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I-CReST 2025: 037-014 – Effect of Oil Concentration and Dripping Distance on the Flaxseed-Ginger Oil Alginate Beads' Properties

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ABSTRACT

This study focuses on the development and characterization of alginate beads for encapsulating flaxseed oil (FO) and ginger oil (GO), with the aim of enhancing their appearance to potentially improve consumer palatability. FO, rich in omega-3 fatty acids, was combined with GO, known for its antioxidant and digestive properties. The oils were encapsulated using the extrusion dripping method with a 2.5% (w/v) sodium alginate solution. The effects of oil concentration and the nozzle-to-gelation bath distance on bead properties specifically size and sphericity were evaluated. Emulsions were prepared with different oil concentrations [FOGO 10%, FOGO 5%, FO 5%, and GO 5% (w/v)] using 1% Tween 80, followed by sonication. Beads were extruded at four distances (10 cm, 15 cm, 20 cm, and 25 cm) into a 2% calcium chloride solution. Rheological parameters, including viscosity and shear rate, were measured using a rheometer. Bead size and sphericity were analyzed using ImageJ software and a sphericity factor formula, respectively. Results showed that a 5% (w/v) FOGO emulsion and a 25 cm dropping distance yielded the most uniformly spherical beads, with an average diameter of 2.04±0.15 mm and a sphericity factor of 0.01±0.022. The findings demonstrate that both oil concentration and extrusion distance significantly influence the physical characteristics of the alginate beads. These findings support the use of optimized alginate bead formulation to improve the appearance and potential palatability of functional oils, paving the way for more consumer-friendly delivery systems in nutraceutical and food applications.

Keywords: Alginate; encapsulation; flaxseed oil, ginger oil

1. INTRODUCTION

The development of microencapsulation systems has gained significant attention across food, pharmaceutical, and nutraceutical industries, particularly for improving the stability, delivery, and palatability of bioactive compounds. Among these, alginate beads are widely used as encapsulating matrices due to their biocompatibility, ease of gelation, and low toxicity [1,2]. Alginate, a naturally occurring polysaccharide derived from brown seaweed, forms stable hydrogels in the presence of divalent cations such as calcium, enabling the entrapment of oils and active substances in bead-like structures [3].

Flaxseed oil (FO), extracted from *Linum usitatissimum L.*, is a functional oil rich in alpha-linolenic acid (ALA), an essential omega-3 fatty acid known for its cardiovascular, antioxidant, and anti-inflammatory benefits [4]. However, its strong flavor and oxidative instability limit direct oral consumption and industrial applications [5]. Ginger oil (GO), derived from *Zingiber officinale*, contains active compounds such as gingerol and shogaol, offering digestive and anti-inflammatory properties [6]. The combination of FO and GO presents a synergistic formulation

with promising health benefits but requires effective delivery strategies to enhance stability and consumer acceptability.

Microencapsulation using alginate beads can mask unpleasant flavors, improve shelf life, and control the release of encapsulated components [7]. However, the physical characteristics of alginate beads, particularly size and sphericity, are influenced by several factors, including the viscosity of the emulsion, oil concentration, and extrusion conditions such as the dripping height [8,9]. Bead size uniformity and sphericity are critical for aesthetic appeal, dose accuracy, and flow properties in end-use applications [10].

This study investigates the impact of oil concentration and nozzle-to-gelation bath distance on the bead size and sphericity of flaxseed-ginger oil alginate beads. By evaluating different emulsions and dripping parameters, the research aims to optimize the production of visually uniform and structurally stable beads. The outcomes offer practical insight into improving the delivery system of functional oils for nutraceutical and food applications.

2. METHODOLOGY

2.1 Materials

Flaxseed oil was obtained from Hemani Herbal LLC (Malaysia), while ginger oil was sourced from Sigma-Aldrich (Malaysia). Sodium alginate powder was supplied by EvaChem (Malaysia), Tween 80 from R&M Chemical (Selangor), and calcium chloride dihydrate served as the crosslinking agent, commonly used in ionic gelation systems [11].

2.2 Preparation of Emulsions

A 2.5% (w/v) sodium alginate solution was prepared in distilled water and stirred at 500 rpm until homogenous. Tween 80 (1% w/v) was added to stabilize the oil-water interface, aiding emulsification [12]. Emulsions were prepared at varying oil concentrations: FOGO 10%, FOGO 5%, FO 5%, and GO 5% (w/v). Each emulsion was sonicated for 1 minute at 25 kHz to ensure uniform droplet dispersion [13].

2.3 Bead Formation via Extrusion Dripping

The emulsions were extruded through a 22G nozzle at 2.47 mL/min into a 2% (w/v) calcium chloride solution stirred at 300 rpm. The nozzle-to-bath distances were set at 10 cm, 15 cm, 20 cm, and 25 cm. The beads were allowed to set for 20 minutes before rinsing with distilled water. This technique is a widely accepted method for fabricating alginate-based beads with controlled size and shape [8,14].

2.4 Rheological Analysis

Emulsion viscosity and shear stress were measured using a rheometer under varying shear rates. These parameters are critical to understanding emulsion flow behavior, which affects bead formation and droplet deformation during dripping [15].

2.5 Bead Characterization

A total of 30 beads from each group were imaged using a digital microscope, and bead diameter was analyzed using ImageJ software. The average bead diameter (D) was calculated using Equation 1 as below:

$$D = (D_{max} + D_{min})/2 \quad (1)$$

The sphericity factor (SF), indicating bead roundness, was determined using Equation 2:

$$SF = (D_{max} - D_{min})/(D_{max} + D_{min}) \quad (2)$$

These equations are commonly used in microencapsulation research involving calcium alginate systems [8,16].

2.6 Statistical Analysis

All data were reported as mean ± standard deviation. A one-way ANOVA was performed to assess the effects of oil concentration and dripping distance on bead diameter and sphericity. When significant differences were detected ($p < 0.05$), Tukey's Honest Significant Difference (HSD) post hoc test was applied to determine specific group differences. Statistical significance was set at $p < 0.05$. [17].

3. RESULTS AND DISCUSSION

3.1 Rheological Behaviour of Emulsions

The emulsions exhibited non-Newtonian, shear-thinning behavior, typical of biopolymer-stabilized systems like those containing sodium alginate. Among the tested formulations, FOGO 10% showed the highest initial viscosity and strongest shear-thinning response, attributed to enhanced droplet interaction and matrix entanglement from higher oil content [6], [12]. This provided good structural resistance at rest and moderate flow under shear, favorable for extrusion.

FOGO 5% and FO 5% emulsions displayed moderate viscosity and shear-thinning profiles, allowing easier flow while maintaining stability during processing [13]. FO 5%, lacking ginger oil, exhibited slightly reduced interfacial stabilization compared to FOGO 5% [4]. The GO 5% emulsion demonstrated moderate-to-high viscosity with reduced structural integrity at high shear, consistent with the nature of essential oils contributing to initial thickness but lower cohesive strength [2], [10]. These findings, as summarized in Table 1, illustrate the distinct rheological profiles of each emulsion and highlight how oil composition affects flow behaviour and bead formation potential during the extrusion process.

Table 1. Rheological parameters of emulsions at different oil concentrations

Oil Formulation	Initial Viscosity Trend	Shear-Thinning Behavior	Final Plateau (High Shear)	Remarks
FOGO 10%	High	Strong	Moderate	High oil content increases droplet interaction and matrix entanglement, enhancing viscosity [6], [12]
FOGO 5%	Moderate	Strong	Moderate–Low	Balanced oil and emulsifier composition supports stability and flowability [13]
FO 5%	Moderate	Strong	Moderate	Similar oil load with absence of ginger oil affects interfacial stability [4]
GO 5%	Moderate–High	Moderate–Strong	Low–Moderate	Essential oil increases initial viscosity but may reduce structural integrity under shear [2], [10]

3.2 Effect of Oil Concentration on Bead Characteristics

Beads produced using higher oil concentrations (e.g., FOGO 10%) had larger diameters, likely due to the higher viscosity of the emulsions, which hindered droplet deformation. Conversely, the FOGO 5% emulsion yielded smaller and more uniform beads. The most optimal morphology—both in size and sphericity—was observed for FOGO 5% at 25 cm extrusion distance, with an average diameter of 2.04 ± 0.15 mm and a sphericity factor (SF) of 0.01 ± 0.022.

One-way ANOVA showed a significant difference in bead diameters between formulations ($p < 0.05$). Tukey's post hoc analysis revealed that beads from FOGO 10% were significantly larger than those from FOGO 5% and GO 5% ($p < 0.01$). Similarly, sphericity factor analysis indicated significant differences between oil types, with FOGO 5% producing the most spherical beads ($p < 0.05$). These findings are consistent with previous studies where high emulsion viscosity yielded larger droplets but reduced morphological control [8,14,16]. Refer to Fig. 1 and 2 for a visual summary of bead diameter and sphericity factor trends.

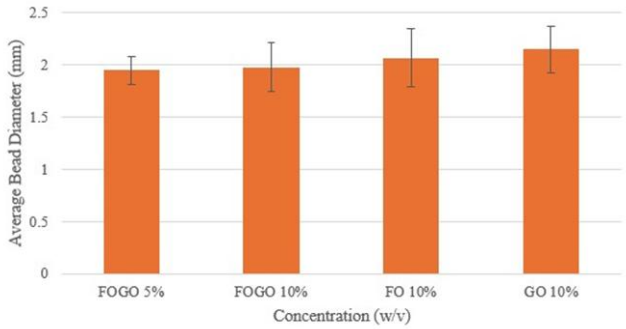

Fig. 1. Average bead diameter across oil formulations (FOGO 10%, FOGO 5%, FO 5%, GO 5%)

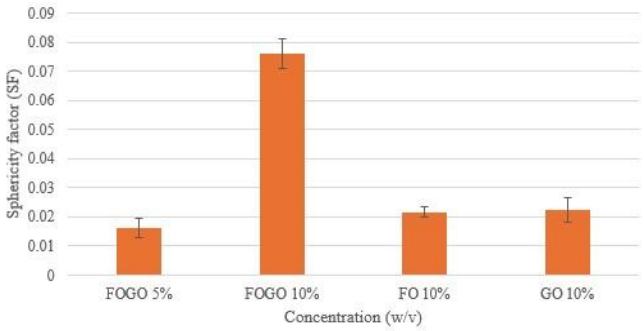

Fig. 2. Sphericity factor (SF) comparison for beads formed from different oil formulations

3.3 Effect of Extrusion Distance on Bead Morphology

Extrusion distance significantly influenced bead uniformity. Beads extruded from 25 cm showed the best sphericity and size consistency. At shorter distances (10 cm and 15 cm), beads tended to form irregular shapes due to premature gelation before full droplet formation.

ANOVA results indicated that extrusion distance had a statistically significant effect on both bead diameter and sphericity ($p < 0.01$). Post hoc analysis showed that 25 cm extrusion produced significantly more spherical beads (lower SF) compared to 10 cm ($p < 0.01$). This reinforces the benefit of allowing droplets to stabilize in air before gelling.

These findings support previous work suggesting that gravitational distance contributes to uniform droplet formation by enhancing detachment and rounding [8,14]. The trends are shown in Fig. 3.

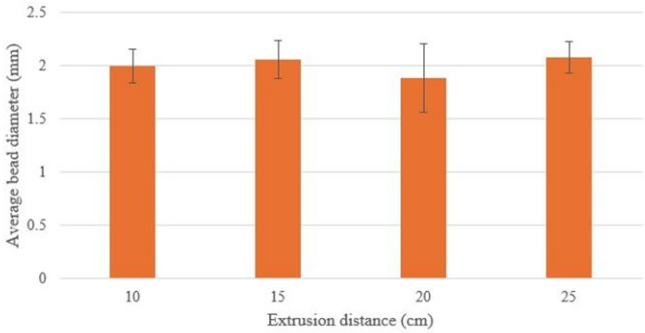

Fig. 3. Average bead diameter at varying extrusion heights (10 cm, 15 cm, 20 cm, 25 cm)

3.4 Optimal Formulation Parameters

Combining a 5% (w/v) FOGO emulsion with a 25 cm dripping height resulted in beads with superior morphology and consistency. This combination balanced emulsion flowability, reduced viscosity drag, and maximized gravitational stabilization, all of which are essential for producing spherical, uniformly sized alginate beads.

Statistically, this condition yielded the lowest SF (0.01 ± 0.022), which was significantly different from all other tested groups ($p < 0.01$). This optimal formulation is particularly suitable for applications requiring aesthetic and physical uniformity, such as functional food delivery and nutraceutical encapsulation [18,19]. A consolidated overview of all sphericity factor values across extrusion distances is shown in Table 2.

Table 2. Sphericity factors of beads extruded at different distances for each oil formulation

Formulation	10 cm	15 cm	20 cm	25 cm
FOGO 10%	0.09 ± 0.048	0.10 ± 0.026	0.06 ± 0.026	0.07 ± 0.032
FOGO 5%	0.04 ± 0.068	0.02 ± 0.031	0.02 ± 0.025	0.01 ± 0.022
FO 10%	0.03 ± 0.011	0.01 ± 0.024	0.03 ± 0.016	0.02 ± 0.006
GO 10%	0.02 ± 0.017	0.03 ± 0.009	0.02 ± 0.013	0.03 ± 0.043

These findings demonstrate the critical roles of emulsion viscosity and dripping height in determining the quality of alginate beads, which are essential parameters for applications in functional food and nutraceutical systems requiring precise morphology and controlled release [18,19].

4. CONCLUSION

The present study demonstrated the successful development of alginate beads encapsulating flaxseed and ginger oils using the extrusion dripping technique. By systematically varying oil concentration and dripping distance, it was evident that these parameters played a crucial role in determining bead size and sphericity. Emulsions containing 5% FOGO exhibited favourable rheological properties, resulting in smaller and more uniformly shaped beads. Additionally, a dripping height of 25 cm allowed sufficient time for droplet stabilization, contributing to improved bead morphology. The combination of 5% FOGO and a 25 cm extrusion distance produced the most optimal bead characteristics. These findings highlight the potential of this formulation strategy in enhancing the physical appearance and consumer acceptability of functional oil-based products in nutraceutical and food applications.

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REFERENCES

[1] Bhushani, J. A., & Anandharamakrishnan, C. (2014). Electrohydrodynamic processing: Advances and opportunities in the food sector. *Journal of Functional Foods, 7*, 12–22. https://doi.org/10.1016/j.jff.2014.01.031

[2] Nurdianah, M. N., & Sarbon, N. M. (2019). Development and characterization of edible seaweed-based film incorporated with ginger essential oil and its application on chicken meat. *Food Packaging and Shelf Life, 22*, 100398. https://doi.org/10.1016/j.fpsl.2019.100398

[3] Mathew, A. S., & Zakaria, Z. A. (2015). Flaxseed oil: An alternative functional food source. *Pharmacognosy Reviews, 9*(18), 73–77. https://doi.org/10.4103/0973-7847.162103

[4] Yang, J., Wu, C., Zhou, D., Qi, Y., Yang, L., & Zhang, Y. (2021). Effect of oil phase composition on the stability and properties of emulsions stabilized by whey protein isolate and pectin. *Food Hydrocolloids, 111*, 106223. https://doi.org/10.1016/j.foodhyd.2020.106223

[5] Mahdi, C., & Setyaningsih, W. (2020). Effect of sodium alginate concentration and calcium chloride on physical properties of encapsulated chili extract. *IOP Conference Series: Earth and Environmental Science, 454*, 012102. https://doi.org/10.1088/1755-1315/454/1/012102

[6] Huang, X., Kakuda, Y., & Cui, W. (2011). Hydrocolloids in emulsions: Particle size distribution and interfacial activity. *Food Hydrocolloids, 25*(5), 989–1004. https://doi.org/10.1016/j.foodhyd.2010.09.016

[7] Burgos-Díaz, C., Pizarro-Cerdá, J., & Soto, C. (2016). Alginate and chitosan-based beads for the encapsulation of functional oils: A comparative study. *Food Research International, 89*(Pt 1), 362–368. https://doi.org/10.1016/j.foodres.2016.08.009

[8] Chan, L. W., Lee, H. Y., & Heng, P. W. S. (2009). Mechanisms of external and internal gelation and their impact on the functions of alginate as a coat and delivery system. *Carbohydrate Polymers, 75*(4), 575–581. https://doi.org/10.1016/j.carbpol.2008.09.020

[9] Raj, V., & Prabha, D. (2018). Formulation and characterization of alginate beads for delivery of therapeutic agents: A review. *International Journal of Pharmaceutical Sciences and Research, 9*(9), 3706–3715. https://doi.org/10.13040/IJPSR.0975-8232.9(9).3706-15

[10] Adilah, Z. A. M., Jamilah, B., & Noranizan, M. A. (2018). Stability and physical characteristics of ginger oil-in-water emulsions stabilized by sodium caseinate–pectin complexes. *Food Hydrocolloids, 79*, 490–499. https://doi.org/10.1016/j.foodhyd.2017.12.018

[11] Javanbakht, S., & Namazi, H. (2017). Preparation and characterization of alginate nanoparticles containing turmeric extract for anti-cancer treatment. *International Journal of Biological Macromolecules, 99*, 1–8. https://doi.org/10.1016/j.ijbiomac.2017.02.065

[12] Piorkowski, D. T., & McClements, D. J. (2014). Beverage emulsions: Recent developments in formulation, production, and applications. *Food Hydrocolloids, 42*, 5–41. https://doi.org/10.1016/j.foodhyd.2014.02.013

[13] Mahfoudhi, N., Chouaibi, M., Donsì, F., Ferrari, G., & Hamdi, S. (2012). Study of emulsifying properties of gum Arabic and octenyl succinic anhydride modified starch in beverage emulsions. *Food Hydrocolloids, 28*(1), 147–153. https://doi.org/10.1016/j.foodhyd.2011.12.006

[14] Lee, J. S., Hong, J. Y., & Byun, Y. (2013). Morphology and physical characteristics of alginate beads containing microemulsion. *Food Science and Biotechnology, 22*(5), 1293–1298. https://doi.org/10.1007/s10068-013-0170-6

[15] Tadros, T. F. (2013). *Rheology of Dispersions: Principles and Applications*. Wiley-VCH Verlag GmbH & Co. KGaA.

[16] Anani, A. R., Karim, R., Fazry, S., & Zainol, M. K. (2022). Alginate encapsulation of oil blends: Physical characteristics and oxidative stability. *International Journal of Food Properties, 25*(1), 455–469. https://doi.org/10.1080/10942912.2022.2052089

[17] Kaltsa, O., Michon, C., Yanniotis, S., & Mandala, I. (2016). Stability of model beverage emulsions containing mixtures of whey protein and pectin. *Food Hydrocolloids, 56*, 280–290. https://doi.org/10.1016/j.foodhyd.2015.12.029

[18] Li, J., Shi, J., Wang, C., & Jiang, Z. (2008). Characterization and in vitro release properties of alginate–chitosan microcapsules containing angelica essential oil. *International Journal of Pharmaceutics, 361*(1–2), 191–196. https://doi.org/10.1016/j.ijpharm.2008.05.028

[19] Kawashima, Y., Okumura, M., Takenaka, H., Kojima, A., & Yamamoto, H. (1999). Microencapsulation of water-soluble drug by lipophilic polymer matrix and controlled release characteristics. *Journal of Controlled Release, 61*(3), 313–320. https://doi.org/10.1016/S0168-3659(99)00118-4