standard deviation. P = Encapsulated Lingzhi mushroom powder, T = Encapsulated Lingzhi mushroom tea.

4. Conclusion

The optimal condition of wall material for encapsulated Lingzhi extracts was 32.75 % maltodextrin, 42.25 % Arabic gum and 25 % modified starch. This formula, considering the practical situation, shows that three parallel experiments were carried out under the following conditions: the average percentage of encapsulation efficiency of flavonoid was 88.39 ± 0.09, for polysaccharide it was 89.53 ± 0.06, and the sensory attributes were evaluated as follows — brown sugar aroma (4.36 ± 0.17), earthy aroma (22.04 ± 0.12), nutty aroma (2.00 ± 0.01), fresh mushroom (11.18 ± 0.19), dried Lingzhi aroma (3.08 ± 0.13), black tea aroma (4.50 ± 0.19), salty (1.00 ± 0.01), earthy flavour (23.14 ± 0.22), and Mushroomy (aftertaste) (2.06 ± 0.09). The encapsulated Lingzhi has a mask and reduces bad aroma, off-flavour, taste (bitterness), feeling factor (pungent) and aftertaste. The intensity of the woody aroma, fermented aroma, fresh Lingzhi aroma, fresh mushroom aroma cardboard aroma, bitterness, earthy, mushroomy, pungent, aftertaste of pungent, bitterness and mushroomy is lower than the Lingzi extract. Future research could study the effect of encapsulated Lingzhi extracts on potential anticancer (*in vivo*). It may be a potential development with wide prospects for the functional food market.

Table 6
Volatile flavour compounds in Lingzhi extracts and encapsulated Lingzhi extracts identified by GC E-Nose.

Retention Time (min)	Formula	Name	Sensory descriptors	Lingzhi extracts (μg/g)	Encapsulated Lingzhi extracts (μg/g)
17.44	C_2H_4O	Acetaldehyde	•Aldehydic; Etheral; Fresh; Fruity; Pleasant; Pungent	1.31 ± 0.05	0.88 ± 0.06
18.81	CH_4S	Methanethiol	•Cabbage; cabbage (cooked); Cheese; egg (rotten); Fishy; Garlic; Gasoline; Meaty; Pungent; Rotten; Sulfurous; unpleasant	2.83 ± 0.25	1.37 ± 0.05
21.71	C_3H_6O	Propanal	•acetaldehyde; Cocoa; Earthy; Etheral; Nutty; Plastic; Pungent; Solvent	44.18 ± 2.35	26.78 ± 2.63
23.06	C_3H_6O	propane-2-one	•Apple; characteristic; Fruity; Glue; Pear; Solvent; Sweet; Violet	41.71 ± 3.76	ND
23.54	$C_3H_6O_2$	Methyl acetate	•Blackcurrant; Etheral; Fragrant; Fruity; fruity (sweet); Pleasant; Solvent; Sweet	ND	20.02 ± 0.86
26.67	C_4H_8O	2-methylpropanal	•Aldehydic; Baked potato; Burnt; Floral; Fresh; Fruity; Green; Malty; Pungent; Sharp; Spicy; Toasted	8.38 ± 0.68	2.13 ± 0.11
30.58	$C_4H_8O_2$	Ethyl Acetate	•Acidic; Butter; Caramelized; Etheral; Fruity; Green; Orange; Pineapple; Pungent; Solvent; Sweet	2.46 ± 0.21	ND
32.16	C_7H_{16}	Heptane	•Alkane; Fruity; Gasoline; Sweet	0.21 ± 0.01	0.07 ± 0.01
33.04	$C_4H_{11}N$	1-Butanamine	•Ammoniacal; Fishy	0.63 ± 0.01	0.61 ± 0.03
39.28	$C_5H_{10}O$	2-methylbutanal	•Almond; Apple; Burnt; burnt (strong); choking; Cocoa; Coffee; Fermented; Fruity; Green; iodoform; Malty; Musty; Nutty; powerful; sickly; Sour	10.96 ± 0.59	3.74 ± 0.10
40.26	C_4H_4S	Thiophene	• Alliaceous; Aromatic; Garlic; Sulfurous	16.28 ± 1.34	3.50 ± 0.06

Note: The average ± standard deviation. ND: Not detected.

Table 7
Mean intensity of all attributes in Lingzhi mushroom 6 samples (0 = none to 150 = extremely high).

Attribute	Lingzhi extracts	Encapsulated Lingzhi extracts	Tea	
			Lingzhi extracts	Encapsulated Lingzhi extracts
Appearance				
Brown colour	53.00 ± 4.38	–	–	–
Yellow colour	–	43.00 ± 1.22	55.13 ± 5.22	69.50 ± 0.55
Aroma				
Earthy	4.83 ± 0.41	ND	42.50 ± 3.78	22.04 ± 0.12
Nutty	59.38 ± 1.77	7.03 ± 0.03	ND	2.00 ± 0.01
Woody	2.13 ± 0.35	ND	56.25 ± 3.54	18.00 ± 1.22
Fermented	ND	ND	20.00 ± 0.01	5.50 ± 0.50
Fresh Lingzhi	75.00 ± 5.35	ND	25.00 ± 001	7.20 ± 0.21
Fresh Mushroom	ND	ND	30.00 ± 2.67	11.18 ± 0.19
Dried Lingzhi	88.75 ± 3.54	40.40 ± 0.42	25.00 ± 0.01	3.08 ± 0.13
Brown sugar	56.88 ± 4.58	4.36 ± 0.17	ND	ND
Sweet malt	35.00 ± 4.63	ND	ND	ND
Sweet and sour fruity	108.00 ± 5.26	14.00 ± 1.00	10.00 ± 0.01	ND
Cardboard	ND	3.40 ± 0.14	ND	4.74 ± 0.23
Yeast	ND	ND	ND	ND
Caramelized	78.38 ± 2.33	ND	ND	ND
Vanilla	20.83 ± 2.04	ND	2.00 ± 0.01	ND
Black tea	30.00 ± 0.01	ND	8.17 ± 0.41	4.50 ± 0.19
Umami	73.75 ± 4.43	14.40 ± 0.55	5.00 ± 0.01	3.70 ± 0.21
Flavour and taste				
Bitter			103.13 ± 4.58	84.46 ± 1.02
Salty			2.00 ± 0.01	1.00 ± 0.01
Earthy flavour			31.88 ± 2.59	23.14 ± 0.22
Black tea flavour			3.00 ± 0.01	17.38 ± 0.79
Mushroomy flavour			52.86 ± 4.96	24.10 ± 1.08
Umami flavour			ND	ND
Feeling factor				
Pungent			65.63 ± 4.96	54.20 ± 0.87
After-taste(AT)				
Pungent AT			50.63 ± 1.77	24.26 ± 0.87
Bitter AT			84.293 ± 5.35	49.46 ± 1.22
Mushroomy AT			10.00 ± 0.01	2.06 ± 0.095

Note: The average ± standard deviation.

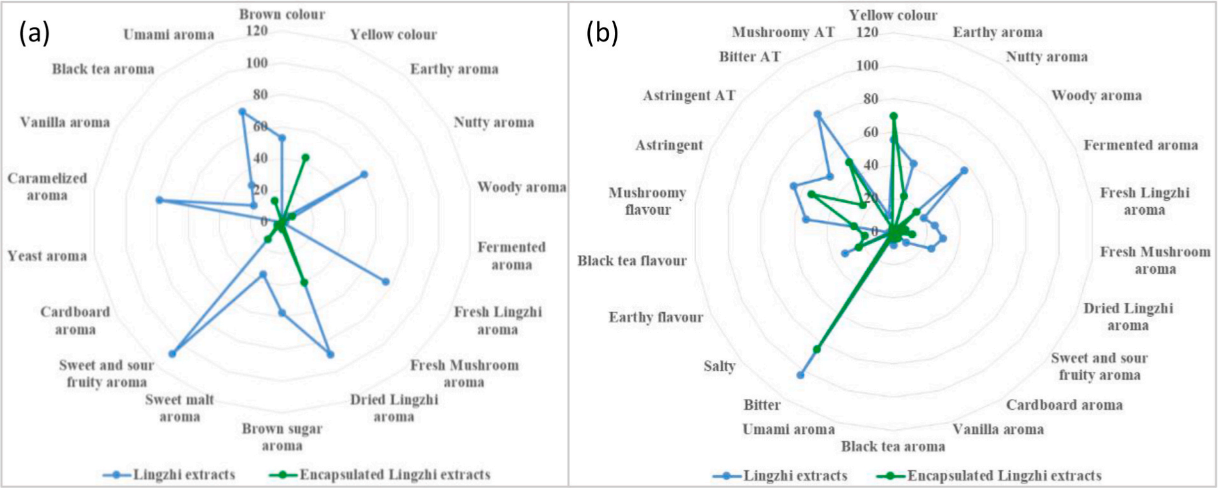


Fig. 8. Spider-web diagram illustrating the sensory descriptors profile for comparing Lingzhi extracts with encapsulated Lingzhi extracts. Panel (a) represents the comparison between Lingzhi extracts and encapsulated Lingzhi extracts, while panel (b) depicts the comparison between Lingzhi extracts and encapsulated Lingzhi extracts tea.

CRediT authorship contribution statement

Threethip Chuensun: Writing – original draft, Methodology, Data curation. **Teera Chewonarin:** Formal analysis. **Witida Laopajon:** Formal analysis, Data curation. **Rajnibhas Sukeaw Samakradhamrongthai:** Writing – review & editing. **Worrapob Chaisan:** Data curation. **Niramon Utama-ang:** Writing – review & editing, Supervision, Project administration.

Ethics statement

The authors gratefully acknowledge Chiang Mai University, Research Ethic Committee (CMUREC63/142).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Assoc. Prof. Dr. Niramon Utama-ang reports financial support was provided by Chiang Mai University. Threethip Chuensun reports a relationship with Research and Researchers for Industries scholarship (RRI, code PHD60I0048) under the Thailand Research Fund (TRF) that includes: funding grants. If there are other authors, they 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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