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Microencapsulation of Kencur (*Kaempferia galanga* L.) Extract Using Various Coating Materials

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ABSTRACT

Kencur (*Kaempferia galanga L.*) extract is rich in phenolic compounds that function as antioxidants, and it has also been reported to have anti-diabetic potential. To mask its undesirable aftertaste, the extract of kencur was microencapsulated using whey protein isolate (WPI), gum arabic (AGM), or maltodextrin (MDE). The antioxidant properties and essential oil content of spray-dried microencapsulated kencur extract were then compared with those of the pure extract. Microcapsules were prepared by dispersing kencur extract into each coating solution, homogenizing, and spray-drying the mixtures. The resulting microcapsules were evaluated for production yield, particle size distribution, morphology, antioxidant activity (percent radical scavenging activity, %RSA), total flavonoid content, and total phenolic content. Statistical analysis (ANOVA with Duncan's post-hoc test at α= 0.05) identified significant differences among the coating materials. The microencapsulation yields were 67.21% with WPI, 58.64% with AGM, and 61.95% with MDE. The antioxidant activities (%RSA) of the microcapsules were 46.07% for WPI, 47.18% for AGM, and 44.89% for MDE. The flavonoid content was 18.19 mg QE/g for WPI, 19.29 mg QE/g for AGM, and 18.83 mg QE/g for MDE, while the total phenolic content was 5.76 mg GAE/g for WPI, 6.62 mg GAE/g for AGM, and 5.25 mg GAE/g for MDE. The coating materials significantly influenced microencapsulation yield, antioxidant activity, and total phenolic content ($p<0.05$), but the flavonoid content was unaffected. Overall, microcapsules with gum arabic (AGM) exhibited the highest antioxidant activity and phenolic content.

Keywords: *antioxidant activity, flavonoids, kencur extract, microencapsulation, total phenolics*

INTRODUCTION

Functional foods are food products that contains specific compounds conferring health benefits. In recent times, the importance of functional foods has as increased, particularly for maintaining and enhancing the body's immune system. Consumption of antioxidant compounds is closely linked to improved immunity, as these compounds neutralize free radicals and reactive oxygen species, thereby inhibiting oxidative reactions that lead to various degenerative diseases (Adawiah *et al*., 2015). Recent studies suggest that due to potential health risks from excessive synthetic antioxidant use, such as increased cancer risk, obtaining antioxidants from whole, natural food sources is safer and more effective in supporting immune function (Kozlov *et al*., 2024; Mrityunjaya *et al*., 2020). Research by Mrityunjaya *et al*. (2020) demonstrated that several spice-based nutritional supplements can reduce the risk of viral infections by increasing the body's immune response.

Kencur (*Kaempferia galanga* L.), a medicinal and culinary herb native to Southeast Asia, is widely valued for its antioxidant, anti-inflammatory, and antimicrobial properties, making it an important ingredient in traditional Indonesian remedies culinary spices, food ingredients, and refreshing beverages (Wang *et al.,* 2021). Previous studies have reported that kencur has shown significant antihyperglycemic effects in diabetic animal models, likely due to its flavonoid-rich content that offers antioxidant and immunomodulatory benefits, helping reduce blood glucose levels and improve metabolic health (Kokila and Raghavan, 2020; Hoskin and Power Coombs, 2022; Sudatri *et al.*, 2019). In this case, flavonoids serve as antioxidants that help repair damage to pancreatic β-cells (insulin-producing cells) caused by streptozotocin induction. The flavonoids present in kencur rhizome can lower blood glucose levels at certain doses, indicating that kencur has potential as an anti-diabetic treatment (Mohammad *et al.,* 2016).

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Kencur rhizomes contain various phenolic compounds known to function as antioxidants. Apart from its antioxidant activity, kencur extract has been reported to exhibit anti-diabetic, anti-inflammatory, anti-tuberculosis, and anti-cancer properties (Setyawati *et al.,* 2018). Phytochemical evaluations have demonstrated that kencur rhizomes are rich in diverse secondary metabolites, including phenolic compounds, flavonoids, tannins, terpenoids, and steroids, which collectively contribute to its antioxidant potential, aromatic profile, and wide-ranging pharmacological activities (Adianingsih *et al.*, 2021). Comprehensive GC-MS analyses have revealed that kencur rhizomes contain numerous volatile terpenoid compounds, predominantly ethyl *p*-methoxycinnamate (Vidya *et al.,* 2022). However, the direct use of kencur extract in food products faces several limitations. Recent studies have reported that kencur extract has poor applicability, low stability, and imparts an undesirable aftertaste (Sulistyowati *et al.*, 2023). Microencapsulation offers a potential solution to overcome these drawbacks (Setyawati *et al.,* 2018).

Microencapsulation has been proven effective in protecting active compounds from degradation during processing and storage (Aminah *et al.*, 2023). Among the various encapsulation techniques, spray-drying is one of the most effective and widely used for preserving bioactive compounds, because the short heat exposure during the process minimizes thermal degradation (Nurhidajah *et al.,* 2024). In addition to its high efficiency, spray-drying can be readily scaled up for industrial production (Bucurescu *et al.,* 2019). One critical factor in spray-drying microencapsulation is the selection of a suitable coating material (Aminah *et al.,* 2023). Several studies have explored different coating materials for microencapsulation of rhizome-derived active compounds, including whey protein isolate (WPI), gum arabic (AGM), and maltodextrin (MDE) (Liu *et al.,* 2016; Bucurescu *et al.,* 2019; da Silva Júnior *et al.*, 2023).

Selecting an appropriate coating material can produce microcapsules with high stability and applicability, while also masking the unpleasant aftertaste of the active extract (Meena *et al.*, 2021). To date, microencapsulation of kencur extract by spray-drying using WPI, AGM, and MDE as coating materials has not been reported. Therefore, the present study was conducted to produce kencur extract microcapsules using these three coating materials via spray-drying. This research provides valuable information for selecting the best coating material in the preparation of kencur extract microcapsules to achieve the highest retention of phytochemical content.

MATERIALS AND METHOD

Materials

Fresh kencur (*Kaempferia galanga* L.) rhizomes were obtained from local farmers in Tembalang District, Semarang, Indonesia. The microencapsulation coating materials used were WPI (Beyon Nutrition, Indonesia), AGM (Ingredion, Thailand), and MDE with dextrose equivalent (DE) 10–12 (Lihua Starch, China). All chemical reagents, including ethanol, methanol, Folin-Ciocalteu reagent, sodium carbonate (Na_2CO_3), gallic acid, potassium acetate (CH_3COOK), aluminum chloride ($AlCl_3$), quercetin, and 2,2-diphenyl-1-picrylhydrazyl (DPPH), were purchased from Sigma-Aldrich (St. Louis, MO, USA). Laboratory work was conducted at several facilities: extraction by maceration was performed at Muhammadiyah Semarang University, microencapsulation at Soegijapranata Catholic University, and phytochemical and analyses at Diponegoro University, Semarang.

Experimental design

This study was an experimental study with a completely randomized design. The independent variables in this study were microcapsules of kencur extract prepared using different coating materials (WPI, AGM, and MDE). The dependent variables evaluated included yield, antioxidant activity, total flavonoid content, total phenolic content, as well as the morphology and particle size distribution of the microcapsules.

Preparation of kencur extract

The kencur powder was prepared from fresh kencur as described by Setiarso *et al.* (2018). Extraction was carried out by maceration using 70% ethanol (v/v) at a solid-to-solvent ratio of 1:3 (w/v) at room temperature for 24 h, following established procedures for polyphenol-rich plant materials (Hikmawanti *et al.,* 2021; Herawati and Saptarini, 2019). The mixture was filtered through a 200-mesh filter paper, and the filtrate was concentrated using a rotary evaporator at 50 °C to remove the solvent, as described by Pedro *et al.* (2025). The concentrated extract was collected and stored in a dark bottle at 4 °C until analysis to minimize oxidative degradation (Nonglang *et al.,* 2025).

Microencapsulation of kencur extract

Microencapsulation of kencur extract was performed by spray drying, a technique widely used to protect bioactive compounds and improve powder stability (Al-Hamayda *et al.,* 2023; Cevik *et al.,* 2024). Each coating material-whey protein isolate (WPI), gum arabic (AGM), or maltodextrin (MDE)-was prepared by dissolving 30 g of powder in 100 mL of distilled water and homogenizing at 10 000 rpm for 10 min (da Silva Júnior *et al.,* 2023). Subsequently, 1 g of the concentrated extract was added, and the mixture was homogenized for 30 min to form a stable emulsion (Vidya *et al.,* 2022). The emulsion was spray-dried at an inlet temperature of 150±1 °C and outlet temperature of 80±2 °C, with a feed flow rate of 4 mL min^{-1} and air pressure of 5 bar (Cevik *et al.,* 2024). The resulting microcapsule powder was collected and stored in metallized vacuum packaging at 4 °C until further analysis.

Microencapsule yield calculation

The microencapsulation yield was calculated to evaluate the efficiency of the spray-drying process, as described by da Silva Júnior *et al.* (2023). Yield (%) was defined as the ratio of the weight of microcapsules obtained to the total solids in the initial feed solution, multiplied by 100. This was calculated using the formula 1.

$$\text{Yield (\%)} = \frac{\text{weight of microcapsule obtained (g)}}{\text{amount of solids used in initial feed solution (g)}} \times 100\% \quad (1)$$

Antioxidant activity (DPPH assay)

Antioxidant activity was determined using the DPPH free-radical scavenging method adapted from Brand-Williams *et al.* (1995) and updated by Baliyan *et al.* (2002). A 0.2 g sample was mixed with 1.5 mL of 0.2 mM DPPH in ethanol and 3.5 mL of absolute ethanol, vortexed, and incubated in the dark for 60 min at 25±2 °C. Absorbance was measured at 517 nm using a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan). Ethanol served as the blank and the DPPH solution without sample as the control. The radical-scavenging activity (RSA) was calculated using the equation 2.

$$\text{Antioxidant Activity (\%RSA)} = \frac{\text{arsorbance of control-absorbance of sample}}{\text{absorbance of control}} \times 100\% \quad (2)$$

Total flavonoid content

Total flavonoid content was determined by a colorimetric method modified from Cai *et al.* (2016). In a dark test tube, 0.5 g of sample (microcapsule powder) was mixed with 1.5 mL of ethanol, 0.1 mL of 10% $AlCl_3$, 0.1 mL of 1 M CH_3COOK (potassium acetate), and 2.8 mL of distilled water. The mixture was vortexed and then incubated at room temperature (25±1 °C) for 30 min. The absorbance was measured at 415 nm using a UV-Vis spectrophotometer, with distilled water as the blank. A standard calibration curve was prepared using quercetin solutions (20–100 ppm in distilled water). Total flavonoid content in the samples was expressed as milligrams of quercetin equivalents (mg QE) per gram of sample.

Total phenolics content

The total phenolic content of the samples was measured using the Folin-Ciocalteu method as described by Pedro *et al.* (2016) with slight modifications. In a dark tube, 0.5 g of microcapsules powder was mixed with 5 mL of 10% (v/v) Folin–Ciocalteu reagent. The mixture was vortexed and allowed to react for 5 min, after which 4 mL of 7.5% (w/v) Na_2CO_3 solution was added. The reaction mixture was incubated at room temperature (25±1 °C) for 60 min. Absorbance was then measured at 765 nm using a UV-Vis spectrophotometer. Ethanol (without reagents) was used as a blank. A standard curve was generated using gallic acid solutions (100–500 ppm in ethanol). The total phenolic content was expressed as milligrams of gallic acid equivalents (mg GAE) per gram of sample.

Morphological analysis (SEM)

The microstructural morphology of the kencur extract powder and microcapsules was examined by scanning electron microscopy (SEM). Samples of the dried microcapsule powder were mounted on aluminum stubs using double-sided tape and sputter-coated with a thin layer of gold. The coated samples were observed under an SEM (JSM-6510LA, JEOL Ltd., Japan) at an accelerating voltage of 12 kV to evaluate surface morphology and particle shape.

Microcapsule surface morphology was analyzed by scanning electron microscopy (SEM), following the protocol of da Silva Júnior *et al.* (2023). Samples were mounted on aluminium stubs, coated with gold using a sputter coater, and observed under a JEOL JSM-6510LA SEM at 12 kV. Surface texture and particle shape were evaluated to identify structural diffe-rences among coating materials (Vidya *et al.,* 2022).

Particle size analysis

Particle size distribution was determined using a laser diffraction particle size analyzer (Model LLPA-C10, Labtron Equipment Ltd., UK), based on the principle of light scattering (Cevik *et al.,* 2024). Each sample was analyzed in triplicate, and results were recorded as the volume-based particle size distribution, expressed by D10, D50, D90, and $D_{[4,3]}$ values.

Statistical analysis

Each microcapsule formulation was analysed in triplicate (n= 3), and the results are presented as mean ± standard deviation. A one-way analysis of variance (ANOVA) was performed to determine significant differences between treatment groups. When the ANOVA indicated a significant effect ($p<0.05$), Duncan's multiple range test was applied for post-hoc comparison of means. Statistical analysis was conducted using SPSS software (version 22.0, IBM Corp).

RESULTS AND DISCUSSION

Microencapsule yield

As shown in Table 1, the microencapsulation yield of kencur extract ranged from 58.64 to 67.21% across the different coating materials, indicating that the type of coating had a significant effect on yield. The microcapsules prepared with MDE exhibited a higher yield (61.95%) than that with AGM (58.64%), while the highest yield was achieved with WPI as the coating material (67.21%). Lucas *et al.* (2020) similarly reported that curcumin microcapsules using gum arabic as the encapsulant had a lower yield compared to other coating materials. Gum Arabic's complex branched and hydrophilic molecular structure may promote adherence to dryer walls during spray-drying, contributing to reduced microencapsulation yield (Al-Hamayda *et al.,* 2010). In contrast, the WPI-coated microcapsules produced the greatest yield in this study. This result suggests that WPI has a relatively high molecular weight, which raises the glass transition temperature of the drying particles. This refers to the statement of Cevik *et al.* (2024) that high-molecular-weight coating materials have been shown to enhance microcapsule integrity by reducing issues like stickiness, collapse, or particle agglomeration and thereby improve final product yield.

Antioxidant activity

The antioxidant activities of kencur extract microcapsules, expressed as % Radical Scavenging Activity (RSA), were 46.07% for WPI, 47.18% for AGM, and 44.98% for MDE (Table 1). These results suggest that AGM is the most effective coating material for preserving antioxidant activity in kencur extract microcapsules. According to Nurhidajah *et al.* (2024), maltodextrin (MDE) as a coating material does not contribute antioxidant compounds to the microcapsules. The relatively high antioxidant activity observed in AGM-coated microcapsules can be attributed to their higher phenolic content. Interestingly, the antioxidant activity of WPI-coated microcapsules was slightly greater than that of MDE-coated ones, even though the total phenolics in the WPI microcapsules were lower (Table 1).

MDE as a coating material does not have the potential to contribute antioxidants to the resulting microcapsules. The high antioxidant activity of microcapsules prepared with AGM coating material was attributed to the large amount of phenolic compounds trapped in the microcapsule structure. An interesting thing was observed in the microcapsules prepared with WPI coating material which had better antioxidant activity than MDE, in line with the higher total phenolics (Table 1). This finding implies that the WPI coating itself may provide some antioxidant components Additionally, WPI has been reported to have good solubility and emulsifying properties, which can enhance the encapsulation and retention of antioxidant compounds (Patel *et al.,* 2021).

Flavonoid content

The total flavonoid content of the microcapsules ranged from about 18.2 to 19.3 mg QE/g (Table 1). Statistical analysis confirmed that there were no significant differences in flavonoid levels among microcapsules made with WPI, AGM, or MDE coatings. Kencur rhizome extract naturally contains flavonoids such as kaempferol and kaempferide, which are readily soluble in polar solvents (Julianti *et al.,* 2022). Kaempferol is a prominent bioactive flavonoid from kencur that exhibits various pharmacological activities, including antioxidant, anti-inflammatory, anti-cancer, and anti-obesity effects. Kaempferide is another flavonoid found in kencur rhizomes, identified as having an osteoprotective effect by inhibiting bone resorption (Kumar, 2020).

Although flavonoids are a subclass of phenolic compounds, the results of this study showed that total flavonoid content (18.19–19.29 mg QE/g) was higher than total phenolic content (5.25–6.62 mg GAE/g). This apparent discrepancy can be explained by the different analytical principles and calibration standards used in the two assays. The Folin-Ciocalteu method used for total phenolic content is based on the overall reducing capacity of the sample and is not fully specific to phenolic compounds (Singleton *et al.,* 1999).

Table 1. Yield and chemical properties of kencur extract microcapsules prepared with different coating materials

Coating Material	Yield (%)	Antioxidant Activity (%RSA)	Total Flavonoids (mg QE/g)	Total Phenolics (mg GAE/g)
WPI	67.21±1.28^{c}	46.07±0.85^{b}	18.19±0.26^{a}	5.76±0.54^{b}
AGM	58.64±0.92^{a}	47.18±1.03^{c}	19.29±0.51^{a}	6.62±0.84^{c}
MDE	61.95±1.16^{b}	44.98±0.68^{a}	18.83±0.97^{a}	5.25±0.26^{a}

Note: Values represent mean ± standard deviation (n= 3). Different superscript letters (a–c) within a column indicate significant differences (p<0.05). GAE= gallic acid equivalent, QE= quercetin equivalent, WPI= whey protein isolate, AGM= gum arabic, MDE= maltodextrin

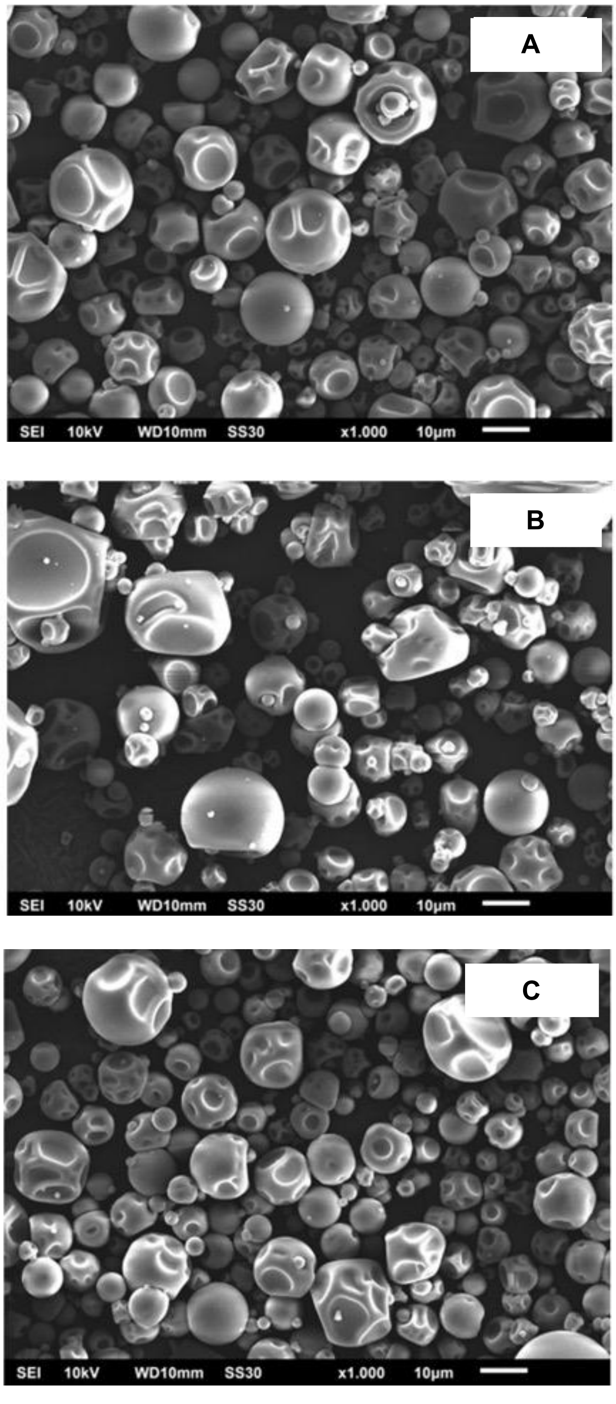
In complex matrices such as microencapsulated systems, phenolics may interact with coating materials, particularly proteins such as whey protein isolate, leading to lower apparent recovery in the Folin-Ciocalteu assay (Milinčić *et al.,* 2022). In contrast, the aluminium chloride colorimetric method selectively forms stable complexes with flavonoid structures, especially flavonols and flavones, and its response is highly sensitive to the reference standard used, such as quercetin (Pękal and Pyrzynska, 2014; Shraim *et al.*, 2021). Kencur rhizome is known to be rich in flavonol-type compounds, including kaempferol and kaempferide, which show strong complexation with aluminium chloride (Shraim *et al.*, 2021). As a result, the aluminium chloride assay may yield relatively high flavonoid values even when the overall phenolic content appears lower. Therefore, the higher flavonoid content observed in this study reflects both the dominance of flavonol-type compounds in kencur and the methodological characteristics of the analytical assays rather than a contradiction in phenolic chemistry.

Total phenolics

The total phenolic content of kencur extract microcapsules was significantly influenced by the coating material (Table 1). Microcapsules with AGM had the highest total phenolics (6.62 mg GAE/g), followed by those with WPI (5.76 mg GAE/g), while MDE yielded the lowest total phenolic content (5.25 mg GAE/g). These results indicate that the choice of coating material affected the retention of phenolic compounds in the microcapsules. Consistent with our findings, Sukardi *et al.* (2023) observed that the total phenolic content of red galangal rhizome extract microcapsules increased when gum arabic was used as the coating, whereas using higher proportions of maltodextrin resulted in lower phenolic retention. Gum arabic has a branched molecular structure that confers a strong ability to protect phenolic compounds by binding to them (Busch *et al.,* 2017). The microcapsules prepared with WPI showed a relatively low total phenolic content compared to the other coatings. Phenolic compounds are known to interact with milk proteins (such as whey proteins), leading to lower phenolic recovery and reduced antioxidant activity (Milinčić *et al.*, 2022).

Morphological structure

The SEM analysis showed that microcapsules prepared with different coatings generally exhibited irregular shapes (Figure 1). Some microcapsules were nearly spherical, but most had dented and wrinkled surfaces. Notably, no cracks were observed on the surface of any microcapsules.



Note: SEM images showing the morphology of kencur extract microcapsules prepared with A= whey protein isolate (WPI), B= gum arabic (AGM), and C= maltodextrin (MDE) as coating materials. Micrographs were captured at magnifications of 1000× with a scale bar of 10 μm. The WPI coating produced smoother, more spherical particles, while AGM and MDE microcapsules exhibited wrinkled or dented surfaces typical of spray-dried powders

Figure 1. SEM micrographs of kencur extract microcapsules

These observations are in line with previous reports that spray-dried microcapsules typically have uneven, wrinkled surfaces (Bucurescu *et al.,* 2018; Patel *et al.,* 2021). The rapid drying during the spray-drying process causes a quick formation of a rigid surface layer, while the interior of the particle continues to shrink, resulting in a wrinkled, indented structure (da Silva Júnior *et al.,* 2023; Nguyen *et al.,* 2021). In this study, the type of coating material did not appear to noticeably affect the qualitative morphology of the microcapsules. In general, smoother microcapsule surfaces can reduce inter-particle interactions, which may be beneficial in certain applications (Gonçalves *et al.,* 2017). Moreover, microcapsules with smoother surfaces have been associated with faster release rates of encapsulated ingredients (Aquiar *et al.,* 2017; Bucurescu *et al.,* 2018).

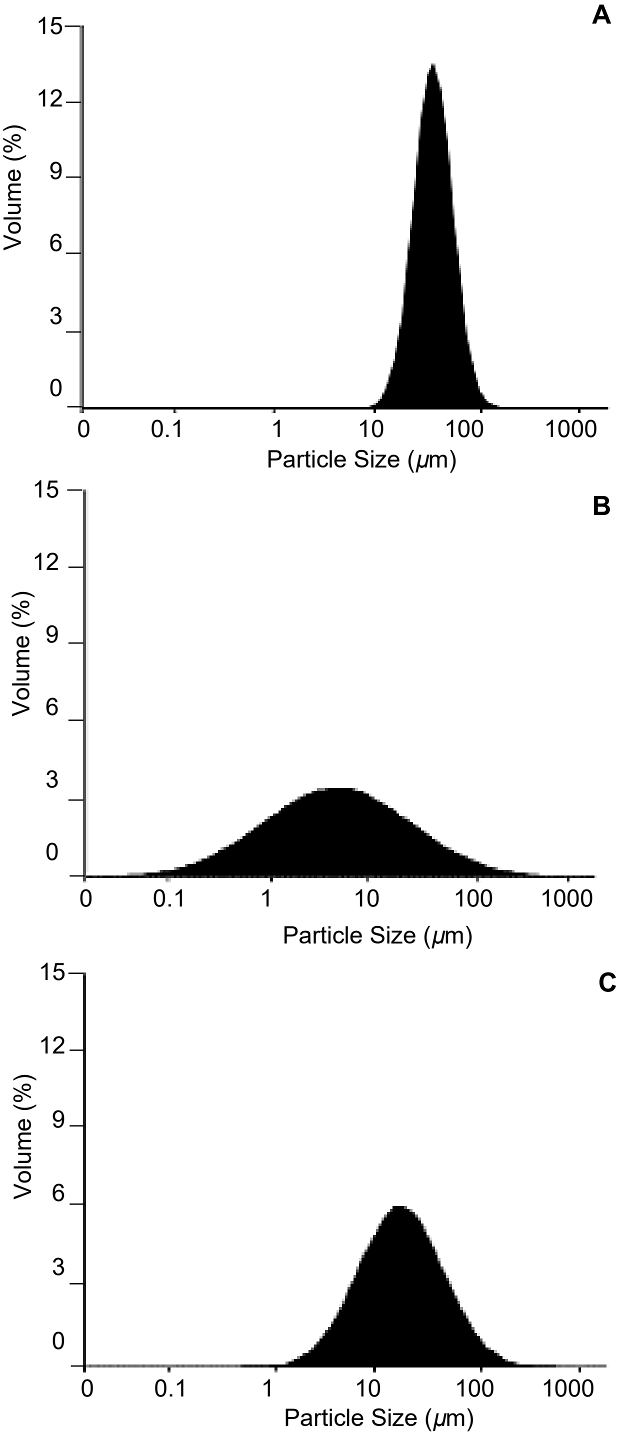
Particle size distribution

The particle size distribution of the microcapsules was unimodal (Figure 2). Based on the particle size analysis results (Table 2), the microcapsules had particle sizes spanning from approximately 0.45 mm up to 59.83 mm. The volume-weighted mean diameter ($D_{[4,3]}$) of the microcapsules was influenced by the coating material: microcapsules with an AGM coating had the smallest $D_{[4,3]}$ (38.16 mm), followed by those with MDE (43.61 mm), while the WPI-coated microcapsules showed the largest $D_{[4,3]}$ (49.34 mm). These results demonstrate that the type of coating material affected the particle size of the resulting microcapsules.

The influence of coating type on particle size can be linked to differences in the homogenization and drying process. Cano-Higuita *et al.* (2015) noted that the homogenization conditions have a substantial impact on the final particle size of spray-dried microcapsules. Particle size is an important characteristic related to product dispersibility (Aminah *et al.,* 2023). Generally, larger microcapsules may allow for a more sustained release of bioactive components due to greater internal porosity, whereas smaller microcapsules tend to exhibit better techno-functional properties in applications (Čujić-Nikolić *et al.,* 2019; Nurhidajah *et al.,* 2024).

CONCLUSION

The type of coating material had a significant effect on the yield, antioxidant activity, and total phenolic content of kencur extract microcapsules ($p < 0.05$). In contrast, there was no significant difference in flavonoid content among microcapsules with different coatings. Of the coating materials tested, gum arabic (AGM) produced microcapsules with the highest antioxidant activity and total phenolics.



Note: Particle size distribution curves for microcapsules prepared with different coating materials with A= whey protein isolate (WPI), B= gum arabic (AGM), and C= maltodextrin (MDE). Data were obtained using laser diffraction (LLPA-C10, Labron UK) and expressed as volume frequency (%) versus particle diameter (μm). Distinct Gaussian curves illustrate the difference in size uniformity between treatments

Figure 2. Particle size distribution curve of kencur extract microcapsules

Table 2. Particle size distribution and span index of kencur extract microcapsules

Coating Material	D_{10} (µm)	D_{50} (µm)	D_{90} (µm)	$D_{[3,2]}$ (µm)	$D_{[4,3]}$ (µm)	Span Index
WPI	20.56±0.41	32.50±0.67	59.83±0.92	41.28±1.13	49.34±0.95	1.21±0.08
AGM	0.45±0.03	4.47±0.29	37.86±0.74	1.26±0.12	38.16±0.88	8.38±0.64
MDE	4.92±0.15	15.16±0.42	51.37±0.81	10.75±0.35	43.61±0.79	3.06±0.25

Note: Values represent mean ± SD (n= 3). $D_{[3,2]}$ represents the surface-weighted mean diameter, $D_{[4,3]}$ represents the volume-weighted mean diameter, Span index= $(D_{90}– D_{10})/D_{50}$ indicates size distribution breadth

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