INDONESIAN FOOD SCIENCE AND TECHNOLOGY JOURNAL (IFSTJ)

Journal homepage : online-journal.unja.ac.id/ifstj/issue/archive

Microencapsulation by Spray Drying of *Cosmos caudatus* Kunth Extract Using Gum Arabic: Influencing Factors and Controlled Release

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***Abstract*: Advanced drug delivery systems are required due to the increasing advancement in science and technology, with a common example being microencapsulation. This system is affected by the manufacturing conditions and slow release of bioactive compounds inside microcapsule. In general, phytochemicals in the edible plant, *Cosmos caudatus* Kunth, specifically flavonoids, offer several health benefits but are susceptible to degradation which reduces biological activities. Therefore, this study aimed to encapsulate extract using spray drying method, which can be used as wall material in Gum Arabic. Microencapsulated product was also tested for biological activities. The effect of microcapsule production was investigated, including the concentration of wall material and the stirring speed. Furthermore, the optimal conditions of microcapsule were selected based on the highest encapsulation efficiency. The results showed that a concentration of 4% (w/v) Gum Arabic and a stirring speed of 800 rpm were the optimal conditions, leading to a percentage release of 71.87%. Microcapsule under these conditions produced an IC_{50} value of 55.09 ± 0.57 µg/mL as an inhibitor of alpha-amylase enzyme. The characterization by scanning electron microscope (SEM) showed spherical forms with a mean diameter of 152.00 µm. The bioactive substance in microcapsule was released at pH 2.2 and pH 7.4 for 30 to 120 min, with a percentage release of 38.05% and 95.14%, respectively. In conclusion, this study confirmed that microencapsulation played a crucial role in the development of plant extract with retained biological functions.**

***Keywords*: *Cosmos caudatus* Kunth; Gum Arabic; microencapsulation; release; SEM**

Manuscript received April 29, 2024; revised Oct 18, 2024; accepted Nov 19, 2024. Available online December 28, 2024

I. INTRODUCTION

Diabetes mellitus (DM) is a metabolic disorder caused by elevated blood sugar levels that leads to inadequate insulin secretion in the pancreas, commonly known as hyperglycemia [1; 2]. Data from the International Diabetes Federation shows that the incidence of people impacted by DM is increasing each year. In 2030, DM cases are expected to reach 578 million patients, and 700 million in 2045 [3]. An effective solution to overcome the disease is by inhibiting the action of alpha-amylase enzyme, which hydrolyzes carbohydrates, thereby reducing glucose absorption [4]. One of the inhibitors used is the synthetic drug acarbose [5; 6], which has several side effects, including discomfort in the stomach, diarrhea, and bloating [7; 8]. However, this problem can be addressed by exploring alternative treatments, such as incorporating herbal plants into complementary therapies [9]. Herbal plants contain bioactive compounds that offer various health benefits, including enzyme inhibition associated with DM without causing adverse effects. The availability of herbal plants in developing countries has led to extensive investigations into the use. As reported in various studies, one promising antidiabetic herbal plant is *Cosmos caudatus* Kunth [10].

C. caudatus K. is often used as a food complement in Indonesia due to the characteristic aroma and taste. The compounds

contained include phenolics, alkaloids, tannins, polyphenols, flavones, flavanones, essential oils, and flavonoids [11; 12]. In general, flavonoids are used as antidiabetic agents, which can reduce glucose absorption, leading to the inhibition of alpha-amylase enzyme in the hydrolyzing carbohydrates [13, 14]. The common problem often faced in the use of natural ingredients as drugs is bioavailability in the body. Flavonoids are often degraded by gastric acid and digestive enzymes, hence, a particular method is needed to protect the core compound from external factors [15]. In this context, microencapsulation technology can be used to avoid adverse effects caused by environmental factors [16; 17].

Microencapsulation acts to protect the core material of bioactive compounds, such as flavonoids in the form of solids, liquids, or gasses, by using coating in the form of microparticles [18, 19]. Spray drying method is often used because it can dry materials that are not resistant to high temperatures, such as flavonoids [20]. Several factors, such as the choice of a coating material influence microcapsule in manufacturing. Coating material in microencapsulation must have properties that provide a layer but cannot react with the main compound [21]. In general, gum Arabic is often used as an encapsulation material due to the high fiber content, probiotic effects, and low-calorie value. It is a mixture of polysaccharides and glycoproteins that are the main sources of ribose and arabinose [22]. Some properties of the properties include high viscosity compared to maltodextrin, which can enhance the viscosity of the coated compounds [23]. Furthermore, Gum Arabic has other several properties such as high solubility, making it suitable for protecting volatile compounds when used as coating material [24; 25]. The concentration of coating material used must also be considered because it can affect the characteristics of microcapsule [16; 26]. The higher the concentration of coating material, the more perfect the formation of coating wall in microencapsulation process. The stirring speed also affects the interfacial tension in the final result of microencapsulation process. The faster the stirring time, the smaller the interfacial tension, leading to a smaller droplet size [16].

Microcapsule release is determined by evaluating the number of active compounds released under highly acidic (pH 1–3) and physiological conditions (pH 7.4) [27; 28]. Microencapsulation process using spray drying method was investigated as part of this study. Several variables were applied to determine the ideal microcapsule conditions, including the concentration of Gum Arabic and the stirring time. The effectiveness of microcapsule for the treatment of type 2 DM was evaluated through alpha-amylase inhibition assay performed under optimal conditions. Studies on inhibiting the activity of alpha-amylase enzyme have also not been carried out using microencapsulation of *C. caudatus* K. with Gum Arabic as coating material. A previous study was conducted on microencapsulation of *C. caudatus* K. using chitosan-NaTPP with alpha-amylase enzyme inhibition value of 92.85 ± 1.21 µg/mL[10]. The use of Gum Arabic with emulsifying properties is expected to provide better protection for the core material when used as alpha-amylase inhibitor, resulting in a lower IC_{50} value. Therefore, this study aimed to investigate the effect of using Gum Arabic concentration and stirring speed on the potential of *C. caudatus* K. as an antidiabetic agent based on the results of alpha-amylase enzyme inhibition activity.

II. MATERIAL AND METHODS

A. Material and Instrumentation

In this study, the materials used include specifically soluble starch (ACS grade) derived from potatoes, acarbose (95%), alpha-amylase enzyme of type *Aspergillus oryzae* (Merck, 150 units/mg protein), and glacial acetic acid (pharmaceutical primary standard). Other materials include Gum Arabic (from the acacia tree, branched polysaccharide), D-(+) glucose (analytical standard), 3,5-dinitro salicylic acid (DNS) reagent (98%, HPLC grade), sodium hydroxide (98%, pellets, anhydrous), sodium acetate (Merck, analytical standard 99%), sodium sulfite (98%), potassium sodium tartrate tetrahydrate (99%), quercetin (95% HPLC, solid) and ascorbic acid (pharmaceutical secondary standard). The powdered *C. caudatus* K. leaves were collected on board by UPT Materia Medica Batu, East Java, Indonesia, with a species determination letter. Furthermore, several instruments were used for this study, namely Fourier transform infrared spectrometer (FTIR with type Shimadzu Prestige 21), UV-Vis spectrophotometer (Shimadzu), scanning electron microscope (SEM with TM 3000 Hitachi), particle size analyzer (PSA with CILAS 1090), and spray dryer (Buchi).

B. Methods

Extract Preparation

C. caudatus K. powder was weighed up to 250 g, then 400 mL of 96% ethyl alcohol was added. The mixture was stirred and allowed to stand for 72 hours at room temperature in a tightly closed condition. Furthermore, the maceration solution was processed using a rotary evaporator under vacuum conditions with a temperature set to vaporize at 68°C and a speed of 110 rpm to obtain ethanol extract of *C. caudatus* K. [10].

Microencapsulation Process

Ethanol extract of *C. caudatus* K. (0.1 g) was dissolved in 5 mL of 96% ethyl alcohol and stirred until a homogenous mixture was obtained. Subsequently, 50 mL of Gum Arabic solution with concentration variations of 2%, 4%, 6%, and 8% (w/v) was also added by stirring at various speeds of 600, 800, 1000, and 1200 rpm) for 90 min. The colloidal microcapsule was dried using spray dryer (Buchi) with an inlet temperature of 105°C, outlet temperature of 85°C, and air pressure of 1 bar to obtain microcapsule in powder form [29].

Determination of Total Flavonoids Content (TFC)

Ethanol extract of *C. caudatus* K. was weighed at 0.1 g, dissolved in 2 mL methanol, and incubated at 40°C for 45 min. The solution was then centrifuged for 10 min to separate the supernatant from the mixture. About 1.2 mL of supernatant was added with 1.2 ml of 2% $AlCl_3$. Furthermore, the two solutions were homogenized and incubated for 60 min at 25°C. UV-VIS spectrophotometers recorded the absorbance at wavelength 420 nm after incubation. The calculation of flavonoids was based on the standard quercetin curve expressed in milligrams of quercetin (QE)/g of sample [30].

Encapsulation Efficiency Calculation

The optimal conditions for microcapsule were stated in encapsulation efficiency with the formula [28]:
EE (%) = (TFC Microcapsule/TFC Extract) x 100%.....(1)

Information:
TFC = Total Flavonoids Content

Alpha Amylase Inhibition Assay

Each sample, including *C. caudatus* K. ethanol extract, microcapsule, and acarbose, was prepared with various concentrations of 20, 40, 60, 80, and 100 µg/mL. About 250 µL solution was added to a test tube to add 250 µL of alpha-amylase enzyme at a concentration of 50 µg/mL concentration. The solution was then incubated at 37°C for 30 min, added with 250 µL 1% starch solution (w/v), and further incubated for 10 min at 25°C. About 500 µL of DNS reagent was added to each test tube with different concentrations and incubated using boiling water for 5 min until the solution turned brownish red. After incubation, cooling was carried out at room temperature followed by the addition of 5 mL distilled water. The solution can be homogenized, and the absorbance can be measured at a wavelength of 490 nm. The absorbance value obtained can be used to calculate the percent inhibition with the formula:

$$\text{Inhibition (\%)} = \frac{\text{Absorbance control} - \text{Absorbance sample}}{\text{Absorbance control}} \; x \; 100\% \; (2)$$

Controlled absorbance refers to the measurement of enzyme activity without an inhibitor. In this study, the absorbance measurement was used to assess the enzyme activity of *C. caudatus* K. ethanol extract, microcapsule, and acarbose inhibitor. Subsequently, a correlation curve was made between the percentage of inhibition and the concentration A linear regression equation was then obtained, which was calculated as the IC_{50} value [10].

Characterization of Microcapsule

The characterization of *C. caudatus* K. ethanol extract and microcapsule under optimal conditions was conducted using SEM. Meanwhile, to determine the morphology of the sample, FTIR spectrophotometer was used at wavenumbers 4000-400 cm^{-1}. Particle size distribution of microcapsule was determined using PSA.

Release Assay

Release of flavonoids from microcapsule was investigated under two different media conditions. Initially, 0.005 g of microcapsule were immersed in a mixture comprising 5 mL of phosphate-buffered saline solution with HCl (pH 2.2, mimicking gastric conditions) and 5 mL of a mixture of phosphate-buffered saline solution with NaOH (pH 7.4, simulating small intestine conditions). Microcapsule was then incubated at 37°C for 120 min with a steady stirring rate of 100 rpm. The samples were subjected to a specific examination at the scheduled intervals of 30, 60, 90, and 120 min. The percentage of release was determined according to Eq. 3 by comparing TFC released with the total in microcapsule. The experiment was carried out in triplicate [29].

Release (%) =

$$\frac{Total\ flavonoid\ compound\ released}{Total\ flavonoid\ compound\ in\ microcapsules} \; x \; 100\% \ldots (3)$$

Data Analysis

Data analysis was conducted using SPSS software version 26. Normality and homogeneity tests were performed on the samples, while One-way Analysis of Variance (ANOVA) was conducted with a confidence level of 95% (alpha > 0.05). Post hoc Tukey's test was used to determine significant differences, with a value of $p < 0.05$ considered statistically significant.

III. RESULT AND DISCUSSION

Microencapsulation Process

The ratio between coating material and the active compound influences microencapsulation process as it affects the formation of a layer between the polymer and the core material, leading to higher efficiency [16]. A higher concentration of Gum Arabic as a coating increases viscosity. Gum Arabic is a coating material with emulsifying properties due to the composition of polysaccharides and glycoproteins, leading to hydrophilic and hydrophobic polypeptide chains that stabilize the emulsion [25]. Increasing the concentration enhances the formed emulsion, resulting in a thicker solution. **Figure 1** shows the impact of Gum Arabic concentration on microencapsulation efficiency. The higher the concentration, the greater the microencapsulation efficiency, as observed in the increase from 2% to 4%. This enhancement is attributed to Gum Arabic emulsifying properties, leading to increased viscosity. The high viscosity of coating layer protects the core material during drying, forming more stable microcapsule and a strong shell [31].

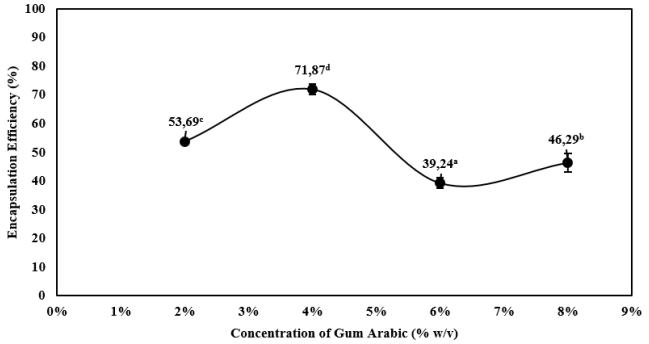

Figure 1. The curve of the relationship between the concentration of Gum Arabic and the efficiency of encapsulation. Different notation (a, b, c, and d) indicates significant differences at the α = 0.05.

High concentrations of Gum Arabic, at 6% and 8% decreased flavonoids compared to 4%. This is because the increased viscosity of the emulsion inhibits the atomization process during spray drying, causing a significant amount of bioactive compound to remain unencapsulated and to be lost through evaporation [32]. At high concentrations, the emulsion becomes less stable, leading to inadequate protection of microcapsule, which makes the core compounds prone to evaporation [33]. The determination of concentration is important to adjust the concentration appropriately to achieve optimal protection. An extremely low concentration may lead to imperfect or fragile coating formation, reducing encapsulation efficiency. On the other hand, an extremely high concentration inhibits the atomization process during drying [34].

Another factor that influences microcapsule results is the stirring speed, affecting the size of the particles formed. The lower the speed, the larger the particle size of microcapsule and vice versa. When the stirring speed is faster, particle size becomes smaller, and this affects compounds contained in microencapsulation, which will return to the environment [35]. This increase in microencapsulation efficiency can be attributed to the size produced after spray drying. **Figure 2** shows the relationship between stirring speed and encapsulation efficiency. There was an increase in speed between 600 and 800 rpm because the ability of coating to trap the core compound of the active drug ingredient requires energy, in this case, stirring. When the energy required decreases, the ability of coating to trap the active ingredients will decrease as well as microencapsulation efficiency. Slow stirring leads to the formation of large droplets after heating, indicating an incomplete reaction [36].

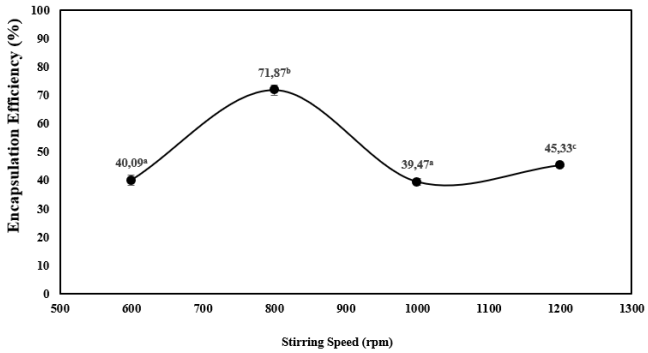

Figure 2. The curve of the relationship between the stirring speed and the encapsulation efficiency. Different notation (a, b, and c) indicates significant differences at the α = 0.05.

Excessive speeds, such as 1000 and 1200 rpm, may reduce microencapsulation efficiency. The increased stirring speed and impact frequency due to faster speeds lead to release of the treated compound back into the solvent. In addition, excessively rapid stirring may result in irregular microcapsule with gaps and lead to the loss or disappearance of a core compound. Speed influences the formation of emulsions and stability. When stirring is faster than usual, the temperature increases, which affects a decrease in viscosity and increased collision. Decreased viscosity leads to less protection of the core compound, and reduced encapsulation efficiency [37].

Alpha Amylase Inhibition Assay

Three types of samples were used to test the inhibitory effect of alpha-amylase enzyme namely C. *caudatus* K., ethanol extract, microcapsule, and acarbose used to demonstrate anti-diabetic activity. **Table 1** shows the results of the inhibitory activity of alpha-amylase enzyme, indicated by the value of IC_{50}.

TABLE 1
IC_{50} VALUE OF EACH INHIBITOR SAMPLE

Sample	**IC_{50} (μg/mL)***
C. caudatus K. ethanol extract	46.96 ± 0.91^{a}
Microcapsule of *C. caudatus* K. extract	55.09 ± 0.57^{b}
Acarbose	34.33 ± 0.15^{c}

*Different letter notation (a, b, and c) indicates significant differences in each sample for the α = 0.05.

The lower the IC_{50} value of the inhibitor, the greater the ability to inhibit alpha-amylase enzyme [38]. Data in **Table 1** showed that the value obtained for microcapsule inhibitor under optimum conditions was greater than the control acarbose and extract. The different conditions are because acarbose is an important oligosaccharide compound that inhibits alpha-amylase activity in the pancreas. Therefore, it has a structure similar to that of substrate [39]. On the basis of the structure, the formation of glucose and maltose in the starch hydrolysis process can be inhibited by the active side of acarbose, namely the presence of a carboxyl group and a nitrogen group, effectively inhibiting enzyme activity [40]. In the ethanol

extract, various secondary metabolites suitable as antidiabetic compounds were found, leading to a higher IC_{50} value compared to acarbose. Compounds such as kaempferol, luteolin, apigenin, myricetin, and specifically quercetin, play a role in lowering blood sugar levels in type 2 DM patients [41]. With these compound contents, *C. caudatus* K. ethanol extract has an effect in inhibiting the activity of alpha-amylase enzyme in the hydrolysis process, potentially serving as an inhibitor.

IC_{50} value in microcapsule was higher compared to the ethanol extract and acarbose. This is due to the bioactive compounds that are not fully released from microcapsule, correlating with the imperfect encapsulation efficiency. Some hydroxyl groups in flavonoids, which function to inhibit alpha-amylase enzyme, may bind to Gum Arabic coating during spray drying process. Therefore, the enzyme inhibition ability decreases due to the reduction of active hydroxyl groups [42]. Inhibition of alpha-amylase enzyme by flavonoids in extract can occur through hydroxylation and substitution binding on the beta ring. Hydroxyl groups on rings A and B of flavonoids enhance enzyme inhibition effect, where C3' and C4' groups on ring B interact with the active site through hydrogen bonding. Oxygen from the C3' and C4' hydroxyl groups on ring B binds to the enzyme active site, while C3 on ring C interacts with the substrate site. The glucose level decreases because alpha-amylase enzyme is inhibited [43]. The main purpose of microcapsule production is to protect and control the release of active compounds, not to increase activity. Therefore, microcapsule is expected to protect the core material in the stomach phase and release completely in the intestinal phase to be used as an antidiabetic agent.

Characterization of Microcapsule with FTIR, SEM, and PSA

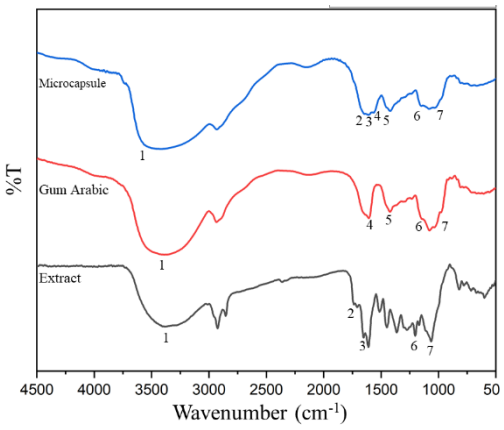

Figure 3. FTIR spectra of: microcapsule under optimal conditions, Gum Arabic, and ethanol extract of *C. caudatus* K.

Figure 3 shows FTIR analysis results for *C. caudatus* K. extract, Gum Arabic, and microcapsule. The peak wavenumbers obtained are presented in **Table 2**. FTIR spectra show strong and broad absorption peaks at wavenumbers of 3385.83 cm^{-1} (extract), 3374.42 cm^{-1} (Gum Arabic), and 3412.92 cm^{-1} (microcapsule) (peak 1). The wavenumbers obtained represent vibrations of hydrogen bonds. The shift indicates the formation of bonds between coating material and extract. The wavenumbers associated with C=O (1651-1737 cm^{-1}) and C=C (1610.19 cm^{-1}) functional groups from extract correspond to flavonoids (peaks 2 and 3). These wavenumbers were also found in microcapsule with C=O (1644.42 cm^{-1}) and C=C (1611.62 cm^{-1}), which experienced a shift compared to extract. Additionally, the absorption intensity was weaker in microcapsule compared to extract. Characteristic absorption peaks of Gum Arabic coating were observed at wavenumbers of 1607.34 cm^{-1} and 1421.93 cm^{-1}, representing the COO carboxylate functional groups (peaks 4 and 5). In microcapsule, these peaks were present at wavenumbers of 1565.98 cm^{-1} and 1420.51 cm^{-1}, indicating the encapsulation process. Peak 7 is characteristic of long polysaccharide bonds and serves as a fingerprint region with wavenumbers 1065.38-818.65 cm^{-1} (extract), 1036.86-805.81 cm^{-1} (Gum Arabic), and 1079.64-1032.58 cm^{-1} (microcapsule). This can be inferred from the peaks formed, indicating a coating process based on the shift in wavenumbers between extract and microcapsule. The difference in absorption intensity is due to the formation of new bonds between functional groups and the formation of new groups from Gum Arabic coating. The similarity in absorption peaks suggests that microcapsule contain bioactive compounds from extract, while the differences indicate encapsulation process has occurred.

TABLE 2
FTIR SPECTRA

No	Wavenumber (cm^{-1})			Functional groups [44; 45]
	Extract	Gum Arabic	Microcapsule	
1	3385.83	3374.42	3412.92	-O-H stretching Alcohols
2	1651-1737	-	1644.42	C=O carbonyl flavonoids
3	1610.19	-	1611.62	C=C stretching aromatics
4	-	1607.34	1565.98	COO-asymmetric stretching carboxylates
5	-	1421.93	1420.51	COO-symmetric stretching carboxylates
6	1363.46	1232.25	1149.53	C-O stretching alcohols
7	818.65 - 1065.38	805.81 - 1036.86	1032.58 - 1079.64	C-O-C stretching ethers

Figure 4 shows SEM images of extract and microcapsule produced under optimal conditions (4% Gum Arabic concentration and 800 rpm stirring speed). The results indicated that the surface analysis of microcapsule was uneven and had indentations with imperfect round shapes. The imperfectly round shape of microcapsule may be influenced by the choice of drying method and coating material used. Similar shapes

were found in other studies that examined the effect of drying method on microcapsule morphology. Spray drying leads to a more rounded shape of microcapsule compared to freeze-drying coatings that resemble glass lumps. The emulsifying properties of Gum Arabic have an impact on the viscosity produced when used in coatings. High viscosity affects the outcome and morphology of microcapsule during drying. The resulting shape will be irregular, as observed in microcapsule with uneven morphology. Moisture content can also affect the shape of microcapsule. Gum Arabic, with 6 hydroxyl groups forms complex structures as evidenced by the absorption in FTIR characterization, which experiences a shift in the OH group wavelength. These hydroxyl groups cause an increase in moisture content, resulting in wrinkles on the surface due to moisture loss during the drying process [46]. However, compared to ethanol extract, SEM results of microcapsule show a more distinct layer formation with sizes ranging from approximately 1.05 to 9.30 µm. The sizes fall in the range of particle sizes required for microcapsule, ideally around 1-1000 µm [47; 48]. The morphology affects the characteristics of microcapsule produced, such as active ingredient release and retention. Morphology types can be categorized into two, namely producing fine particles or having concave and folded surfaces. The irregular morphology is caused by the rate of water evaporation used during drying [49].

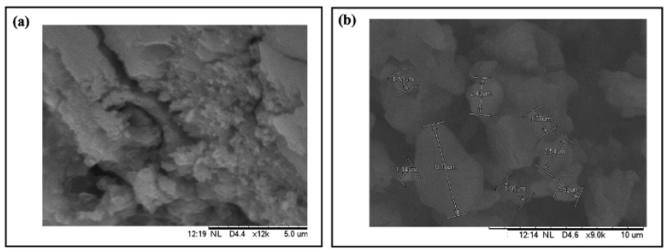

Figure 4. SEM results of: (a) ethanol extract of *C. caudatus* K.; (b) microcapsule of ethanol extract of *C. caudatus* K. under optimal conditions.

The analysis results in **Figure 5** show that microcapsule obtained meets the particle size requirements produced from spray drying process (3–612 µm) with an average diameter value of 152.00 µm [50]. The generated sizes are heterogeneous, as evidenced by the characterization results showing multiple high peaks. The inlet temperature of 105°C used in spray drying is relatively high, causing water vapor to have difficulty diffusing through the particle surface due to the formation of a crust layer on the droplet surface [51]. The ability of Gum Arabic to form a viscous solution may inhibit the nozzle from forming small and uniform droplets. Based on structure, GA coating has long complex bonds that form branched molecules with high molecular weight. This structure, when used in microencapsulation, will lead to a large surface area, resulting in smaller particle sizes [33]. The smaller the size of microcapsule, the greater the impact on the release test due to the larger surface area.

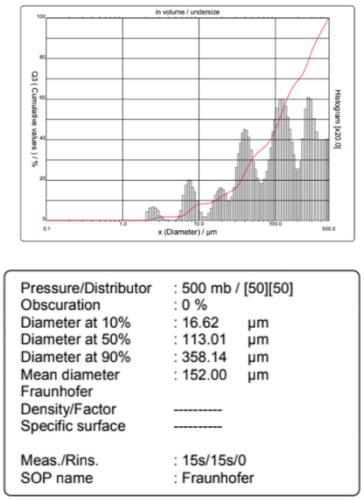

Figure 5. Particle size distribution of microcapsule of extract of *C. caudatus* K. prepared under optimal conditions.

In Vitro Release Test

Microcapsule were analyzed for in vitro release. Based on the results, pH 2.2 and 7.4 were found in two different environments. **Figure 6** shows the release patterns of *C. caudatus* K. extract and microcapsule. As shown in **Figure 6**, extract was released at a slightly lower pH of 2.2 than 7.4. For example, 30.02% of extract was released at pH 2.2 level in 30 min and increased to 38.05% in 120 min. In 30 and 120 min, microcapsule released 71.44% and 95.14% of active compounds under pH of 7.4. The percentage release value was derived by comparing TFC after dissolution in the medium with TFC of microcapsule, as described in Equation 3.

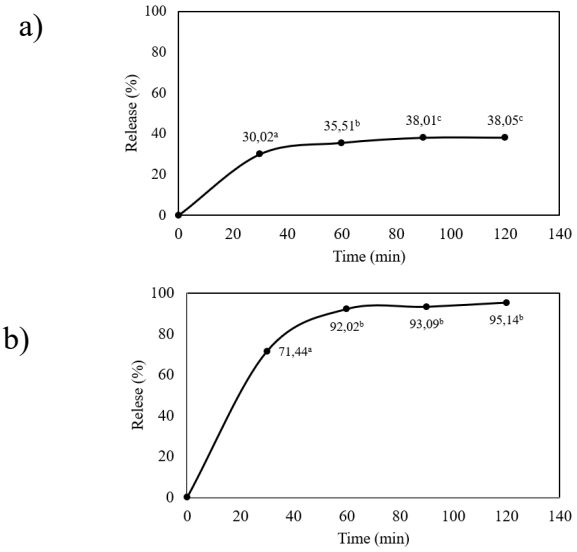

Figure 6. Results of microcapsule in vitro release test: (a) pH 2.2; (b) pH 7.4, at 37°C. Different letter notations (a, b, and c) indicate significant differences in each sample for the $\alpha = 0.05$.

The release profile of the active ingredient from microcapsule shows significant changes related to pH and time effects at 37°C. At pH 2.2, the initial release reached around 30%, and release percentage continued to increase over time. Release testing results showed that flavonoids in microcapsule were more difficult to release at pH 2.2, with lower release values compared to pH 7.4. The lower release condition is due to the stability of Gum Arabic coating structure under acidic conditions. At low pH (pH 2,2), the concentration of hydrogen ions increased, preventing compound oxidation. Additionally, at pH below the pKa of Gum Arabic (~6.5), most carboxyl groups are in the COOH form, reducing electrostatic repulsion and making microcapsule more stable in acidic conditions [52]. The higher encapsulation efficiency value (71.87%) helps protect the core material from damage due to pH changes, allowing the therapeutic benefits of flavonoids to be maximized without the risk of degradation due to pH. SEM results also showed a smooth and non-cracked microcapsule surface, which indicated good stability and lower compound release in acidic pH, providing more effective protection for the core compound. On the contrary, at pH 7.4, the released extract reached 95.14% in 120 minutes. The higher release value is likely due to the weak hydrogen bonds between extract and the polymer tissue in phosphate-free buffer, which accelerates the release rate. The smaller size of microcapsule increased the surface area, speeding up the release process. These results indicate that compared to acidic conditions, neutral pH better supports the release of the substance [53].

IV. CONCLUSION

In conclusion, the concentration of Gum Arabic and stirring speed were found to influence microencapsulation process of *C. caudatus* K. extract. The optimal conditions identified were a 4% Gum Arabic concentration (w/v) and a stirring speed of 800 rpm. In vitro biological activity assessment showed that microcapsule from *C. caudatus* K. extract had IC_{50} value of 55.09 ± 0.57 µg/mL in alpha-amylase inhibitory assay. FTIR spectra indicated the presence of carboxylate functional groups at 1644.42 cm^{-1} and 1565.98 cm^{-1}, confirming coating process. SEM analysis showed that microcapsule had rough surfaces and were predominantly spherical, with sizes ranging from 1.05 to 9.30 µm and an average diameter value of 152.00 µm. In vitro release studies demonstrated that the release of *C. caudatus* K. extract was more efficient at pH 7.4 compared to pH 2.2. This study focused solely on one type of polysaccharide polymer, suggesting the need for further investigation into the effects of other polymers that could effectively protect core compounds such as flavonoids. Future studies should also explore drying methods to achieve microcapsule with optimal shape and functionality.

ACKNOWLEDGMENT

This study was funded by Kementerian Riset, Teknologi and Pendidikan Tinggi Republik Indonesia of 2024 (PTM grant number: 00309.42/UN10.A0501/B/PT.01.03.2/2024)

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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