

Encapsulation of Red Chili Powder Using Arabic Gum as a Coating Agent

Dharia Renate^{1*}, Windika Pebryanti¹, Editha Renesteen²

¹Department of Agriculture Technology, University of Jambi, Jl. Raya Jambi-Muara Bulian, Km. 15 Mendalo Indah, Jambi 36361, Indonesia

²Faculty of Pharmasi, The Republic of Indonesia Defense University, Kawasan IPSC Sentul, Sukahati, Kec. Citeureup, Kabupaten Bogor, Jawa Barat 16810, Indonesia

*Corresponding author: Dharia Renate, Email: dhariarenate@unja.ac.id

Submitted: February 26, 2025; Revised: October 9, 2025, December 3, 2025;

Accepted: January 1, 2026; Published: February 27, 2026

ABSTRACT

Red chili (*Capsicum annum* L.) powder is highly susceptible to degradation due to the instability of capsaicin, its primary bioactive compound. Therefore, this study aims to evaluate the effect of Arabic gum concentrations as a coating agent on the physicochemical characteristics of encapsulated red chili powder. The study procedures were carried out using a Completely Randomized Design (CRD) with 6 levels of Arabic gum concentration, such as 0% as a control, 0.3%, 0.6%, 0.9%, 1.2% and 1.5%. Data were then analyzed using Analysis of Variance (ANOVA) at the 1% and 5% levels to determine the effect among treatments. Subsequently, the analysis was followed by Duncan's New Multiple Range Test (DNMRT) at the 5% significant level. The results showed that Arabic gum significantly affected encapsulation performance. The optimal treatment was obtained at 0.9% Arabic gum, with a yield of 74.01% and color parameters of L 33.07, a* 19.33, and b* 14.33. Moisture content, solubility, encapsulated capsaicin (CE), total capsaicin (CT), and encapsulation efficiency were 12.83%, 83.61%, 0.73 mg/g, 7.85 mg/g, and 9.26%, respectively. In conclusion, the use of Arabic gum at a concentration of 0.9% effectively enhanced physical and chemical stability of red chili powder through improved encapsulation characteristics. These results confirm its potential as a functional encapsulating agent in spice powder formulation, particularly for applications in food and nutraceutical industries.

Keywords: Arabic gum; encapsulation; capsaicin; curly red chili powder; physicochemical properties

INTRODUCTION

Curly red chili (*Capsicum annum* L.) is widely cultivated in Indonesia and valued for its distinctive pungency, aroma, and red pigment, making it essential in the food industry as a seasoning, natural colorant, and functional ingredient (Novitasari, 2018; Ahmad et al., 2021). However, the fresh curly red chili contains more than 90% water, making it highly perishable with a postharvest loss rate reaching up to 40% (Anjayani &

Ambarwati, 2021). This significant loss shows the need for proper postharvest handling and processing technologies to extend shelf life and maintain product quality.

According to previous studies, curly red chili contains the active compound *capsaicin* at 0.430-0.923 mg/g (Ferniah et al., 2018), which is unstable, volatile, and easily degradable during the storage process (Renate et al., 2014). One of the key bioactive compounds in red chili is capsaicin, a phenolic alkaloid responsible for its spiciness and biological activity. Capsaicin has

shown antioxidant, antimicrobial, and anti-inflammatory properties that are valuable in functional foods and health-related applications (da Silva Anthero et al., 2022; Timilsena et al., 2020). However, it is thermolabile and highly sensitive to oxidation, light, and moisture during drying and storage, which leads to significant degradation and loss of functionality over time (Ferniah et al., 2018; Renate et al., 2014). Therefore, further technology is needed to protect it from damage through encapsulation techniques (Palupi et al., 2014).

Encapsulation is widely applied to protect sensitive bioactive compounds, such as capsaicin from degradation during processing and storage (Aminah & Hersoelistyorini, 2021). One of the popular encapsulation methods is coagulation, which has the advantage of being relatively cheap, easy to use, and able to produce capsules that preserve, enhance efficiency, and support controlled release of the core substance (Napiórkowska & Kurek, 2022).

Several studies have reported the use of various encapsulating agents for curly red chili or capsaicin. Palupi et al., (2014) used 5% sodium alginate combined with photo-oxidized tapioca starch that has been exposed to light-induced oxidation to enhance its film-forming properties, resulting in a moderate encapsulation efficiency value of 29.409%. Another study on red chili powder by Rosida et al., (2019) using Arabic gum, maltodextrin coating agents (90:10), and 25% powdered red chili resulted in an efficiency of 64.436%. However, the study did not explore the individual contribution of Arabic gum.

The process of encapsulating active compounds, such as sensitive capsaicin, requires a biodegradable coating material that can form a film layer encasing the core material. The material must also be able to mix with the core substance chemically without any chemical reaction (Mahmudah, 2015). The concentration of coating material plays an important role in encapsulation process. A high concentration increases the emulsion viscosity, making atomization more difficult and potentially causing wall matrix deformation, such as puffing, ballooning, or cracking (Zen et al., 2021). These results suggest that Arabic gum has potential as encapsulation agent for curly red chili powder, but its concentration-dependent effects have not been systematically evaluated. Previous studies often employed Arabic gum in combination with other agents, leaving a gap in understanding its sole performance in encapsulating capsaicin. Therefore, a focused investigation is needed to examine the specific impact of its concentration on encapsulation efficiency, stability, and capsaicin preservation in curly red chili powder.

Arabic gum, a natural complex polysaccharide composed mainly of arabinogalactan protein (AGP),

has been frequently used as encapsulating agent due to its excellent emulsifying, film-forming, and water-soluble properties (Idrus, 2013; Napiórkowska & Kurek, 2022). The amphiphilic structure of the material enables it to stabilize emulsions and form protective barriers around core materials. The combination of Arabic gum and Alginate (0.8%:1.5% w/v) in Abdin et al., (2021) produced encapsulation efficiency of 91.17% for anthocyanin extract. However, the effect of varying Arabic gum concentrations on encapsulation performance of curly red chili powder has not been thoroughly studied. Although the agent has emulsifying properties, this study did not evaluate emulsion stability or droplet size directly. The main focus was on encapsulation performance based on physicochemical parameters, such as moisture content, solubility, yield, color values, capsaicin content, and encapsulation efficiency. Therefore, this study aims to evaluate the effect of Arabic gum concentration as a coating agent on physicochemical characteristics of encapsulated curly red chili powder and to identify the optimal concentration that yields the highest encapsulation efficiency, stability, and capsaicin retention.

METHODS

Materials

The raw materials used in this study included fresh curly red chili (TM99 variety, Indonesia) with several specifications, namely average length of 10 to 12 cm, weight of 8 to 10 g per fruit, bright red color at full maturity, and harvested at 80 to 85 days after planting. These specifications were selected to ensure the consistency and quality of capsaicin content. Other materials included aquadest (Smart Lab, Indonesia), sodium alginate (Sigma-Aldrich, St. Louis, MO, USA), CaCl_2 0.1 M (Merck, Germany), Arabic gum (Sigma-Aldrich), standard capsaicin (EMD Millipore, USA), and absolute ethanol (Merck, Germany).

Tools used included oven (Memmert, Germany), color reader (Lovibond, China), 60 mesh sieves (BBS, Indonesia), blender (Philips, Netherland), analytical scales (Ohaus, United States of America), syringe (Terumo, Indonesia), beaker cups (Iwaki, Indonesia), measuring cups (Iwaki, Indonesia), measuring flasks (Iwaki, Indonesia), hot plate stirrer (B-One, United States of America), filter paper No.42 (Whatman, Britain) and UV-Vis spectrophotometer (Labomed Inc, United States of America).

Study Design

The study design followed a Completely Randomized Design (CRD), using different concentrations of Arabic

gum (% b/v) as treatments. Each treatment was repeated 3 times, producing 18 experimental samples overall.

P₀ = No Addition of Arabic Gum

P₁ = 0.3% Arabic Gum (Arabic gum 0.3 g into 100 mL of aquadest solvent)

P₂ = 0.6% Arabic Gum (Arabic gum 0.6 g into 100 mL of aquadest solvent)

P₃ = 0.9% Arabic Gum (Arabic gum 1.5 g into 100 mL of aquadest solvent)

P₄ = 1.2% Arabic Gum (Arabic gum 1.2 g into 100 mL of aquadest solvent)

P₅ = 1.5% Arabic Gum (Arabic gum 1.5 g into 100 mL of aquadest solvent)

Curly Red Chili Powder Method

Fresh curly red chili were cleaned, sorted, and their stems were removed. Chili was dried in an oven at 65 °C for 7 hours, then ground and sieved to obtain curly red chili powder with a mesh size of 60. The resulting powder exhibited a moisture content of approximately 13%, which was consistent with the results of Murti (2017) under similar drying conditions (Murti, 2017).

Encapsulation Method

Encapsulation materials used comprised Arabic gum with concentrations of 0.3, 0.6, 0.9, 1.2, and 1.5 g, sodium alginate 1.5 g, and 1 g of curly red chili powder. Furthermore, the process began by heating 100 mL of aquadest prepared in a 500 mL volume beaker glass using a hot plate stirrer. Arabic Gum was added based on the treatment levels and stirred at 65 °C until fully dissolved. Subsequently, this mixture was left to stand at ambient conditions for half an hour. Alginate was added at a fixed concentration to all treatments and stirred with a magnetic stirrer until homogeneous. This formulation approach followed the complex coacervation method used by Palupi et al. (2014). Arabic gum concentration functioned as the sole variable in this study, while

alginate remained unchanged for every formulation. The control treatment contained only sodium alginate without the addition of Arabic gum. Furthermore, red chili powder was added and stirred until homogeneous. Approximately 100 mL of CaCl₂ 0.1 M was prepared in a 500 mL beaker and stirred using a magnetic stirrer. A 0.1 M calcium chloride (CaCl₂) solution was used as a crosslinking agent to induce gelation between sodium alginate and calcium ions, following the complex coacervation method adapted from Palupi et al. (2014). This concentration was selected to ensure sufficient crosslinking for bead formation without causing structural brittleness. The solution of encapsulated curly red chili powder was put into a syringe and dripped into CaCl₂ solution to ensure that beads were produced, and after the drip was completed, it was left to stir for 5 minutes. Subsequently, the solution was filtered with a stainless steel strainer. Beads were placed on aluminum foil on a baking sheet and placed in a 45 °C oven to dry for 5 hours. These dried encapsulated curly red chili powder beads were packed in plastic ziplock bags and stored at room temperature in a sealed desiccator to prevent moisture absorption before further analysis (Palupi et al., 2014). The formulation for making powdered curly red chili encapsulation was found in Table 1.

Yield

Encapsulation yield was calculated by comparing the dry weight of encapsulated curly red chili powder to the total weight of the initial encapsulating materials, multiplied by 100% (Palupi et al., 2014). The dry weight was obtained by correcting the final encapsulated weight with moisture content using the Equation 1.

$$\text{Yield (\%)} = \frac{\text{Encapsulate weight} - (\text{Encapsulate weight} \times \text{moisture content})}{\text{total weight of encapsulating materials}} \times 100\% \quad (1)$$

This parameter reflected the process efficiency in converting the initial formulation into a dry powder,

Table 1. Curly red chili powder encapsulated formulation

Treatment	Encapsulation materials			Aquadest (mL)	CaCl ₂ 0.1 M (mL)
	Arabic gum (g)	Alginate (g)	Red chili powder (g)		
P ₀	0	1.5	1	100	100
P ₁	0.3	1.5	1	100	100
P ₂	0.6	1.5	1	100	100
P ₃	0.9	1.5	1	100	100
P ₄	1.2	1.5	1	100	100
P ₅	1.5	1.5	1	100	100

excluding water content, which was essential in determining encapsulation performance and process effectiveness.

Moisture Content

Moisture content of encapsulated chili powder was assessed by the oven-drying method. Aluminum dish was preheated at 105 °C for 1 hour, cooled in a desiccator for 15 minutes, and weighed to obtain the dish weight. A 1 g sample of encapsulated curly red chili powder was then added, and the dish was weighed again to obtain the initial sample weight. The sample was dried in an oven at 105 °C for 3 hours, cooled in a desiccator for 15 minutes, and reweighed. Furthermore, the drying process was repeated in 30-minute intervals until a constant weight was reached. Moisture content was determined based on the weight loss and reported as a percentage (AOAC, 2005).

Solubility

Solubility of encapsulated red chili powder was evaluated using the gravimetric approach, calculated from the undissolved residue's weight remaining on the surface of filter paper. Initially, the filter paper underwent pre-drying at 105 °C for 30 minutes. A 1 g sample of encapsulate was dissolved in 100 mL of distilled water, then filtered using the pretreated filter paper. After filtration, the paper containing the residue was oven-dried at 105 °C for an hour and subsequently set in a desiccator for 15 minutes. The final weight of the filter paper with the retained residue was then recorded (AOAC, 1984). The formula of the solubility using Equation 2.

$$\text{Solubility (\%)} = \frac{\text{final weight (g)} - \text{filter paper weight (g)}}{\frac{100 - \text{moisture content}}{100} \times \text{starting weight}} \times 100\% \quad (2)$$

Color

Color analysis of encapsulated curly red chili powder was conducted using a color reader (Lovibond, China). Before measurement, the device was calibrated following standard procedures. Color reader was operated by pressing the power and LAB buttons. The L^* , a^* , and b^* values were then recorded for each sample. The resulting color attributes were interpreted using the ColorHexa web tool (Good, 2002).

Capsaicin Content

Encapsulated curly red chili powder that has been ground was taken as much as 0.25 g dissolved in 25 mL of absolute ethanol, then filtered to produce the filtrate. Subsequently, the filtrate was diluted with distilled water to a final volume of 50 mL. The amount of encapsulated capsaicin (C_T) was determined by

considering a dilution factor of 200 times. For the total capsaicin content (C_T), 0.1 g of encapsulated chili powder was dissolved in absolute ethanol and diluted to 100 mL in a measuring flask with a dilution factor of 1000 times. A 5 mL aliquot of each sample was then analyzed using a spectrophotometer set to a wavelength of 280 nm (Palupi et al., 2014). The formula of the capcaisin content using Equation 3.

$$\text{Capsaicin content (\%)} = \frac{\text{Abs} \times \text{BM} \times \text{FP} \times \text{V} \times 10^{-3} (\text{L})}{\epsilon \times t \times w (\text{g})} \times 100\% \quad (3)$$

Where: Abs = Absorbance, BM = Molecular weight capsaicin 305.41×10^3 (mg/mol), FP = Dilution Factor, V = Sample volume in cuvettes 5 mL, ϵ = The absolute ethanol molar coefficient at (λ 280 nm) 175000 (L/cm.mol), t = High absorbance solution 1 cm, and w = Sample weight (g).

Encapsulation Efficiency

Encapsulation efficiency or EE was calculated by comparing the level of capsaicin successfully extracted from encapsulated powder with the total capsaicin content, using absolute ethanol as the extraction solvent in Equation 5 (Yang et al., 2014).

$$\text{EE (\%)} = \frac{\text{Encapsulated Capsaicin Level}}{\text{total capsaicin level}} \times 100\% \quad (5)$$

Data Analysis

The results acquired from the tests underwent analysis with Analysis of Variance (ANOVA) at a significance level of 1% and 5%. Significant differences were further assessed using Duncan's New Multiple Range Test (DNMRT) at the 5% significance level.

RESULTS AND DISCUSSION

Yield of Encapsulated Curly Red Chili Powder

The yield of encapsulated curly red chili powder was significantly affected by the concentration of Arabic gum used as a wall material ($F_{cal} > F_{table}$ at the 1% level), as presented in Table 2. Based on DNMRT test ($p < 0.05$), the yield at a 1.2% Arabic gum concentration did not significantly differ from those at 0.6% and 0.9%, but it was significantly different from the 0%, 0.3%, and 1.5% concentrations. Compared to the control (0%), encapsulate yield at 0.3%, 0.6%, 0.9%, 1.2%, and 1.5% concentrations decreased by 6.83%, 8.73%, 10.11%, 9.98%, and 15.41%, respectively. The decrease in yield showed that the presence of Arabic gum slightly reduced material recovery, due to increased wall thickness and retention of liquid in the matrix.

Table 2. Average yield, moisture content, and solubility data of encapsulated red chili powder with various arabic gum concentrations

Concentration of arabic gum	Encapsulated powder yield (%)	Moisture content of encapsulated powder (%)	Solubility of encapsulated powder (%)
0%	82.33±0.39 ^d	13.88±0.54 ^d	78.73±0.85 ^a
0.3%	76.71±1.41 ^c	12.92±0.42 ^{cd}	81.82±0.34 ^{cd}
0.6%	75.13±1.37 ^{bc}	11.90±0.69 ^{bc}	82.33±0.66 ^{cd}
0.9%	74.01±1.33 ^b	12.83±0.27 ^{bc}	83.61±0.54 ^d
1.2%	74.10±0.65 ^b	10.79±0.60 ^a	81.60±0.62 ^c
1.5%	69.64±0.29 ^a	12.67±0.64 ^{bc}	80.14±0.92 ^b

Note: Values within the same row marked with different letters showed a significantly different ($p > 0.05$)

The decrease in yield was caused by the high viscosity of Arabic gum, ensuring that it interfered with the atomization process and resulted in the formation of large and long droplets. This caused the drying speed to decrease to ensure that encapsulated yield decreased (Zen et al., 2021). The high viscosity of Arabic gum was due to its having arabinogalactan protein (AGP) and glycoprotein (GP) groups that acted as emulsifiers and thickeners (Zen et al., 2021).

A similar decline in encapsulation yield with increasing wall material was observed by Khasanah et al. (2015) in cinnamon leaf oleoresin microcapsules using maltodextrin and gum Arabic, where higher coating material content led to increased viscosity and lower recovery. Furthermore, Palupi et al. (2014) reported that the coacervation method using alginate and oxidized tapioca also showed reduced yields at higher wall material concentrations due to aggregation and loss during bead formation. Zen et al. (2021) found that high concentrations of coating agents could trap excess moisture or cause inefficient film formation, reducing the recovery of encapsulated turmeric extract.

These results showed that optimal concentrations were essential to achieve a balance between matrix stability and recovery efficiency. In this study, the 0.3–0.9% Arabic gum range resulted in a higher yield than 1.5%, suggesting that moderate gum addition was more effective for encapsulation using the coacervation method.

While Arabic gum was beneficial for improving encapsulation integrity and bioactive protection, this result showed a trade-off between improved matrix functionality and recovery efficiency. Therefore, yield alone could not be used as a sole indicator of encapsulation success but must be interpreted alongside encapsulation efficiency (EE) and core retention indicators such as capsaicin content.

The addition of Arabic gum increased the viscosity of encapsulation solution, which could have interfered with the sedimentation process or caused partial loss of the microcapsules during separation steps. Similar results were reported by Palupi et al. (2014), who emphasized that coacervation efficiency was influenced by the viscosity of the wall material solution.

Moisture Content of Encapsulated Curly Red Chili Powder

Moisture content was a crucial parameter in evaluating the quality and stability of encapsulated powders, specifically in terms of shelf life and microbial safety. As shown in Table 2, moisture content of encapsulated curly red chili powder varied significantly with different concentrations of Arabic gum. The results from DNMRT test at the 5% significance level suggested that moisture content at 0% Arabic gum concentration (without any Arabic gum) was not significantly different from those at concentrations of 0.3%, 0.6%, 0.9%, and 1.5%, but it differed significantly from the 1.2% Arabic gum concentration.

Overall, moisture content tended to decrease with rising Arabic gum concentra containing 0.3%–1.2% Arabic gum exhibited lower moisture levels, indicating improved drying performance. However, at 1.5%, a slight increase in moisture (12.67%) was observed, suggesting that overly viscous matrices could hinder water evaporation during the drying process. This decrease was attributed to the formation of a denser, less porous encapsulation matrix by Arabic gum, which promoted more efficient water release during drying (Khasanah et al., 2015).

Arabic gum's complex molecular structure and hydrophilic branching groups enhanced water interaction during encapsulation but also contributed to improved drying when the matrix became compact

(Abdin et al., 2021). At Arabic gum concentration of 1.2%, encapsulation matrix became denser and less porous, facilitating more efficient water release during the drying process. This resulted in lower residual moisture content in the final product. However, at 1.5%, moisture content slightly increased (12.67%), likely due to excessive viscosity and hindered evaporation. Low moisture content values could slow the growth of microorganisms and contribute to a decrease in the rate of degradation of encapsulated compounds (da Silva Anthero et al., 2022).

Moisture content was a critical parameter affecting powder stability, particularly in relation to shelf life and microbial growth. In this study, moisture content decreased with increasing Arabic gum concentration, with the lowest value recorded at the 1.2% treatment (Table 2). This suggested that Arabic gum improved the drying efficiency of encapsulated material, possibly by creating a more cohesive and less porous matrix that retained less water.

These results were consistent with Palupi et al. (2014), where wall materials with good film-forming ability contributed to lower residual moisture content and improved powder flowability. Therefore, the observed moisture values confirmed that encapsulation system used in this study was appropriate for producing microbiologically stable powder products with acceptable shelf life. Similarly, Khasanah et al. (2015) found that increasing gum concentrations reduced water retention up to a point, beyond which too much gum caused encapsulation inefficiencies. In another study, Zen et al. (2021) noted that lower water content in encapsulated turmeric powder improved powder handling and prevented microbial growth.

The decreased moisture content observed in this study supported the effectiveness of Arabic gum in forming protective, stable encapsulation matrices under the coacervation method. Low residual moisture ensured

longer shelf life, less stickiness, and reduced risk of degradation or microbial spoilage.

Solubility of Encapsulated Curly Red Chili

Solubility was related to the capability of the powder to be dispersed in water (da Silva Anthero et al., 2022). In this study, solubility reflected the powder ability to disperse rapidly and completely in water, indicating good matrix integrity and low cross-linking density. Solubility was significantly influenced by Arabic gum concentration ($F_{cal} > F_{table}$ at 1%), with the highest value recorded at 0.9% (Table 2). For solubility, the increase compared to control was 3.93% (0.3%), 4.57% (0.6%), and 6.20% (0.9%), showing that moderate gum concentration enhanced powder rehydration. However, at 1.2% and 1.5%, solubility dropped slightly, possibly due to excess coating material inhibiting dispersibility.

The high solubility observed at 0.9% Arabic gum suggested that the wall material formed a well-balanced structure, enabling efficient hydration and dissolution. This trend suggested that Arabic gum enhanced powder solubility by improving the hydrophilicity and dispersibility of encapsulating matrix. Its function as an emulsifier and film-forming agent enabled the formation of porous, water-accessible structures that facilitated dissolution. This result was consistent with Rosida et al. (2019), who demonstrated that Arabic gum improved the solubility and reconstitution behavior of microencapsulated chili powder. Higher solubility was essential to ensure efficient release of core bioactive compounds, particularly capsaicin, during application in food formulations (Zen et al., 2021).

Color of Encapsulated Curly Red Chili Powder

ANOVA showed that the L^* , a^* , b^* color parameters of encapsulated curly red chili powder were significantly

Table 3. Color attributes (L^* , a^* , b^*) of encapsulated red chili powder with various concentrations of arabic gum concentration

Concentration of arabic gum	Value		
	L^*	a^*	b^*
0%	36.5±0.40 ^c	23.23±0.15 ^b	17.57±0.31 ^b
0.3%	31.36±0.72 ^{ab}	18.30±1.3 ^a	12.30±1.32 ^a
0.6%	31.60±1.15 ^{ab}	21.50±1.39 ^b	14.13±1.59 ^a
0.9%	33.07±2.35 ^a	19.33±2.15 ^{ab}	14.33±0.67 ^a
1.2%	30.40±0.70 ^b	19.27±0.57 ^{ab}	13.03±1.11 ^a
1.5%	32.20±2.90 ^{ab}	18.43±1.07 ^{ab}	13.53±1.98 ^a

Note: Values within the same row marked with different letters show a significantly different ($p > 0.05$)

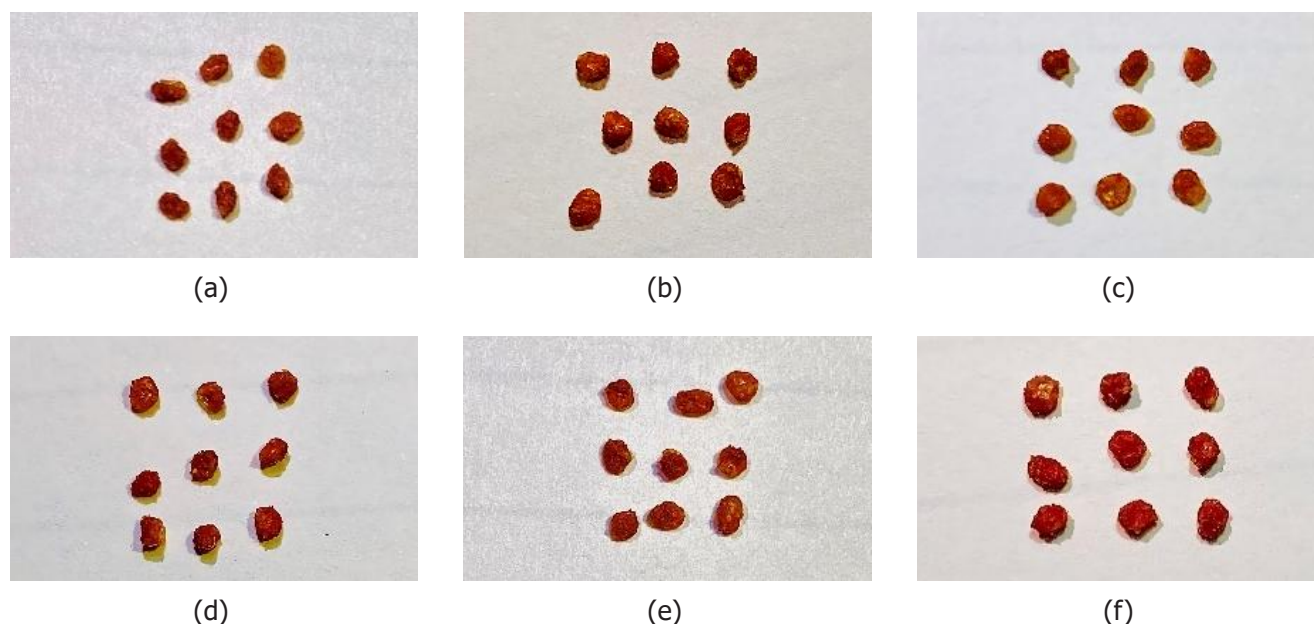


Figure 1. Visual appearance of encapsulated curly red chili powder at different Arabic gum concentrations: (a) 0%, (b) 0.3%, (c) 0.6%, (d) 0.9%, (e) 1.2%, and (f) 1.5%.

influenced by the varying concentrations of Arabic gum ($F_{cal} > F_{table}$ at 1%), as shown in Table 3.

L* Value (brightness)

L* color intensity showed a brightness level or brightness that ranged from 0 to 100. When the number was closer to 0 means that a darker color and numbers up to 100 will display a brighter color (Rosida et al., 2019). In this study, increasing Arabic gum concentration was associated with a decrease in L* values, suggesting that encapsulated powder became darker with more coating material.

As shown in Table 3, variations in Arabic gum concentration significantly influenced the L* value of encapsulated red chili powder. According to the results of DNMRT at the 5% significance level, the L* value at 0% Arabic gum (control) differed significantly from those obtained with concentrations of 0.3%, 0.6%, 0.9%, 1.2% and 1.5%. This decrease was attributed to the increased deposition of wall material, which thickened the outer matrix layer and reduced surface reflectance. The thicker the layer formed during coacervation, the more light was absorbed rather than reflected, leading to a darker visual appearance.

This trend was consistent with results by Palupi et al. (2014), who observed that the brightness of encapsulated red chili powder decreased as the thickness of the alginate–tapioca oxidate coating increased. Similarly, Rosida et al. (2019) reported that

turmeric powder encapsulated with polysaccharide-based materials exhibited lower L* values due to pigment entrapment and lower light scattering.

From a technological standpoint, darker powder color was still acceptable for applications where visual intensity was desired, such as spicy flavor blends or concentrated pastes. However, lower L* values could limit the use of such powders in products requiring bright visual appeal, such as seasoning sachets or dry soup mixes. The sample with 0% Arabic gum retained the brightest color ($L^* = 36.5$), while 1.2% Arabic gum yielded the darkest ($L^* = 30.40$), reflecting this trade-off.

a* Value (redness)

a* value represented the redness intensity of a color, where higher values showed more intense red hues (Rosida et al., 2019). In this study, Arabic gum concentration had a limited effect on a* value of encapsulated red chili powder. As shown in Table 3, a* value for the control (0%) was 23.23, and ranged between 18.30 and 21.50 for the treated samples.

According to DNMRT analysis at the 5% significance level, only the 0.3% Arabic gum treatment showed a significant difference from the control, while the other treatments (0.6%, 0.9%, 1.2%, and 1.5%) were statistically similar. This suggested that Arabic gum concentration did not drastically alter the redness of the powder, except at very low levels.

The preservation of a* values across treatments showed that Arabic gum acted as a protective coating,

minimizing the degradation of red pigments such as capsanthin and capsorubin during the drying process. These results were supported by Zen et al. (2021), noting that encapsulation using biopolymers such as Arabic gum maintained pigment integrity under thermal conditions.

Rosida et al. (2019) demonstrated that Arabic gum's film-forming capability limited oxidative degradation of carotenoids, while Palupi et al. (2014) found that biopolymer encapsulation reduced thermal damage to red pigments. Although the a^* values in this study were slightly lower than those reported by Zen et al. (2021) in spray-dried microcapsules, the use of oven drying in this process explained this difference in pigment retention efficiency.

Although there was a slight decrease in redness with increasing Arabic gum concentration, the values remained in an acceptable visual range for powdered red chili products. As a result, this consistency was important for ensuring product color stability and consumer appeal, particularly when the powder was used as a coloring or flavoring agent in food applications. This was crucial for ensuring consumer appeal and consistent visual quality in spice-based powder products.

b^* Value (yellowish)

b^* value represented the yellowness of the powder, where higher values indicated a stronger yellow hue (Rosida et al., 2019). In this study, b^* value of encapsulated red chili powder ranged from 12.30 to 17.57, showing that the control (0%) treatment had the highest yellowness, while gum-treated samples exhibited slightly lower and more stable values (Table 3).

Based on DNMRRT follow-up test at the 5% significance level, b^* value at a 0.3% Arabic gum concentration was not significantly different from those

at concentrations of 0.6%, 0.9%, 1.2%, and 1.5%, but it was significantly different from the control (0% Arabic gum). Although there was no consistent upward or downward trend, the treatments with 0.6% and 0.9% Arabic gum showed a moderate increase in b^* compared to the lowest value at 0.3%. This variation suggested that Arabic gum influenced the final color attributes by partially masking or altering the natural carotenoid content, possibly due to its intrinsic opacity and color (Noviyani et al., 2022).

The stabilization of b values across treatments reflected the role of Arabic gum in limiting thermal degradation of carotenoid pigments. In red chili (*Capsicum spp.*), carotenoids such as capsanthin and capsorubin were the principal red pigments, while carotenoids, including lutein and β -carotene, contributed to the yellow component of the color. Similar protective effects of polysaccharide wall materials on pigment retention were reported for encapsulated red chili (Palupi et al., 2014), and gum arab was also shown to improve retention of heat-sensitive compounds in other matrices (e.g., phenolics in cocoa extracts; Zen et al., 2021).

The addition of Arabic gum concentration did not differ significantly from the value of b^* encapsulation of red chili powder. Arabic gum, as a coating material, formed texture and film, as well as bound and emulsified well. This was to ensure that Arabic gum maintained the yellow color pigment of powdered red chili by protecting the core material from the process of destructive change (Zen et al., 2021).

Capsaicin Levels of Encapsulated Curly Red Chili Powder

Capsaicin was the principal bioactive compound in red chili, responsible for its pungency and therapeutic potential. In encapsulated products, the retention of

Table 4. Data analysis of encapsulated capsaicin (C_E), total capsaicin (C_T), and encapsulation efficiency (EE) of red chili encapsulated powder with increased arabic gum concentration

Concentration of arabic gum	C_E (mg/g)	C_T (mg/g)	Encapsulation efficiency (%)
0%	0.87±0.02 ^c	11.52±0.44 ^e	7.53±0.43 ^a
0.3%	0.84±0.02 ^c	10.41±0.37 ^d	8.09±0.08 ^{ab}
0.6%	0.77±0.03 ^{bc}	8.64±0.30 ^c	8.94±0.09 ^b
0.9%	0.73±0.06 ^b	7.85±0.38 ^b	9.26±0.41 ^b
1.2%	0.63±0.06 ^a	7.16±0.33 ^a	8.84±0.63 ^b
1.5%	0.59±0.02 ^a	7.36±0.21 ^{ab}	7.98±0.54 ^a

Note: - Values in the same row with different letters are significantly different ($p > 0.05$).

- C_E indicates the level of capsaicin encapsulated.

- C_T shows total levels of capsaicin.

capsaicin was critical to ensure both functional and sensory quality. In this study, 3 parameters, namely Encapsulated Capsaicin (C_E), Total Capsaicin (C_T), and Encapsulation Efficiency (EE), were used to evaluate the effectiveness of encapsulation process. Their interrelation provided insight into how well the matrix traps and protects capsaicin during drying.

In Table 4, it was evident that variations in Arabic gum concentration significantly influenced both encapsulated capsaicin content (C_E) and the total capsaicin content (C_T) in encapsulated curly red chili powder. The data showed that the C_E value peaked at 0.3% (0.84 mg/g) and then decreased progressively at higher concentrations. Similarly, C_T values declined from 11.52 mg/g in the control to 7.16 mg/g at 1.2%, showing a loss of total capsaicin as Arabic gum concentration increased. Arabic gum has a high viscosity, during the drying process, it made the formed skin layer firm, ensuring that the core material was protected (Rosida et al., 2019).

Encapsulated capsaicin (C_E) was the amount of capsaicin trapped inside the capsule matrix. Products with a high C_E showed that capsaicin was well protected by coating material (Rosida et al., 2019). The core material that was not perfectly encapsulated remained on the surface of the matrix wall (Timilsena et al., 2020). Total capsaicin (C_T) referred to the total capsaicin present in encapsulation product, both inside the matrix and on the surface of the capsule wall. Arabic gum as a coating agent formed a film and provided good binding and emulsifying properties, enabling it to protect the core material from degradation (Zen et al., 2021).

Although higher Arabic gum concentrations (0.6–1.2%) increased the amount of wall material, the total capsaicin content (C_T) significantly decreased. This was attributed to dilution effects, increased matrix thickness leading to uneven drying, or the possible degradation of capsaicin during thermal processing at higher viscosity levels. Furthermore, when C_T declined while EE remained relatively stable or decreased slightly, it implied that the actual amount of capsaicin retained in the beads was reduced, not only encapsulation efficiency.

The lowest capsaicin content observed in the control treatment, which lacked Arabic gum, showed higher susceptibility to degradation due to insufficient encapsulant protection. This result was consistent with Palupi et al. (2014), who reported that encapsulation materials with higher matrix integrity could better retain heat-sensitive compounds. Therefore, increasing Arabic gum concentration enhanced encapsulation matrix and improved chemical stability of capsaicin, contributing to the functional value of the powder for food applications.

The highest C_E was observed at 0.3% Arabic gum concentration, suggesting that this formulation produced the most efficient entrapment of capsaicin in the matrix. This could be due to an optimal wall-to-core ratio that allowed proper droplet formation and network solidification during coacervation. At this level, the matrix was likely sufficiently dense to encapsulate active compounds without excessive viscosity that could hinder proper mixing or droplet formation.

Encapsulation Efficiency of Encapsulated Curly Red Chili

Encapsulation efficiency was a key indicator of the success of encapsulation process, representing the proportion of bioactive compounds successfully trapped in the wall matrix relative to the total core material. A higher EE showed a more effective barrier against environmental degradation and greater functional stability of the final product (da Silva Anthero et al., 2022).

The high percentage of encapsulation efficiency that occurred functioned optimally (Zen et al., 2021). A low encapsulation efficiency compromised the stability of the product, as the active compounds were less protected against environmental factors during storage. Therefore, recent studies on micro- and nanoencapsulation in food science prioritized enhancing encapsulation efficiency and prolonging shelf life (Zabot et al., 2022).

In this study, Arabic gum concentration had a significant effect on EE ($F_{cal} > F_{able}$ at 1%), with values ranging between 6.59% and 9.26% (Table 4). The highest EE was achieved at 0.9% Arabic gum, which did not differ significantly from 0.3%, 0.6%, and 1.2%, but was significantly higher than both the control (0%) and the 1.5% treatment.

The increase in EE up to 0.9% could be attributed to Arabic gum's excellent emulsifying and film-forming properties. Its branched polysaccharide structure supported the formation of a dense matrix capable of entrapping core compounds efficiently during coacervation. At moderate concentrations, this structure allowed for stable emulsions and efficient bead formation, thereby minimizing capsaicin diffusion during drying (Palupi et al., 2014; Rosida et al., 2019). Abdin et al. (2021) noted that the highest encapsulation efficiency of anthocyanin extract encapsulation was achieved with a value of 91.17% at a concentration of sodium alginate and Arabic gum of 1.5:0.8 g/100 mL.

A decline in encapsulation efficiency (EE) was observed at 1.5% Arabic gum. This decline could be mechanistically explained by an excessive increase in solution viscosity at high gum concentrations, which impaired effective emulsification and droplet

formation during coacervation, leading to irregular wall development and greater capsule porosity. In turn, such structural heterogeneity limited moisture release during drying and promoted active compound loss, reducing capsaicin retention. These mechanisms were supported by prior observations that formulation viscosity and wall-material proportion strongly influenced bead formation and core retention (Palupi et al., 2014; Abdin et al., 2021). The highest encapsulation efficiency of anthocyanin extract encapsulation, with a value reported that the effect of gum arab on retention of heat-sensitive constituents depended on both matrix composition and processing conditions (Zen et al., 2021). Therefore, increasing coating concentration did not linearly improve EE, instead, an optimal wall-to-core ratio was required to balance matrix cohesiveness and processing efficiency.

These results suggested that EE was not simply enhanced by increasing coating material concentration. An optimal gum level was essential to balance matrix cohesiveness and processing efficiency. This was consistent with previous studies (Abdin et al., 2021; Zen et al., 2021), emphasizing that excessively viscous encapsulant solutions impaired structural uniformity and led to reduced core retention.

In summary, 0.9% Arabic gum provided the most effective encapsulation system for capsaicin in curly red chili powder, combining high retention with efficient matrix formation. Maintaining this balance was essential for developing encapsulated products with high bioactive stability and extended shelf life.

CONCLUSION

In conclusion, the concentration of Arabic gum as a coating agent influences various encapsulation characteristics of red chili powder, including yield, moisture content, solubility, color parameters (L , a , b^*), capsaicin content, and encapsulation efficiency (EE). Arabic gum coating agent with a concentration of 0.9% is the treatment that exhibits the best characteristics with a yield value of 74.01%; L^* 33.07; value a^* 19.33; value b^* 14.33; moisture content 12.83%; solubility 83.61%; capsaicin encapsulated (C_E) 0.73 mg/g; total capsaicin (C_T) 7.85 mg/g; and encapsulation efficiency 9.26%. These results show that the use of Arabic gum at optimal concentration improves encapsulation performance, offering potential for application in spice powder processing industries to enhance product shelf-life and preserve the stability of bioactive compounds such as capsaicin during storage and distribution. The results emphasize the importance of optimizing wall material concentrations

to achieve desirable encapsulation outcomes. The implications of this study extend to the food industry, where microencapsulation using Arabic gum was used to protect sensitive bioactive compounds like capsaicin, extend shelf life, and enhance the functional properties of powdered food products intended for storage and commercial distribution.

ACKNOWLEDGEMENT

This research is private funding, we deeply appreciate to the Laboratory Research Assistant of Food Technology Department of University of Jambi for its generous support towards our research. This has enabled us to conduct our research more smoothly and achieve better results. We aspire to see our research outcomes positively impact both the realm of science and society at large.

CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding any part of this article.

REFERENCES

- Abdin, M., Salama, M. A., Gawad, R. M. A., Fathi, M. A., & Alnadari, F. (2021). Two-Steps of Gelation System Enhanced the Stability of Syzygium cumini Anthocyanins by Encapsulation with Sodium Alginate, Maltodextrin, Chitosan and Gum Arabic. *Journal of Polymers and the Environment*, 29(11), 3679–3692. <https://doi.org/10.1007/s10924-021-02140-3>
- Ahmad, N. I., Bunga, Y. N., & Bare, Y. (2021). Etnobotani Tanaman Cabai Merah Keriting (*Capsicum Annum L.*) Di Desa Waiwuring, Kecamatan Witihamu Kabupaten Flores Timur. *Spizaetus: Jurnal Biologi Dan Pendidikan Biologi*, 2(2), 8–17. <https://doi.org/10.55241/spibio.v2i2.46>
- Anjayani, D., & Ambarwati, E. (2021). Mutu dan Daya Simpan Buah Cabai Merah (*Capsicum annum L.*) sebagai Tanggapan terhadap Berbagai Jenis Pupuk Hayati. *Vegetalika*, 10(3), 159. <https://doi.org/10.22146/veg.47817>
- da Silva Anthero, A. G., Munhoz Moya, A. M. T., Torsoni, A. S., Cazarin, C. B. B., & Hubinger, M. D. (2022). Characterization of Capsicum oleoresin microparticles and in vivo evaluation of short-term capsaicin intake. *Food Chemistry: X*, 13, 1–12. <https://doi.org/10.1016/j.fochx.2021.100179>
- Ferniah, R. S., Pujiyanto, S., & Kusumaningrum, H. P. (2018). Indonesian red chilli (*Capsicum annum L.*) capsaicin

- and its correlation with their responses to pathogenic *Fusarium oxysporum*. *NICHE Journal of Tropical Biology*, 1(2), 7. <https://doi.org/10.14710/niche.1.2.7-12>
- Good, H. (2002). *Color Measurement of Cereal and Cereal Products*.
- Idrus, S. (2013). Mikroenkapsulasi Minyak Ikan Yang Mengandung Asam Lemak Omega-3 Menggunakan Gum Arab Sebagai Bahan Pelapis. *Majalah Biam*, 9(1), 23–29.
- Khasanah, L., Umi, Anandhito, B. K., Rachmawaty, T., Utami, R., & Manuhara, G. J. (2015). Pengaruh Rasio Bahan Penyalut Maltodekstrin, Gum Arab, Dan Susu Skim Terhadap Karakteristik Fisik Dan Kimia Mikrokapsul Oleoresin Daun Kayu Manis (*Cinnamomum burmannii*). *Jurnal Agritech*, 35(04), 414. <https://doi.org/10.22146/agritech.9325>
- Mahmudah, N. L. (2015). Enkapsulasi Minyak Mawar (*Rosa damascena* Mill.) Dengan Penyalut B-Siklodekstrin Dan B-Siklodekstrin Terasetilasi. In *Skripsi. Jurusan Kimia. Fakultas Matematika dan Ilmu Pengetahuan Alam. Universitas Negeri Semarang*.
- Murti, K. H. (2017). Pengaruh Suhu Pengeringan Terhadap Kandungan Vitamin C Buah Cabai Keriting Lado F1 (*Capsicum Annuum* L.). *Jurnal Keteknik Pertanian Tropis Dan Biosistem*, 5(3), 245–256. <https://jkptb.ub.ac.id/index.php/jkptb/article/view/434/363>
- Napiórkowska, A., & Kurek, M. (2022). Coacervation as a Novel Method of Microencapsulation of Essential Oils—A Review. *Molecules*, 27(16). <https://doi.org/10.3390/molecules27165142>
- Novitasari, R. (2018). Studi Pembuatan Pikel Cabai Keriting Utuh (*Capsicum annuum* var. *glabiusculum*). *Teknologi Pertanian*, 7(1), 33–45.
- Noviyani, T., Wartini, N. M., & Harsojuwono, B. A. (2022). Effect Of Comparison Of Maltodextrin And Gum Arabic On The Characteristics Of Cassava Leaf (*Manihot esculenta* C.) Encapsulate Colorante Extract. *Jurnal Rekayasa Dan Manajemen Agroindustri*, 11(1), 1–13.
- Palupi, N. W., Setiadi, P. K. J., & Yuwanti, S. (2014). Enkapsulasi Cabai Merah dengan Teknik Coacervation Menggunakan Alginat yang Disubstitusi dengan Tapioka Terfotooksidasi. In *Jurnal Aplikasi Teknologi Pangan* (Vol. 3, Issue 3). www.journal.ift.or.id
- Renate, D., Pratama, F., Yuliati, K., & Priyanto, G. (2014). Model Kinetika Degradasi Capsaicin Cabai Merah Giling Pada Berbagai Kondisi Suhu Penyimpanan. *Jurnal Agritech*, 34(03), 330–336. <https://doi.org/10.22146/agritech.9462>
- Rosida, D. F., Dewi, A. E. Y., & Elianarni, D. (2019). Characteristics of Chili Powder (*Capsicum Frutescens* L.) with Maltodextrin Encapsulants from Starch of White Yam (*Dioscorea Alata*) The Making of Maltodextrin of. *Proceedings Of the 16th ASEAN Food Conference (16th AFC 2019) - Outlook and Opportunities Of Food Technology and Culinary For Tourism Industry*, 19–25. <https://doi.org/10.5220/0009984100002964>
- Timilsena, Y. P., Haque, A., & Adhikari, B. (2020). *Encapsulation in the Food Industry: A Brief Historical Overview to Recent Developments*. 11, 481–508. <https://doi.org/10.4236/fns.2020.116035>
- Zabot, G. L., Schaefer Rodrigues, F., Ody, L. P., Tres, M. V., Herrera, E., Palacin, H., Córdova-Ramos, J. S., Best, I., & Olivera-Montenegro, L. (2022). Encapsulation of Bioactive Compounds for Food and Agricultural Applications. In *Polymers* (Vol. 14, Issue 19, pp. 1–37). MDPI. <https://doi.org/10.3390/polym14194194>
- Zen, M. B., Ganda Putra, G. P., & Suhendra, L. (2021). Karakteristik Enkapsulat Ekstrak Kulit Buah Kakao (*Theobroma cacao* L.) pada Perlakuan Variasi Jenis dan Konsentrasi Bahan Penyalut. *Jurnal Rekayasa Dan Manajemen Agroindustri*, 9(3), 356. <https://doi.org/10.24843/jrma.2021.v09.i03.p09>