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Research article

The combination of different carriers in producing plant-based seasoning powder from oyster mushroom (*Pleurotus sajor-caju*)

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Abstract: The increasing popularity and prioritization of plant-based nutritional foods have heightened the focus on research and the diversification of plant-derived products. Therefore, this paper centers on producing a plant-based seasoning powder from oyster mushroom, an available commodity, using its concentrated extract and various carriers to maximize retention of bioactive nutrients and ensure compliance with the product's physicochemical and microbiological quality standards. The optimal ratio of the combination between maltodextrin (MD) and gum arabic (GA) was obtained through a range of investigated ratios, which was a completely randomized setup with concentrations of 5, 10, 15, and 20% for MD, and 0, 0.5, 1.0, 1.5, and 2% for GA. The outcome has shown that MD combined with GA significantly affected the seasoning powder product; at a mixing ratio of 10% MD and 1% GA, it exhibited the highest stability and optimal physicochemical properties. The high retention of key bioactive compounds, including flavonoids, phenolics, lysine, glutamic acid, and β-glucan, with respective contents of 0.0034 g QE, 0.28 g TAE, 0.0052 mg, 2.32 mg, and 10.86 mg per 100 g dry matter. The powder demonstrated satisfactory yield and solubility, and the brightness index was the highest among all tested formulations. Moreover, the water activity reached 0.42, ensuring the product's enzymatic and microbiological stability.

Keywords: Carrier; gum arabic; maltodextrin; physicochemical properties; plant-based products

1. Introduction

Oyster mushroom (*Pleurotus sajor-caju*) is favored for consumption not only for its affordable price but also for its nutritional and functional benefits. Many studies have highlighted that it contains high levels of proteins, essential amino acids, dietary fiber, and diverse bioactive constituents [1]. These bioactive compounds include polysaccharides and phenolic compounds, which are associated with antioxidant, antihypertensive, antidiabetic, antiviral, and immunomodulatory properties [2, 3]. However, this fresh crop has a high respiration rate and high water content and lacks an epidermal structure [4]. As a result, they are prone to mechanical damage, bacterial spoilage, weight loss, and enzymatic browning, leading to rapid deterioration in quality after harvesting. Moreover, the cultivation conditions for oyster mushrooms are relatively simple, with high annual yields; thereby, without appropriate preservation methods, this nutrient-rich resource is prone to significant wastage

[4, 5]. Traditional preservation methods, such as thermal treatment or cold storage, are commonly used to prolong shelf life, but they still have shortcomings, especially in retaining nutritional content during storage [6]. Instead of applying a single approach solely for a single purpose, such as storage or processing, a combination of multiple processing methods can enhance nutrient retention in the raw material while generating value-added products, thereby diversifying mushroom-based product lines and providing additional income for mushroom growers.

Nowadays, demand for vegan-based products has been on the rise due to their health benefits. Numerous studies have reported that plant-based diets provide high levels of dietary fiber, vitamins, and beneficial micronutrients, while also containing abundant phytochemicals with antioxidant, anti-inflammatory, and metabolic-supporting properties [7, 8]. A study further demonstrated that individuals following plant-based diets exhibited significant improvements in glycemic control, reduced insulin resistance, and lower serum cholesterol levels compared with those following omnivorous diets [9]. This study focused on producing a vegetarian seasoning powder derived from oyster mushrooms, which undergo extraction and concentration to maximize nutrient retention, followed by drying to produce a seasoning product that meets quality and nutritional standards. During drying, the use of carriers for microencapsulation is essential to protect core compounds from adverse environmental factors such as pH, temperature, oxygen, and light. Choosing an appropriate carrier (also referred to as wall material) is particularly critical, as it forms a protective barrier for thermally sensitive bioactive ingredients, reduces moisture content, extends shelf life, and helps preserve functional activity [10, 11]. Current research trends emphasize the use of food-grade, naturally derived carriers, most notably maltodextrin (MD), a starch-based polysaccharide, and gum arabic (GA) or acacia resin [12]. A substantial body of evidence indicates that incorporating maltodextrin and gum arabic, either individually or in combination, during drying enhances microencapsulation efficiency and minimizes antioxidant losses [13, 14]. A comparison of spray-dried chokeberry juice reported that, with maltodextrin and gum arabic, the powder achieved high retention rates of bioactive compounds ranging from 63% to over 97% [15]. Another study strongly demonstrated that a combination of maltodextrin and gum arabic effectively protected and retained bioactive constituents from an extract of palmyra palm peel, which aligns with its antioxidative characteristics [16]. Collectively, these findings underscore that selecting suitable natural carriers in drying is highly effective for retaining phenolic, flavonoids, and antioxidant compounds in plant-based materials. Therefore, the objective is to obtain the most effective ratio in combining MD and GA to enhance the stability as well as chemical and nutritional properties of the oyster mushroom's seasoning powder. The product is designed to follow the concept of sustainable development, emphasizing the valorization of abundant, locally available raw materials, while aligning with the emerging global trend toward healthy vegetarian diets by promoting customer choice diversification.

2. Materials and Methods

2.1 Materials

Freshly harvested oyster mushroom (*Pleurotus sajor-caju*) from a My Thoi farm, without physical damage or insect defects, was transported to An Giang University and Vietnam University, Ho Chi Minh City (Vietnam). Maltodextrin (DE < 15%) and gum arabic were bought from My Uc Science & Technology JSC (Vietnam), and other analytical-grade chemicals were sourced from Sinopharm Chemical Reagent Co., Ltd.

2.2 Experimental design

Fresh oyster mushrooms were pretreated according to the procedure described in the doctoral dissertation of Giang Nguyen [17] before their use in the production of vegetarian seasoning powder as follows. Fresh oyster mushrooms were cleaned and dried in a solar dryer until the moisture content was reduced to below 10%. The dried mushrooms were then ground into powder and subjected to enzyme-assisted extraction of nutritional and bioactive compounds using cellulase. The extraction was performed at a water-to-material ratio of 20:1 (v/w), with 4% (w/w) cellulase, pH 5.5, at 50°C for 8 h. The resulting extract was concentrated under vacuum at 80°C and 600 mmHg for 60 min. The concentrated oyster mushroom extract was then subsequently used as a raw material for the study, according to the experimental design described below. To identify an optimal concentration of each investigating carrier in the combination of maltodextrin

and gum arabic to produce powder. The concentrations of the carriers under examination were set up completely randomized with three replications as follows: maltodextrin (in a ratio of 5, 10, 15, and 20%) and gum arabic (in a ratio of 0, 0.5, 1, 1.5, and 2%) based on the wet weight of the concentrated oyster mushroom solution. Specifically, 500 mL of the concentrated solution for each sample was dried using a spraying dryer (Yamato ADL311-A, Japan) at an inlet air temperature of 150°C with an input flow rate of 3 mL/min. The obtained powder product was kept in glass jars with lids for further quality analyses. For each test, 10-15 g of the powder product was dissolved in 500 mL of hot water and analyzed.

2.3 Physical properties analysis

2.3.1 Color analysis: L* (representing the brightness), a* (red-green section), b* (yellow-blue section) parameters of the powder after drying were measured using a colorimeter (Konica Minolta CR400).

2.3.2 Powder yield determination: the yield (Y) was defined by a ratio obtained from the weight of powder after drying (m_1) to the weight of the extraction before drying (m_2).

$$Y\ (\%) = (m_1/m_2) \times 100$$

2.3.3 Water activity (a_w): Each sample (1.0 g) was measured using digital water activity meters Aqualab (4TEV, USA). All samples were measured at 28-30 °C.

2.3.4 Solubility: The ability to dissolve the sample powder was checked based on the procedure carried out by Cano-Chauca et al. [18] with some adjustments. Following a series of steps, including dissolving, centrifuging, and drying to obtain a constant weight. Solubility was calculated as the ratio between the mass of dry matter in the constant weight and the initial sample mass.

2.4 Chemical properties analysis

The glutamic acid content (mg/100 g dry matter) was approached by following the method of Stauß et al. [19]. Briefly, a 0.2 mL aliquot of the sample was reacted with phosphate buffer (pH 6.0) and 2% ninhydrin, heated at 90°C for 15 min, diluted to 25 mL with distilled water, and quantified as glutamic acid using a standard curve $y = 4.1191x + 0.0814$ ($R^2 = 0.9999$).

The level of lysine (mg/100 g dry matter) in the powder was detected following the assay outlined by Hasani et al. [20] through the reaction of the sample with buffer (pH 8.0) and 1,2-naphthoquinone-4-sulfonate (NQS), diluting to 5 mL with distilled water, and measuring absorbance at 480 nm. Lysine concentration was quantified using a lysine standard curve, $y = 0.0009x + 0.139$ ($R^2 = 0.980$).

The concentration of β-glucan (mg/100 g dry matter) was assessed based on the Phenol-Sulfuric method [21]. Briefly, samples were ethanol-precipitated (96%, 4°C, 24 h), filtered, alkaline-treated (1 M NaOH, 60°C, 1 h), reacted with phenol and sulfuric acid, and the absorbance was measured at 490 nm. β-Glucan concentration was quantified using a standard glucan curve $y = 2745.61x + 0.0003$ (R^2=0.9999).

The content of flavonoid (g QE/100 g dry matter) and ***phenolic*** (g TAE/100 g dry matter) was identified relying on the colorimetric method described by Sumaiyah et al. [22]. Total flavonoid content was determined using the aluminum chloride colorimetric method through the reaction of samples with $NaNO_2$, $AlCl_3 \cdot H_2O$, and NaOH to form a stable yellow complex, and absorbance was measured at 510 nm using a UV–Vis spectrophotometer (V730, Jasco, Japan), its content was quantified using a quercetin calibration curve $y = 8.2634x + 0.0182$ ($R^2 = 0.9999$). Total phenolic content was determined using the Folin–Ciocalteu reagent. Samples were reacted with Folin–Ciocalteu reagent and Na_2CO_3, and absorbance was measured at 750 nm using a UV–Vis spectrophotometer (V730, Jasco, Japan). The content was quantified using a tannic acid calibration curve ($y = 0.0021x + 0.0064$; $R^2 = 0.9999$).

Note: Where y represents absorbance and x represents concentration for all standard curves.

2.5 Data analysis

Statgraphics Centurion XVI software (USA) was used to analyze the statistics of this study; the LSD test was used to identify differences between trial averages at a 5% confidence level (P = 0.05), and Microsoft Excel was used for computation and graphing. The suitability of the predicted model during optimization was

evaluated using the R^2 correlation coefficient. The equation for optimizing the response surface method (RSM) was derived from general form experiments, as indicated below.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} X_i X_j$$

In the equation, Y represents the objective function, β_0 stands for the constant term, β_i denotes the linear coefficient, β_{ii} represents the squared coefficient, β_{ij} indicates the interaction coefficient, and X_i and X_j represent the survey variables.

3. Results and Discussion

3.+1 Effects of different mixing ratios between maltodextrin and gum arabic on the product's physical properties

3.1.1 Recovery yield

This parameter is one of the critical indicators for evaluating the economic and efficient potential of the entire process. According to Table 1, the interaction between the two carriers was not statistically significant ($P > 0.05$), indicating that their combination did not produce a synergistic or antagonistic effect beyond their individual effects ($P < 0.05$). The results revealed that the recovery yield increased in direct proportion to the concentration of added MD, with the highest yield of 19.20% at 20% MD addition. However, the difference between 15 and 20% was not statistically significant ($P > 0.05$). In addition, GA had a considerable impact on recovery yield: it initially rose with increasing concentration, then decreased when the addition exceeded 1%, but the highest yield was obtained at 2% GA (18.55%). The mechanisms of each carrier can explain this during the drying process: they both reduce stickiness and wall deposition within the drying chamber. Moreover, they enhance particle formation and structural stability due to their high glass transition temperature, which facilitates the formation of stable powder particles during drying, thereby minimizing product loss [23]. Carrier supplementation also contributes to reducing the final moisture content and improving powder flowability, thereby increasing the recovery of dry product. Furthermore, carriers act as protective agents for heat-sensitive compounds, such as proteins and vitamins, by reducing their degradation during drying, thereby further enhancing the effective recovery yield [24].

Table 1. Physical properties of seasoning powder from oyster mushroom

The ratio of MD (%)	**Recovery yield (%)**	**a_w**	**Solubility (%)**
5	10.95^{c}	0.337^{c}	94.55^{a}
10	14.81^{b}	0.403^{a}	94.10^{b}
15	19.08^{a}	0.403^{a}	93.77^{c}
20	19.20^{a}	0.398^{b}	93.73^{c}
Level of significance	**	**	**
The ratio of GA (%)	**Recovery yield (%)**	**a_w**	**Solubility (%)**
0	13.73^{e}	0.383^{c}	94.22^{b}
0.5	15.75^{c}	0.400^{b}	94.64^{a}
1.0	16.78^{b}	0.398^{b}	93.87^{c}
1.5	15.25^{d}	0.407^{a}	93.74^{c}
2	18.55^{a}	0.336^{d}	93.73^{c}
Level of significance	**	**	**
Significance level of interaction	NS	**	NS

The superscripts offer the statistical difference at 1% significance level; NS indicates no statistically significant difference at the 5% level ($P > 0.05$).

3.1.2 Water activity (a_w)

Despite the low moisture content (MC) of the powder after drying (2-3%), which was consistent with previous studies on similar dried powder products [23-25]. Different food products have similar MC but remain significantly different in terms of safety and spoilage susceptibility; thus, MC should be measured in parallel with a_w to provide a comprehensive moisture analysis [26]. According to the results, the water activity

(a_w) of the powder was greatly affected by the concentration of added carriers, both in the individual factors (main effects) and in their interaction ($P < 0.01$). There was a fluctuation in the aw with increases in the levels of added MD and GA. It initially rose gradually, but when the MD content exceeded 15%, and the GA content exceeded 1.5%, the product's aw declined significantly. The a_w increase can be explained due to the molecular structure of MD with the large number of branches bearing hydrophilic groups, which enhances the holding water ability of MD [27], or it is partly attributable to the higher porosity of the powder, which facilitates the absorption of water from the surrounding environment into the pores of the powder after drying [28]. This finding was similar to previous related studies; Cao et al. [29] also reported a decrease in a_w values from 0.25 to 0.23 while increasing MD concentration to 30%. Powder products with a_w values below 0.60 are considered microbiologically safe, which indicates the condition is insufficient to support the growth or survival of microorganisms, as the available water is too limited for cellular metabolic activity. This threshold is widely used in food microbiology to ensure microbial stability and safety [30]. The absence of total aerobic microorganisms in the analysis further confirmed this microbiological safety result. However, the range of 0.2-0.4 is considered the most favorable, as it provides enhanced stability against undesirable reactions, including oxidation, browning, hydrolysis, and enzymatic activity [31].

3.1.3 Solubility

The powder's soluble capacity depends on several factors, including drying methods, drying temperature and duration, thermal treatment during concentration, and the type of carrier [32,33,34]. Both individual and cooperative effects of MD and GA on powder's solubility were in the range of 93.73–94.64% (Table 1). Results show that, with a gradual increase in the proportion of added carriers in both MD and GA, the solubility of the seasoning powder decreased significantly ($P < 0.05$). However, the differences among MD and GA ratio combinations were not statistically significant ($P > 0.05$). This can be explained by the effects of the carriers on the powder structure, which usually become denser and less porous after drying, thereby reducing the particles' surface area and water permeability [23]. At the same time, the high concentration of the carrier may reduce the bulk density and lead to a more compact particle structure, which significantly affects solubility [35]. Moreover, GA is characterized by its high molecular weight, which limits its solubility; therefore, excessive addition can reduce the dissolution rate or result in incomplete solubility of the powder [36]. In addition, a previous study on spray-dried apple juice powder noted that, among the produced samples, formulations containing GA as the carrier had higher moisture content than those prepared with MD. This may be attributed to the higher water-retention capacity of hydrocolloids relative to starch derivatives, thereby reducing the powder's solubility and increasing caking and stickiness, which decrease the surface area for contact and reduce particle porosity [37]. Therefore, determining an appropriate blending ratio of MD and GA is essential to ensure stable MC in the dried powder, minimize particle agglomeration, and maintain flowability and dispersibility when reconstituted in water [27].

3.1.4 Color

Table 2 presents the color index values under the influence of different carriers and their combinations. Significant differences ($P < 0.05$) were observed in L* and a* values in color parameters among samples with varying concentrations of MD and GA. For instance, powders containing MD exhibited higher L* values compared to those produced with GA. Conversely, powders produced with GA as the carrier displayed a darker color than those produced with MD. However, the combination of MD and GA did not have a significant effect on brightness or the red/green hue coordination values ($P > 0.05$). This difference may be attributed to the intrinsic color of the carriers, which affects the final product's color characteristics. The b* values of samples with higher GA concentrations were greater than those of the other samples. This difference can be attributed to the inherently reddish color of GA compared to MD. In a similar study, the effects of pectin type and concentration, GA, and MD as carriers for tamarind powder on color indices were investigated. Among the different carriers, powders produced with Whey Protein Concentrate (WPC) and GA exhibited higher a* and b* values [38]. Maillard reactions between reducing sugars may explain these color variations, as may the protein components present either in GA itself or in the raw material, which in this case was the concentrated extract of oyster mushrooms. Gum arabic is a mixture of glycoproteins and polysaccharides, with

protein content ranging from 1 to 3% [23]. However, the extent of non-enzymatic browning and the resulting color indices depend strongly on the drying chamber's processing time and temperature. A study by Shishir and Chen [24] reported that the increase in powder color was due to higher temperatures and intensified non-enzymatic browning reactions.

Table 2. Color observation at different mixing ratios between MD and GA of seasoning powder from oyster mushrooms

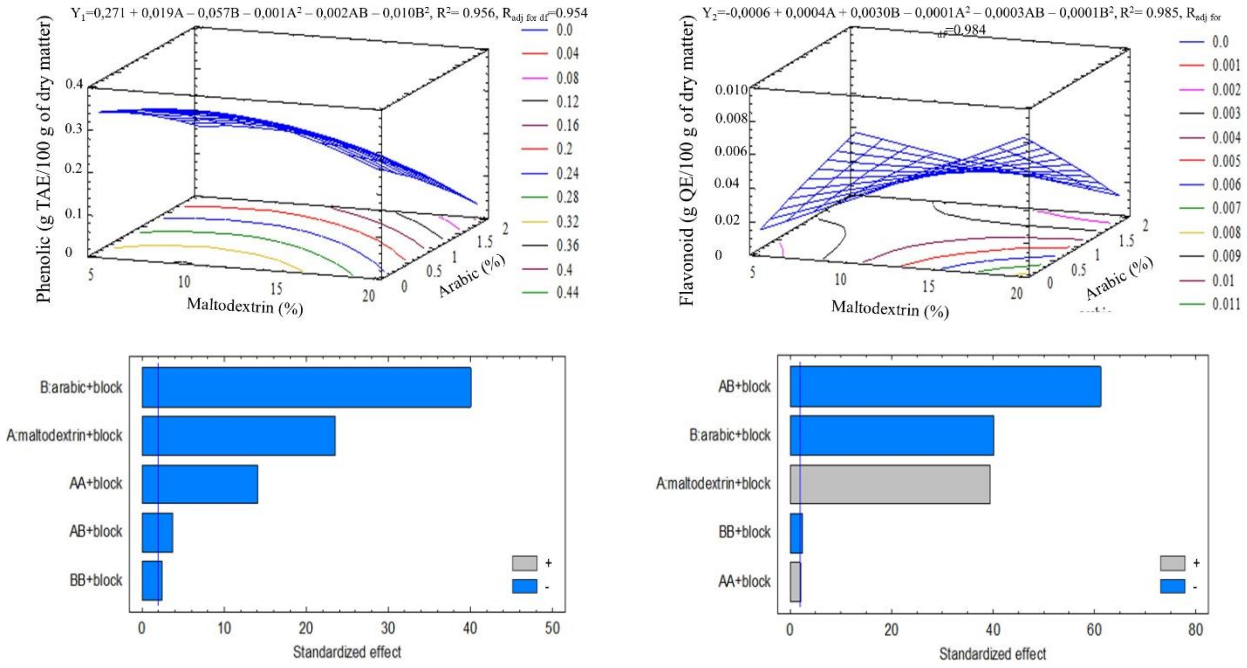
The ratio of MD (%)	**L**	**a**	**b**
5	64.03^{d}	-4.95^{a}	10.18^{a}
10	70.63^{b}	-5.54^{b}	10.46^{a}
15	69.15^{c}	-5.61^{b}	10.12^{a}
20	75.00^{a}	-6.22^{c}	9.65^{b}
Level of significance	**	**	NS
The ratio of GA (%)	**L**	**a**	**b**
0	66.83^{d}	-5.59^{c}	9.92^{ab}
0.5	65.68^{d}	-5.24^{a}	9.91^{b}
1.0	70.45^{c}	-5.41^{b}	10.05^{ab}
1.5	73.83^{a}	-5.90^{e}	10.23^{ab}
2	71.72^{b}	-5.75^{d}	10.39^{a}
Level of significance	**	**	NS
Significance level of interaction	NS	NS	**

The superscripts offer the statistical difference at 1% significance level; NS indicates no statistically significant difference at the 5% level ($P > 0.05$).

3.2 Effects of different mixing ratios between maltodextrin and gum arabic on the product's chemical properties

3.2.1 Phenolic compounds

The negative regression coefficients of both maltodextrin and gum arabic in all equations (first-order and second-order) indicate an inverse effect. As the concentration of either carrier or the combination of these two carriers increased, the phenolic compounds tended to decline (Figure 1). The highest phenolic content was recorded at 10% maltodextrin, and the lowest concentrations of gum arabic were 0.28 and 0.33, respectively. This trend indicated that using too much carrier above the optimal concentration can cause dilution, leading to a decrease in active compounds in the dry powder or an increase in solution viscosity. Moreover, prolonging the drying time leads to greater degradation of phenolic compounds [39,40]. Maltodextrin and gum arabic, when mixed with the extract, formed a matrix that encapsulated the phenolic molecules, thereby reducing their exposure to high temperatures and oxygen during the spray-drying process [41,42]. Maltodextrin is a commonly used carrier due to its low cost, high solubility at high solid concentrations, and its ability to increase the glass transition temperature of the dried product, reduce adhesion, and retain volatile compounds [43].



(a) Phenolic (b) Flavonoid

Figure 1. The content of phenolic and total flavonoid compounds at different mixing ratios between MD and GA

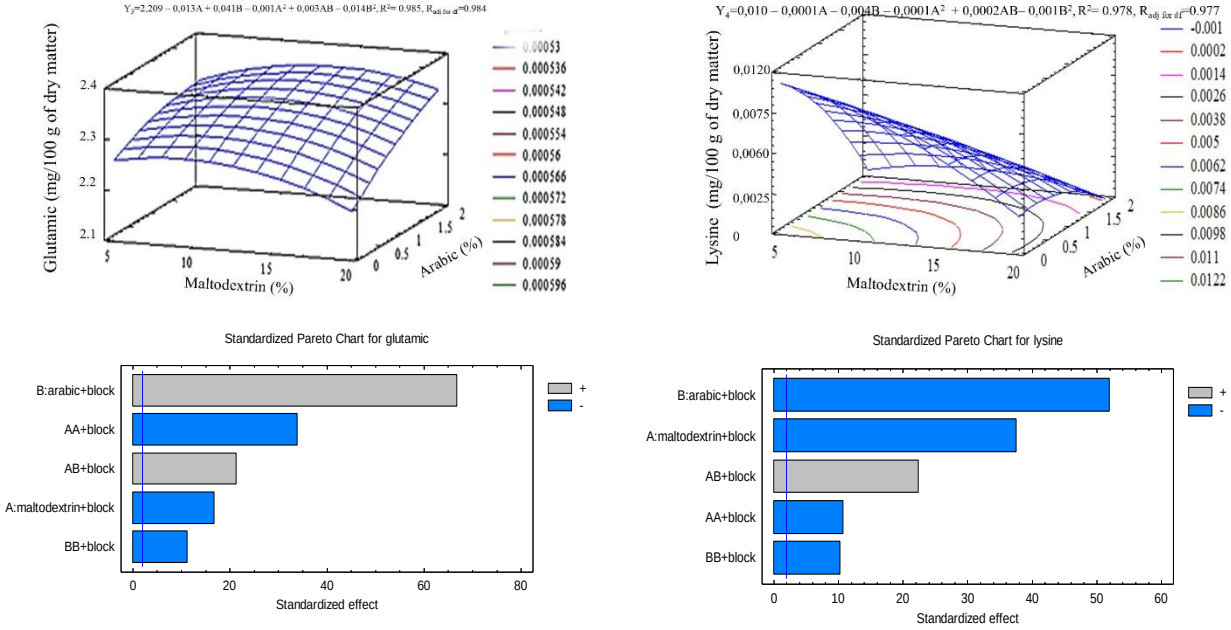
3.2.2 Flavonoid compounds

The regression equation for flavonoids showed a positive first-order coefficient for maltodextrin, indicating that increasing maltodextrin concentration significantly enhanced total flavonoid content after drying (Figure 1). This showed that maltodextrin has the ability to retain flavonoids during drying, due to its encapsulating and limiting exposure to high temperatures and oxygen. However, the first-order coefficient of gum arabic was negative, which indicated that further increases in its concentration caused a great loss in the flavonoid recovery. A similar trend was observed in the interaction between both carriers, indicating that the flavonoid level reached a maximum at the optimum point and then decreased with further increases in both carrier levels. Indeed, the maximum flavonoid content (approximately 0.0034 g QE/100 g) was obtained at 10% maltodextrin and 1% gum arabic. Both carriers had a statistically significant impact on flavonoids ($P < 0.05$). Specifically, maltodextrin creates a solid protective frame surrounding flavonoid molecules, preventing evaporation or interacting with oxygen, while gum arabic acts as a durable coating layer to support the efficiency of maltodextrin's mechanism [44]. Therefore, the highest flavonoid recovery after drying was obtained when integrating maltodextrin and gum arabic at their respective optimal levels. Previous studies have observed comparable protective effects of flavonoids when they were microencapsulated using polysaccharide-based carriers. For instance, Gomes et al. [45] found that spray-dried papaya powder supplemented with 14% MD contained significantly higher levels of polyphenols and flavonoids than freeze-dried papaya. This increase was attributed to the shorter drying duration, which effectively retained these compounds within the carrier matrix. However, if the concentration of gum arabic was too high, the flavonoids could be diluted, causing a decline in their content. The results clearly showed that using more than 1% gum arabic significantly reduced flavonoid content.

3.2.3 Glutamic acid

It is a non-essential amino acid, but is crucial for cellular metabolism, protein synthesis, and brain function, acting as an excitatory neurotransmitter involved in learning and memory [18]. The results indicate that the ratios of maltodextrin and gum arabic significantly influenced the glutamic acid content of the seasoning powder extracted from oyster mushrooms. The positive first-order regression coefficient for gum arabic in the equation indicates that, as concentration increased from low levels, the glutamic acid content

obtained after spray drying increased significantly (Figure 2). Results show that the addition of gum arabic effectively helped to limit the loss of glutamic acid content during drying due to its features as a good emulsifying and film-forming agent, helping to evenly coat the glutamic acid molecules in the microcapsules, before they undergo intramolecular cyclization to form pyroglutamic acid (5-oxoproline) or maillard reactions, especially under heat and low water activity [46]. However, maltodextrin and the combination of both carriers showed opposite influences (negative order coefficients), indicating that the concentrations continuously increased beyond the optimal degree of the carriers, while the glutamic acid content began to decrease (Figure 2). Excessive addition of carriers can cause a dilution effect, increase the viscosity of the extracted solution, prolong drying time, and accelerate glutamic acid degradation [39,40]. Especially, MD can trap water molecules for longer, leading to higher internal temperatures near the end of drying [33]. Indeed, glutamic acid content increased to an optimal value and subsequently declined with further increases in both carriers. Specifically, glutamic acid content reached its peak at 2.32 g/100 g dry matter with 10% maltodextrin and 2.34 mg/100 g dry matter with 1.5% gum arabic.



(a) Glutamic acid (b) Lysine

Figure 2. The content of glutamic acid and lysine at different mixing ratios between MD and GA

3.2.4. Lysine

The regression model showed that maltodextrin and gum arabic both negatively affected the obtained lysine content. While the positive interaction coefficient implies that the combination of these two carriers enhances lysine retention more effectively than using them individually, this effect was similar to that of the glutamic compound. In particular, with a relatively high concentration of maltodextrin and a small amount of gum arabic, lysine content was efficiently increased. The highest content was 0.0052 mg/100 g dry matter, obtained at a 10% maltodextrin and 1% gum arabic concentration. However, the negative quadratic coefficients for both carriers still indicated a tendency for lysine content to decrease with excessive carrier use. The findings were similar to prior relevant studies. Kurek & Pratap-Singh [47] and Pérez-Pérez et al. [48] reported that excessive single use of maltodextrin or gum arabic may dilute proteins and lead to lower lysine retention compared to more balanced carrier systems.

The mechanism by which the combination of GA and MD protects amino acid compounds is the formation of a polysaccharide matrix through hydrogen/ionic bonding with their polar regions, which keeps the amino acids within the matrix and reduces their direct exposure to oxygen and heat. This can lower the

rate of degradation or Maillard reactions involving glutamic and lysine [49]. However, the similarity in the results between glutamic and lysine contents showed that excessive carrier concentrations can enhance solidification and reduce moisture, but at the same time increase molecular mobility, which may facilitate the migration of hydrolyzed compounds to the capsule surface and decrease mechanical stability. In addition, too much carrier's supplement can dilute the amino acid, thereby reducing the encapsulation and core-protection efficiency, due to weaker matrix hardening, poorer structural homogeneity, or more pronounced reverse diffusion (from the core to the surface). In general, the results obtained are consistent with the microencapsulation theory, which states that the polysaccharide carriers create an outer layer that protects target compounds from degrading agents (heat, oxygen). However, it is necessary to optimize the amount of each carrier to ensure both protection efficiency and to avoid diluting the active ingredient content in the final product [50, 51].

3.2.5. β-glucan

Maltodextrin had positive interactions with the content of β-glucan in the seasoning powder after drying, the highest content was recorded at 15% of maltodextrin concentration with 8.77 mg/100 g dry matter, but when the concentration to 20%, β-glucan significantly reduced to 7.90 mg/100 g dry matter (Figure 3). This may be affected by the negative quadratic coefficients for both carriers (especially gum arabic), which still showed a tendency for β-glucan content to decrease with excessive carrier use. Especially, gum arabic: when the amount added exceeds 1%, the β-glucan content in the product decreased significantly from its highest value of 11.43 to 2.24 mg/100 g dry matter.

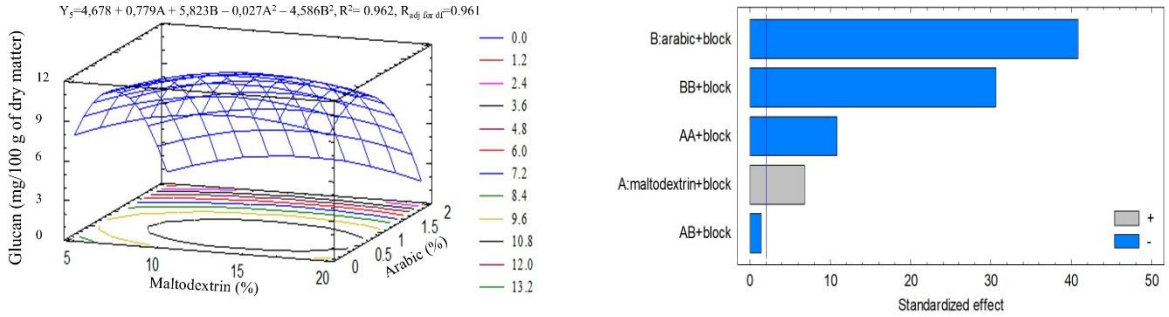


Figure 3. The content of β-glucan at different mixing ratios between MD and GA

During drying, β-glucan under high-temperature conditions may undergo chain scission, reducing molecular weight through thermal degradation. According to the analysis, maltodextrin showed a strong protective effect on β-glucan content, which is consistent with its characteristic. In particular, MD is a hydrophilic polysaccharide composed of D-glucose units primarily linked by α-(1→4) glycosidic bonds. The increase in β-glucan concentration in our microencapsulated samples may be due to the glucose units of MD interacting with the β-glucan functional groups in the powder during the coating process, thereby increasing the β-glucan content in the dried samples [27,52]. According to previous studies by Giang et al. [53, 54] on the bioactive compound content of oyster mushroom extracts, on a dry matter basis the levels of phenolics, flavonoids, β-glucan, lysine, and glutamic acid were reported as 5.74 g TAE, 0.73 g QE, 2.13 g, 8.28 mg, and 32.45 mg per 100 g dry matter, respectively. In comparison, the seasoning powder obtained in the present study still contained detectable amounts of these bioactive compounds, with corresponding values of 0.28 g TAE, 0.0034 g QE, 10.86 mg, 0.0052 mg, and 2.32 mg per 100 g dry matter. These results indicate a certain degree of reduction during processing. On a dry matter basis, the estimated retention ranged from approximately 0.5–5% for phenolics, flavonoids, and β-glucan, while glutamic acid showed a relatively higher retention of about 7%, supporting the functional and sensory relevance of the final product. These results indicate a certain degree of reduction during processing, which was not completely lost and remained detectable in the final product, confirming the retention of bioactive constituents. In particular, the presence of glutamic acid contributes not only to the nutritional value but also to the product's umami-related sensory properties, while the residual phenolic compounds and β-glucan suggest potential antioxidant and functional benefits. Therefore, despite the observed reductions compared with the original mushroom extract, the oyster

mushroom–based seasoning powder retains functional relevance as a value-added food product rather than serving solely as a flavoring agent. Furthermore, the product's physical properties, including color, water activity, and absorption capacity, meet the quality standards and microbiological safety requirements for seasoning granule products currently available on the market [55,56]. Along with the presence of bioactive compounds such as phenolics, flavonoids, and β-glucan, as well as a certain amount of naturally occurring amino acids (lysine and glutamic acid) extracted from oyster mushrooms, without the addition of synthetic monosodium glutamate (MSG). These findings demonstrate that the developed seasoning product not only ensures quality stability but also has strong potential to be developed as a natural and safe seasoning, aligning with current consumer trends toward functional foods and clean-label products.

4. Conclusions

At a 10% maltodextrin and 1% gum arabic mixing ratio, the dried powder showed the greatest benefit, resulting in powders with low stickiness and hygroscopicity, enhanced stability, and desirable functional properties. Notably, key bioactive compounds, including flavonoids, phenolics, lysine, glutamic acid, and β-glucan, were retained at the highest levels, with concentrations of 0.0034 g QE, 0.28 g TAE, 0.0052 mg, 2.32 mg, and 10.86 mg per 100 g dry matter, respectively. In terms of the physicochemical properties, the seasoning powder obtained after drying exhibited a relatively high recovery yield and solubility, reaching 14.86% and 93.76%, respectively. The product showed the highest brightness, as indicated by the L* color parameter, which was optimal compared to other mixing ratios. The water activity (a_w) of the seasoning powder was 0.42, indicating enzymatic and microbiological stability, with no total aerobic bacterial count detected. The study powder meets basic physicochemical standards and also exhibits considerable nutritional content and bioactive compounds. Future research is recommended to focus on comprehensive investigations of particle size distribution and morphological characteristics to elucidate the microencapsulation properties, storage stability, and practical applications of the product, particularly in relation to optimal usage levels and daily nutrient intake recommendations.

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