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EFFECT OF GINGER OLEORESIN CONCENTRATION ON THE ENCAPSULATION PROCESS USING IONIC GELATION

PENGARUH KONSENTERASI OLEORESIN JAHE PADA PROSES ENKAPSULASI MENGGUNAKAN GELASI IONIK

Asep Wawan Permana[1)], Annisah Mardiyyah[2)], Bangkit Wiguna[1)], Hendrawan Laksono[1)], Galih Kusuma Aji[1)], Ayi Mufti[1)], Priyo Atmaji[1)], Muhamaludin[1)], Budiyanto[1)], Ambar Dwi Kusumasmarawati[1)], Wegik Dwi Prasetyo[2)], Anny Sulaswatty[3)], Achmad Sofian Nasori[1)*]

[1)]Research Center for Agroindustry, National Research and Innovation Agency
KST Soekarno, Cibinong, Bogor, Indonesia.
[2)]Department of Chemical Engineering, Pertamina University, Jakarta 12220, Indonesia.
[3)]Research Center for Chemistry, National Research and Innovation Agency, Tangerang Selatan, Indonesia.
Email: achmad.sofian.nasori@brin.go.id

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ABSTRAK

Komponen aktif utama dalam oleoresin jahe adalah gingerol dan shogaol. Gingerol menunjukkan berbagai aktivitas farmakologis, antara lain efek antiinflamasi, antioksidan, dan analgesik. Akan tetapi gingerol bersifat sensitif terhadap panas dan terdegradasi pada suhu tinggi, yang membatasi efektivitas fungsionalnya saat jahe dikonsumsi. Untuk mengatasi keterbatasan ini dilakukan proses enkapsulasi oleoresin jahe sebagai upaya untuk memperbaiki sifat fisik dan fungsional sekaligus meningkatkan penghantaran ke dalam tubuh. Dalam penelitian ini proses enkapsulasi dilakukan dengan pendekatan gelasi ionik dengan hasil berbentuk bead. Alginat digunakan sebagai bahan enkapsulat oleoresin jahe. Karakterisasi bead kering menggunakan FTIR, analisis SEM, uji disintegrasi, dan evaluasi efisiensi enkapsulasi melalui spektrofotometri UV-Vis. Hasil penelitian menunjukkan bahwa bead alginat yang mengandung oleoresin jahe dapat disintesis dengan menggunakan metode gelasi ion, dengan alginat sebagai material polimer dan $CaCl_2$ sebagai agen penghubung. Konsentrasi oleoresin jahe yang diuji dalam studi ini adalah 0,9%, 0,7%, 0,5%, dan 0,3%. Efisiensi enkapsulasi tertinggi adalah 72,480%, dicapai dengan konsentrasi oleoresin jahe 0,7%. Analisis morfologi permukaan mengungkapkan bahwa bead alginat memiliki tekstur kasar dan berpori dengan lipatan yang terlihat pada polimer alginat. Selain itu, waktu disintegrasi bead kering kurang dari 30 menit.

Kata kunci: Alginat, bead kering, enkapsulasi, metode gelasi ionik, oleoresin jahe

ABSTRACT

The primary active components in ginger oleoresin are gingerol and shogaol, with gingerol exhibiting significant pharmacological activities such as anti-inflammatory, antioxidant, and analgesic effects. However, gingerol is heat-sensitive and degrades at elevated temperatures, limiting its functional efficacy when consumed. To overcome this limitation, encapsulation of ginger oleoresin was performed to enhance its physical and functional properties and improve its bioavailability. This study utilized the ionotropic gelation method to encapsulate ginger oleoresin, resulting in the formation of beads. Alginate was employed as the encapsulation matrix. The dried beads were characterized using FTIR, SEM, disintegration tests, and encapsulation efficiency was assessed via UV-Vis spectrophotometry. Results demonstrated that alginate beads containing ginger oleoresin could be successfully synthesized using the ionotropic gelation technique, with alginate as the polymer and $CaCl_2$ as the cross-linking agent. Ginger oleoresin concentrations of 0.9%, 0.7%, 0.5%, and 0.3% were tested. The highest encapsulation efficiency, 72.48%, was obtained with a ginger oleoresin concentration of 0.7%. Surface morphology analysis revealed that the alginate beads exhibited a rough, porous texture with visible folds. Furthermore, the dry beads disintegrated within 30 minutes.

Keywords: alginate, beads, encapsulation, ginger oleoresin, ionic gelation metho

INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) is a widely used herbal plant in various industries, especially in the pharmaceutical sector. It has been traditionally used to treat a wide range of ailments such as pain, fever, inflammation (Angelopoulou *et al.*, 2022), diabetes, diarrhea, obesity, Alzheimer's disease (Liju *et al.*, 2015; Talebi *et al.*, 2021), and various types of cancer. Research has shown that ginger contains active compounds within its oleoresin, including essential oils, phenolic compounds, flavonoids, proteins, saponins, steroids, and carbohydrates (Dhanik *et al.*, 2017). The primary constituents of ginger oleoresin are [6]-gingerol

**Coressponding Author*

($C_{17}H_{26}O_4$), shogaols ($C_{17}H_{24}O_3$), and paradols (Arcusa *et al.*, 2022; Mukherjee and Karati, 2022).

Previous studies have shown that gingerols exhibit a range of pharmacological activities, such as anti-inflammatory, antioxidant, free radical scavenging, and analgesic properties (Poorrostami *et al.*, 2021). However, gingerols are thermally unstable, and at elevated temperatures, they decompose into shogaols, thereby diminishing the efficacy of ginger's active compounds after extraction (Nasori *et al.*, 2022; Bakr *et al.*, 2020). To optimize its therapeutic potential, ginger is formulated into medicinal dosage forms with smaller particle sizes. This transformation into smaller particles has been demonstrated to enhance therapeutic outcomes compared to ginger extracts in larger forms (Bakr *et al.*, 2020). Furthermore, reducing particle size helps preserve the integrity of [6]-gingerol, preventing its degradation during further processing. Bakr *et al.* (2020) reported that small ginger particles can be effectively distributed across various organs and exhibit prolonged stability, making ginger a safe and active compound with minimal side effects.

The delivery of active ginger oleoresin into the body requires an effective method to protect the compound, ensuring targeted release at the desired organ while maintaining its physical stability and functional efficacy. One such method is encapsulation, which involves coating bioactive compounds with other materials. These coating materials are also referred to as carriers, external phases, or shells, while the encapsulated substances are commonly known as active ingredients, core materials, or fillers (Arora, 2012). An interesting approach to encapsulation is the ionic gelation method, which offers several advantages i.e. simplicity, clinical safety, the absence of organic solvents, and mild gelation conditions (Roshan *et al.*, 2016). Kanatt *et al.* (2018) using ionic gelation method to encapsulate onion flake extract and showed that capsules containing 6% extract exhibited the highest and most stable antioxidant activity against gastric fluids.

In this study, ginger oleoresin serves as the encapsulated bioactive compound, with alginate polymer acting as the coating material due to its affordability, ecological sustainability, biocompatibility, and non-toxic nature (Martínez-Cano *et al.*, 2022). Alginate, an anionic polymer, possesses unique biopharmaceutical properties such as biodegradability, biocompatibility, pH sensitivity, and lack of toxicity and immunogenicity, making it an ideal candidate for drug delivery applications (Desbrieres *et al.*, 2019). Additionally, alginate is widely used in other fields such as the food industry for the microencapsulation of probiotics, prebiotics (Chávarri *et al.*, 2010), and nutrients (Desbrieres *et al.*, 2019; Vaziri *et al.*, 2018), as well as in agriculture for wastewater treatment, heavy metal adsorption (Mende *et al.*, 2018), and the encapsulation of bioactive substances (Hu *et al.*, 2016).

The primary property of sodium alginate is its ability to undergo gelation in the presence of calcium ions, which provides a light, safe, and non-toxic gelation process. This method is simple, cost-effective, and does not require organic solvents. Calcium ions (Ca^{2+}) from calcium chloride ($CaCl_2$) are the crosslinking agents in this gelation process. Additionally, Tween 80 is used as a surfactant to reduce interfacial tension, facilitating the mixing of ginger oleoresin with the alginate solution. The aim of this research is to synthesize alginate-encapsulated ginger oleoresin using the ionic gelation method. Furthermore, this study will characterize the resulting beads and evaluate the effects of oleoresin concentration on the morphology of the alginate encapsulation and the encapsulation efficiency.

MATERIALS AND METHODS

Materials

Ginger oleoresin extract was obtained from a previous study by Nasori *et al*. (2022). The reagents used in this study were sodium alginate (Sigma-Aldrich), Tween 80 (Sigma-Aldrich), $CaCl_2$ (Sigma-Aldrich), absolute ethanol (Sigma-Aldrich), $NaH_2PO_4 \cdot H_2O$ (Merck), and $Na_2HPO_4 \cdot 2H_2O$ (Merck). All reagents were of analytical grade.

Methods

Alginate Encapsulation Process

The encapsulation process using alginate was adapted from previous research (Paques *et al.*, 2014; Asadi *et al.*, 2018; Voo *et al.*, 2016), according to the procedure described as follows. First, 1.25 mL of 0.5% (v/v) Tween-80 was dissolved in 250 mL of distilled water. Then, 1.25 g of sodium alginate (0.5% w/v) was gradually added to the Tween-80 solution. The mixture was stirred with an overhead stirrer for 1 hour until a homogeneous solution was formed. After homogenization, the solution was filtered using Whatman filter paper.

For the blank sample, 50 mL of the filtered solution was drawn and dropped into a beaker containing 100 mL of 1% (w/v) $CaCl_2$ using a syringe, forming beads. The remaining mixture (approximately 200 mL) was divided, and 50 mL portions were mixed with different concentrations of ginger oleoresin (0.3%, 0.5%, 0.7%, and 0.9%). These oleoresin-containing mixtures were homogenized with an overhead stirrer for 1 hour. Each solution was then dropped into a beaker containing 100 mL of 1% (w/v) $CaCl_2$ using a syringe, resulting in bead formation.

To isolate the beads from the solution, filtration was performed using filter paper. The beads were then freeze-dried for 24 hours. After drying, the beads were subjected to further characterization.

Fourier Transform Infrared (FTIR) Spectroscopy

Fourier transform infrared (FTIR) spectroscopy was employed to characterize the oleoresin extraction from immersion-ethanol extraction samples using a Nicolet-iS10 instrument equipped with an iD7 attenuated total reflection (ATR) accessory, manufactured by Thermo-Scientific, the United States of America.

Encapsulation Efficiency Determination
Phosphate buffer pH 6.8 Procedure:

To prepare the phosphate buffer solution, the required chemicals and equipment were gathered, including sodium phosphate monobasic (NaH_2PO_4), disodium phosphate dibasic (Na_2HPO_4), deionized water, an analytical balance for precise weighing, and a pH meter calibrated with standard pH solutions.

The appropriate amounts of NaH_2PO_4 and Na_2HPO_4 were calculated using a buffer calculator or preparation tables, based on the desired pH of 6.8. These amounts were then accurately weighed using the analytical balance to ensure precision. The weighed chemicals were dissolved in deionized water in a suitable container, with gentle stirring until complete dissolution was achieved, while taking care to prevent contamination.

The pH of the solution was adjusted by immersing the pH meter electrode, which had been rinsed with deionized water and dried, into the buffer solution. If the pH deviated from 6.8, small increments of NaH_2PO_4 or Na_2HPO_4 were added as needed, while monitoring the pH until the desired value was reached. Once the pH was stabilized at 6.8, the electrode was removed and rinsed thoroughly with deionized water.

The prepared buffer solution was then transferred to a clean, labeled container and sealed to prevent contamination. By adhering to this procedure, the phosphate buffer solution with a pH of 6.8 was prepared with accuracy, ensuring reliability and reproducibility.

Standard Curve Procedure

A standard curve for ginger oleoresin was generated in a phosphate buffer solution at pH 6.8, using a wavelength of 340 nm. The oleoresin content in each dry bead sample, prepared at different concentrations, was then analyzed using an Evolution 220 UV-VIS spectrophotometer (Thermo Scientific) at 340 nm.

Characterization of Dry Beads

The ginger oleoresin content in each dry bead sample, prepared at varying concentrations, was analyzed using an Evolution 220 UV-VIS spectrophotometer (Thermo Scientific) at a wavelength of 340 nm.

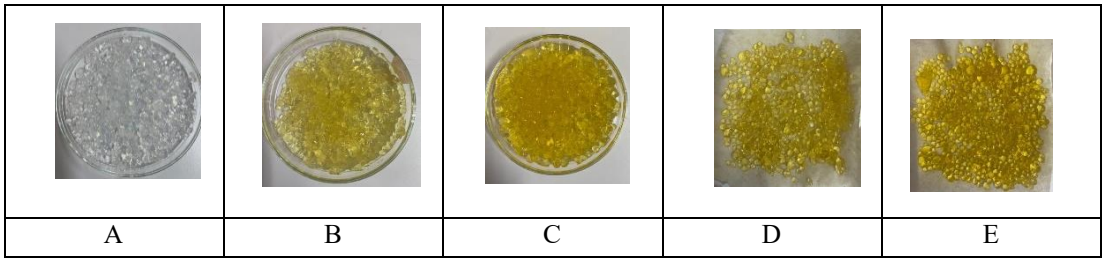
RESULTS AND DISCUSSION

Alginate Encapsulation Process

The formation of alginate beads involves cross-linking between guluronic acid (G) residues in the alginate and Ca^{2+} ions from $CaCl_2$. The Ca^{2+} cations penetrate the alginate droplets and replace the sodium ions in the polymer. This substitution leads to the accumulation of Ca^{2+} in the carboxylate groups of the G residues, resulting in the formation of the characteristic 'egg-box' structure. In this model, each Ca^{2+} cation binds to two polymer chains, which in turn link to multiple other chains, creating a three-dimensional gel network known as Ca-alginate beads (Paques *et al.*, 2014). The formation of these alginate beads is depicted in Figure 1.

Identification of Functional Groups of Alginate Beads

FTIR analysis (Figure 2) reveals that the spectra of blank dry beads and beads with varying oleoresin concentrations show an absorption band at 1734.56 cm^{-1} with moderate intensity. The absorption band at 1597.69 cm^{-1} indicates the presence of carboxylic acid (COO^-), characterized by a sharp peak with strong intensity (Talebi et al., 2021; Nasori *et al.*, 2022). The –Na bond in the alginate isomer is observed at 1516.32 cm^{-1} with strong intensity. In the fingerprint region, -CH_3 bending is detected at 1426.93 cm^{-1}. Additionally, C-O carboxyl groups are identified at absorption bands of 1247.82 cm^{-1} and 1074.3 cm^{-1}.



A	B	C	D	E

Figure 1. The alginate beads formed with various concentrations of ginger oleoresin (A= Blank, B = 0.3%, C = 0.5%, D = 0.7%, and E = 0.9%)

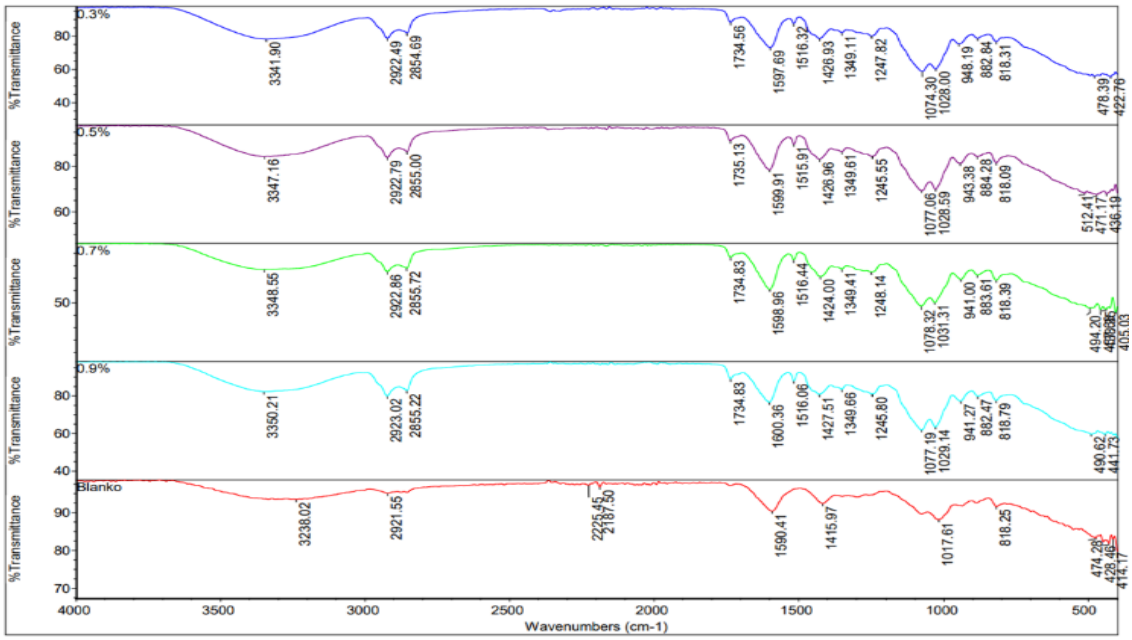


Figure 2. Fourier Transform Infra-Red (FTIR) Dry Beads spectrum on various concentrations of ginger oleoresin (B = 0.9%; C = 0.7%; D = 0.5%; E= 0.3%) versus the blank (A).

Table 1. Results of the FTIR spectrum of the four variations of ginger oleoresin beads

Wavelength Number (cm^{-1})				Frequency Area (cm^{-1})	Functional Groups
0.3 % Oleoresin Beads	0.5% Oleoresin Beads	0.7% Oleoresin Beads	0.9% Oleoresin Beads		
3341.9	3347.16	3348.55	3350.21	3600 – 3300	Hydroxyl Bond (O – H)
2922.49	2922.79	2922.86	2923.02	3000 – 2800	-CH_2 Stretching
1734.56	1735.13	1734.83	1734.83	1600 – 1800	Aromatic Ring (C = C)
1597.69	1599.91	1516.44	1516.06	1600 – 1800	Carboxylic Acid
1516.32	1515.91	1516.44	1516.06	1614 – 1431	Na-Bond in alginate isomer
1426.93	1426.96	1424	1427.51	1450 – 1375	CH_3 Bending
1297.82 & 1074.3	1245.55 & 1077.06	1248.14 & 1078.32	1245.8 & 1077.19	1300 – 1000	Carboxyl Group (COOH)
1028	1028.59	1031.31	1029.14	1030 – 1069	Ketone (C – O – C)

A ketone functional group (C–O–C) is also present at 1028 cm^{-1} (Asadi *et al.*, 2018). The spectra for dry beads with oleoresin concentrations of 0.5%, 0.7%, and 0.9% exhibit the same functional groups as those with a 0.3% oleoresin concentration.

Table 1 presents the FTIR spectra of beads containing four different concentrations of ginger oleoresin. The data reveal that while all ginger oleoresin variations share similar functional groups, distinct differences are observed in the wavenumber values of several peaks. Notably, the absorption band at 3341.9 cm^{-1} for the 0.3% oleoresin concentration shifts to 3347.16 cm^{-1} for the 0.5%, 0.7%, and 0.9% concentrations, with the wavenumber increasing as the oleoresin concentration rises.

Figure 2 highlights the spectral differences between the ginger oleoresin samples and the blank. Specifically, an aromatic ring functional group (C=C) is observed around 1734 cm^{-1} in the ginger oleoresin samples, while this absorption band is absent in the blank. This absence in the blank is attributed to the lack of the aromatic ring functional group, a feature unique to ginger oleoresin.

Encapsulation Efficiency

The relationship between ginger oleoresin concentration and encapsulation efficiency is illustrated in Figure 3. According to the theory, higher concentrations of the active ingredient should correspond to higher encapsulation efficiency, provided that the molecular weight of the polymer material is sufficiently high (Ganesh *et al.*, 2010). As the concentration of the coating material increases, its viscosity also increases. In the context of encapsulation, sodium alginate acts as the coating material, forming a protective layer around the ginger oleoresin to create the beads.

The viscosity of the sodium alginate solution, which reflects its thickness and resistance to flow, plays a critical role in the encapsulation process (Munoz *et al.*, 2023; Pertiwi *et al.*, 2023; Azad *et al.*, 2020; Krisanti *et al.*, 2019). Higher viscosity can enhance the coating process, improve bead formation and stability, and thereby increase encapsulation efficiency. It also reduces the diffusion of ginger oleoresin from the beads' surface during drying.

However, the encapsulation efficiency for the 0.9% oleoresin concentration is lower than that for 0.7%. The high concentration of 0.9% may lead to excessive diffusion, resulting in the release of a substantial amount of ginger oleoresin. This can compromise the effectiveness of the encapsulation process, leading to lower efficiency (Munoz *et al.*, 2023; Pertiwi *et al.*, 2023; Azad *et al.*, 2020; Krisanti *et al.*, 2019).

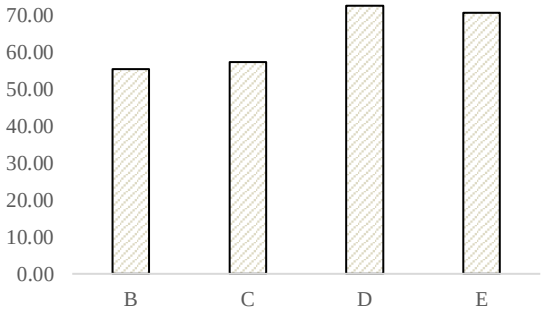


Figure 3. The relationship between ginger oleoresin concentration and encapsulation efficiency oleoresin (B = 0.3%; C = 0.5%; D = 0.7%; E= 0.9%)

Dry Beads Sample Crushing Time

Figure 4 shows the disintegration times of dry bead samples with different oleoresin concentrations (0.3%, 0.5%, 0.7%, and 0.9%). The observed disintegration times were 20 minutes, 23 minutes, 24.2 minutes, 24.3 minutes, and 25.06 minutes, respectively. The optimal disintegration time for coated tablets is typically less than 30 minutes (Markl and Zeitler, 2017), indicating that all tested dry bead samples meet this criterion.

Figure 3 displays a linear relationship, suggesting that higher concentrations of ginger oleoresin result in longer swelling and disintegration times. The disintegration process starts with a rapid increase in the weight of the alginate beads, reaching a peak before suddenly decreasing due to the erosion and disintegration of the beads. This effect is attributed to an ion exchange reaction, where Na^{+} ions in the phosphate buffer solution replace Ca^{2+} ions in the carboxylate groups of the alginate polymer. This exchange of monovalent and divalent ions disrupts the "egg-box" structure of the alginate, causing the polymer chains to separate. As a result, the beads swell and their weight increases. This swelling continues until osmotic pressure causes the particles to disintegrate.

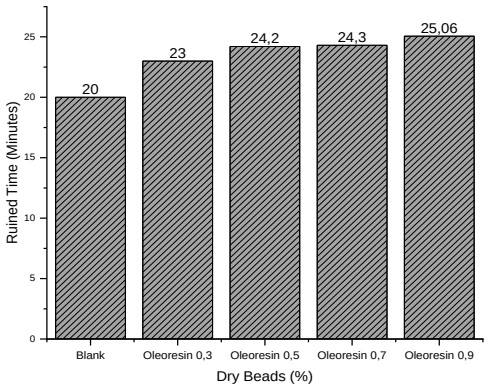


Figure 4. Correlation between oleoresin concentration and sample for disintegration time

Several factors influence the disintegration time of dry bead samples, including encapsulation efficiency and surface morphology (Munoz *et al.*, 2023; Pertiwi *et al.*, 2023; Azad *et al.*, 2020; Krisanti *et al.*, 2019). Encapsulation efficiency reflects the amount of active compound protected by the coating material. A lower encapsulation efficiency means that less of the active compound is coated, leading to a faster disintegration time for the sample.

Surface morphology also plays a significant role (Munoz *et al.*, 2023; Pertiwi *et al.*, 2023; Azad *et al.*, 2020; Krisanti *et al.*, 2019). A porous surface morphology can increase disintegration time because the liquid penetrates the pores more quickly, causing the sample to swell and disintegrate faster. Conversely, a uniform surface morphology with thicker walls of coating or polymer material can inhibit the diffusion process, affecting the rate of swelling and disintegration. The thickness and uniformity of the coating can therefore impact the overall disintegration behavior of the beads.

Surface Morphology of Alginate Beads

Figure 5 illustrates the surface morphology of the beads as observed using scanning electron microscopy (SEM). The dry bead samples selected for analysis were those with oleoresin concentrations of 0.3% and 0.7%. Both samples exhibited surface cracks or folds, which can be attributed to a less dense polymer matrix. When a significant volume of water content is removed, the polymer matrix can fold unevenly, resulting in surface irregularities (Voo *et al.*, 2016).

Figure 5(b) shows that the folds on the surface of the 0.7% oleoresin dry beads are more regular in appearance compared to the folds seen in Figure 5(a). The more regular folds contribute to a thicker surface, which enhances the encapsulation process. Therefore, it can be concluded that higher oleoresin concentrations positively impact the surface morphology of the beads.

Additionally, a yellow arrow in the images points to what are likely NaCl crystals (Gholamian *et al*., 2021). These crystals are a byproduct of the bead formation process and remain on the bead surface even after drying, making them detectable by SEM.

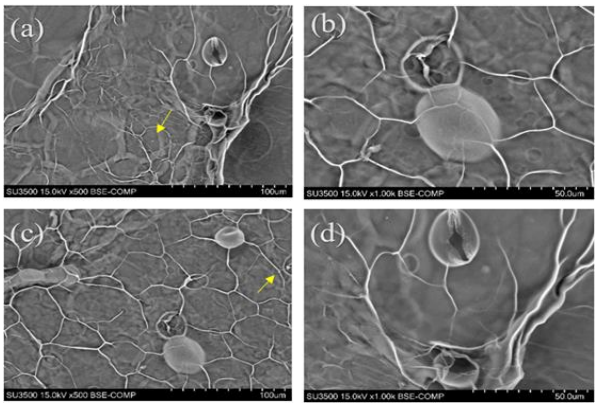


Figure 5. SEM results (a) Oleoresin 0.3% at 500x magnification (b) Oleoresin 0.3% at 1000x magnification (c) Oleoresin 0.7% at 500x magnification (d) 0.7% oleoresin at 1000x magnification

CONCLUSIONS AND RECOMMEDATION

Conclusions

Alginate beads containing ginger oleoresin were successfully encapsulated using the external ionic gelation method, with $CaCl_2$ as the crosslinking agent and Tween 80 as the surfactant The encapsulation efficiency was approximately 72.480% with a ginger oleoresin concentration of 0.7%, and the beads demonstrated an appropriate disintegration time for physiological conditions.

SEM analysis showed that the surface morphology of the alginate beads was rough and porous, with visible folds in the alginate polymer. Beads containing 0.7% ginger oleoresin exhibited more regular, fiber-like folds compared to those with 0.3% oleoresin. This suggests that higher oleoresin concentrations lead to a more homogeneous surface structure, indicating an improved encapsulation process.

Recommendation

For future research, it is recommended to compare this methodology with other encapsulation techniques and explore the use of different encapsulating materials to enhance the development of gingerol oleoresin nanoparticles, particularly for applications in the food and beverage industry.

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