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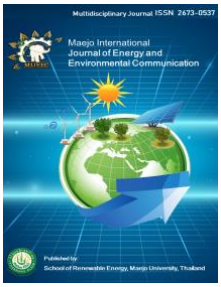

ARTICLE

Energy-efficient extraction and environmental impact of the kinetic release of total phenolic compounds from longan extract beads

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ABSTRACT

The purpose of this work was to investigate the kinetics of the total phenolic compound release from hydrogel in the form of gel beads with alginate and alginate with other wall materials consisting of alginate beads (100A), gelatin (30G/70A), gum arabic (30GA/70A), and pectin (30P/70A) in two media solutions: simulated gastrointestinal fluid (SGF) and simulated intestinal conditions (SIF) for 6 hours. 30GA/70A was found to have an optimal encapsulation effectiveness of 74.86 percent based on the test findings. The release characteristics of 30GA/70A beads tended to the total phenolic compound release was higher than other formulas. The kinetic model of Higuchi and Korsmeyer-Peppas' release It is applied to all kinds of beads to release the total phenolic compound. The best-fitting model in terms of mean R^2 (0.989) was found to be the Korsmeyer-Peppas model. This indicates the principle of diffusion controlled. Moreover, the analytical procedures require sample pretreatment since direct sample processing is usually impossible. MAE is an eco-friendly option that reduces solvent use and energy consumption while enhancing recovery rates. MAE is a potential, cost-effective way to extract valuable plant components with low environmental impact.

1. Introduction

The concept of food has undergone significant alteration in modern society. Food must help in the prevention of disease and advance health in addition to being implemented to support life and promote growth (Narapong et al., 2023). As a result, people decide to eat a diet higher in nutrients. *Dimocarpus longan*, also known as dragon's eye or longan, is a tropical tree species native to tropical Asia and China (Nguyen et al. 2020a), producing edible fruit similar to lychee but less aromatic (Nguyen et al. 2022; Unpaprom et al., 2019). The longan fruit has a pleasant flavor, is low in fat, and is high in vitamin C and antioxidants including gallic acid, ellagic acid, and corilagin, which are polyphenols that are typically present in natural foods (Nguyen et al. 2020b). The total phenolic compound can ability to control blood lipid levels and blood glucose by preventing fats from being absorbed lowers the synthesis and build-up of fat and controls the synthesis of gluconeogenesis and glycolysis (Zeng et al., 2019). Unfortunately, the total phenolic compound has poor stability and bioavailability, is easily degraded, and is sensitive to the conditions of the human digestive system. It also can't be transported effectively through the small intestine (Li et al., 2022). Therefore, the encapsulation of functional ingredients with natural is a technological to preservation of active ingredients in raw materials and deliver important substances

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necessary for health reaches the desired location in the body.

Hydrogels are polymer network gels that are highly water-absorbent and can remain stable in aqueous solutions. This property is caused by the cross-linking of the polymer chains that are the main components. As a result, the encapsulation of many kinds of significant compounds is a popular use for hydrogels. These drugs are administered to the body's intended organs to have positive therapeutic and health-promoting effects (Lin & Metters, 2006). Creating the right hydrogel is crucial to safeguarding the active components throughout delivery. Aside from exterior elements like temperature, light, oxygen, and relative humidity, the gastrointestinal tract's internal components during transit include pH and enzymes.

Sodium alginate is an anionic polysaccharide found in brown algae, commonly used to make hydrogels. Its carboxyl group can cross-link with divalent cations and form insoluble calcium alginate. It is widely used in drug delivery systems (Khlibsuwan et al., 2020). The shape of alginate hydrogels is spherical. Its surface is clear and smooth, and it holds water effectively. Nevertheless, prior investigations have revealed that alginate exhibits elevated porosity, leading to the premature release of significant compounds throughout the process (Dang et al. 2023). To improve the efficiency of release in the target area, research has been done on developing alginate hydrogels in conjunction with other naturally occurring polysaccharides such as gelatin, pectin, and gum arabic. According to some research, alginate can form strong complexes by chain-chain fusion and form hydrogels when divalent cations (such as Ca^{2+}) are added (Fang et al., 2008).

It is well known that one of the most crucial aspects of developing hydrogels is understanding the kinetics of active material release from them, particularly under in vitro release circumstances (Khammee et al. 2021; Vu et al., 2018) helps us comprehend how drugs are released. It is easier to understand if mathematical equations are used to explain it (Chit-aree et al. 2023). The equation's several factors, including particle size, polymorphic form, and efficiency of release, can provide information about the hydrogel structure's release properties, which is helpful when creating or choosing a hydrogel structure that is appropriate for important compounds (Singhvi & Singh, 2011). The purpose of this work was to investigate the kinetics of the total phenolic compound release from hydrogel in the form of gel beads with alginate and alginate with other natural polysaccharides in two media solutions: simulated gastrointestinal fluid (SGF) and simulated intestinal conditions (SIF) for 6 hours.

2. Material and methods

2.1 Extraction procedure by Microwave-Assisted Extraction

Remove the longan peel, then coarsely grind the pulp and seeds of longan. After being dried for 20 hours at 45 ºC in a hot air oven, it was ground into a fine powder and utilized to extract the total phenolic compound from the longan powders.

This research used a method to extract the total phenolic compounds from longan using a microwave-assisted extraction method. These were the extraction methods applied: First, take longan powder at a ratio of 1 gram per 30 milliliters of distilled water and put it in a round-bottomed flask. Then, to aid in condensation during extraction, a modified microwave equipped (Samsung, MS23F300EEK) with a Soxhlet condenser coil extraction unit and a vapor condenser (Coolab, WBCI- 15), and the extraction conditions were used the microwave power was 700 watts, and the extraction duration was 15 minutes. When the extraction is complete, the extract is filtered through a centrifuge (Dynamica, Velocity 18R) at a speed of 6500 rpm for 15 minutes to separate the sediment. Finally, the longan extract was concentrated with a vacuum evaporator until the concentration was 10 Brix. The extract was refrigerated at 4 °C in a tea-colored bottle to prevent deterioration until the following phase of analysis (Narkprasom et al., 2015)

2.2 Preparation of longan beads

Longan beads were prepared using the extrusion encapsulation method and made a minor modification to Chatterjee and Bhattacharjee. (2015) method (Chatterjee & Bhattacharjee, 2015). The encapsulator B390 (BUCHI Labortechnik AG 9230 Flawil, B-390) (Figure 1) was utilized in this study, and the parameters were set at 440 V for electrode voltage, 1440 Hz for frequency, and 3 mL/min for flow rate.

To prepare the longan beads, first need to prepare the wall material. Dissolve 1.5% of the sodium alginate by weight in the longan extract to create an alginate solution. Using a magnetic stirrer, mix the mixture until the substance dissolves and the longan extract has a consistency. Prepare a 1.5% by-weight solution of gum arabic, gelatin, and pectin using the same procedure. Next, four different types of hydrogel solutions were prepared to encapsulate the total phenolic compound. There are four different combinations of alginate: 100% alginate (100 A), 70% alginate with 30% gum arabic (30G/70A), 70% alginate with 30% gelatin (30GA/70A), and alginate 70% with pectin 30% (30P/70A). Drop 30 milliliters of the hydrogel solution into 150 milliliters of the 4% weight-based calcium chloride solution. Give 30 mins to firm in the gel solution. Use three rounds of distilled water washing and pat dry with paper free of dust. Finally, the obtained longan beads were analyzed for their physical characteristics, encapsulation efficiency, total phenolic compound, and study of the release of the total phenolic compound.

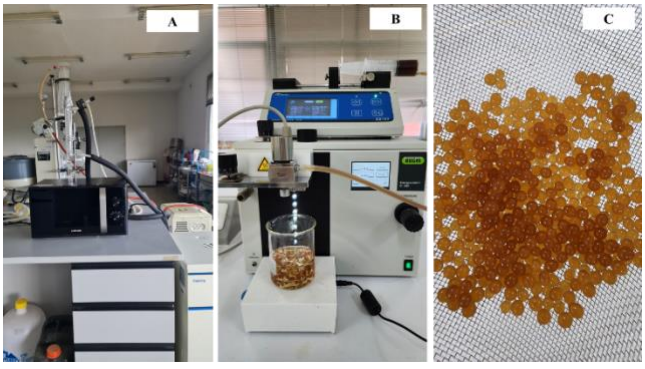

Figure 1 Microwave-assisted extraction and encapsulation by extrusion method (A) Microwave oven with a Soxhlet extractor set, (B)Encapsulator B390, (C) Longan beads

2.3 Quantitative total phenolic compound analysis

The total phenolic compound analysis was modified from Method (Namjouyan et al., 2010) with gallic acid as the standard curve. These are the steps in the analysis. Add 0.1 mL of the sample for analysis using a pipette into the test tube. After that, add 2 ml of 2% sodium carbonate solution (Na_2CO_3), add 0.1 ml of Folin Ciocalteu reagent as a last substance, and measure for 30 minutes. Place foil over the test tube's top and keep it someplace dark. The samples are examined for the total phenolic compounds using a spectrophotometer with a wavelength of 750 nm after the allotted amount of time has elapsed. The data were calculated by comparing it with the gallic acid standard curve, and the results are reported in milligrams of gallic acid equivalents/mg of sample (mg/g Galic acid equivalent, GAE).

2.4 Sizes and shapes

The particle size of the beads was analyzed 20 longan beads were randomly selected from each experiment. Then measure the diameter (D) with a digital vernier caliper to determine (500-196-30, Mitutoyo). Data is recorded as mean ± standard deviation (SD).

2.5 Encapsulation efficiency (EE%)

Quantification of the encapsulated efficiency (EE) of the total phenolic compounds (TPC) was carried out after the beads were dissolved in a 5% (w/v) Na-citrate solution (Quintal et al., 2018) and then centrifuged at 7,500 rpm to dissolve them at 25 ºC for 30 min, analyzed for phenolic compounds in beads from the clear supernatant to calculate the encapsulation efficiency (%) as shown in equation 1 :

$$EE\% = (\text{initial TPC} - \text{TPC in beads} / \text{initial TPC}) \times 100 \quad (1)$$

2.6 The standard sub Study of the release of total phenolic compound in simulated gastric conditions

The content of extract released from beads was determined by sinking a known number of capsules in the release media while agitating at 100 rpm. the release media used were in vitro model digestion fluids: simulated gastrointestinal fluid, SGF (6 h at 37°C), followed by immersion in simulated intestinal fluid, SIF (6 h at 37°C). SGF was prepared from a solution of hydrochloric acid 0.1M corrected with sodium hydroxide to pH 2, and SIF from phosphate buffer (pH 7.5) (Lin & Metters, 2006).

The experiments were conducted in three independent runs in duplicate. The simulated intestinal and gastrointestinal fluid with an aliquot of the alginate particles was maintained during different time intervals (30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, and 360 min). For six hours, the simulated solution was collected every thirty minutes and replaced with a new one every time in the same quantity. Consider the virtual solution kept in the quantity of phenolic compounds that were liberated from the beads was quantified.

$$\text{Total phenolic release (\%)} = (E / E_0) \times 100 \quad (2)$$

where E is the amount of total phenolic compound determined in the release, and E_0 is the initial amount of total phenolic compound in the beads.

2.7 Study of phenolic substance release kinetics in simulated gastric juice conditions

The total phenolic compound release data were used to create a graph comparable to all 4 popular models, as follows: (Azadi et al., 2017)

The zero-order model in equation (3) describes the gradual release of active chemicals, regardless of the initial concentration of the active compounds.

$$\text{Zero-order} = Q = K_0 t \quad (3)$$

The first-order model equation (4) describes release depending on the concentration of the active components.

$$\text{First-order} = \ln(100 - Q) = \ln(Q_0) - k_1 t \quad (4)$$

Higuchi model Equation (5) is used to describe the release of water-soluble and slowly dissolving active substances in solid or semi-solid encapsulants. Diffusion of substances is based on Fick's law and the square root of time.

$$\text{Higuchi} = Q = k_H t^{(1/2)} \quad (5)$$

Korsmeyer-Peppas model Equation (6) is used to describe the diffusion of substances that follow Fick's law and those that do not from systems in which the encapsulated polymer is both water-swelled and non-water-swollen (k_P = constant n= release exponent) whose value depends on the system's diffusion mechanism. In cases where the encapsulator is spherical, values of $n \leq 0.45$ for Fick's law discharge and $0.45 < n < 0.89$ for non-Fick's law release).

$$\text{Korsmeyer – Pepas} = \log (Q_0/100) = k_p t n \quad (6)$$

2.8 Statistical analysis

For each experimental condition, all tests were performed at least three times, and mean values were presented. Data were analyzed of Variance (ANOVA) was performed, followed by Duncan's New Multiple Range Test (95% confidence interval), using IBM SPSS Statistics 26.0 software. The results were expressed as means ± standard deviations.

3. Results and discussion

3.1 Characterization of the concentrated longan extract by Microwave-Assisted Extraction

The chemical and physical characteristics of the longan extract were obtained by the microwave-assisted extraction method at 15 min of extraction time, microwave power at 700 watts, and the ratio of longan /solution of 1:30 g mL^{-1}. Longan extract has an antioxidant activity of 40.89% and a total phenolic compound of 20.14 $mgGAE/g_{sample}$. The total soluble solids and total phenolic compounds in the longan extract increased thrice from the initial when concentrated using a vacuum evaporator quantity to 15 °Brix and 62.42 $mg\ GAE/g_{sample}$, respectively.

Table 1 Physicochemical characterization of natural and concentrated

Longan extract

Analysis	Longan extract	Concentrate
Total Soluble solids (ºBrix)	4 ± 0.03	15 ± 0.07
pH	4.95 ± 0.02	5.12 ± 0.05
Total phenolic compound (mgGAE/gDW)	20.14 ± 0.14	62.46 ± 0.21
Antioxidant activity (%)	40.89 ± 0.29	71.25 ± 0.17

3.2 Characterization of Longan beads from alginate combines natural polymers

Table 2 presents the optimal encapsulation parameters using alginate combined with various polysaccharides. Presumably, the porosity of sodium alginate particles may be decreased, and the release of total phenolic compound encapsulated beads may be impacted when sodium alginate is combined with other natural polysaccharides. Moreover, the viscosity of the beads increases when additional polysaccharides are added to the alginate matrix, enabling a synergistic interaction that improves the beads' stability (Mohamed et al., 2016). Thus, the purpose of this experiment was to examine how sodium alginate combined with gelatin, gum Arabic, and pectin influences the characterization of Longan beads. It was found that the combination of gum arabic and sodium alginate (30GA/70A) had the highest encapsulation efficiency of 74.86 ± 0.1771%. The phenolic content and antioxidant activity were 4.739 mgGAE/g beads and 60.89 %, respectively. Gum Arabic is an emulsifier that is used to improve the mixing of components. The result showed that the addition of gum Arabic could improve the loading efficiency of longan beads. Gum Arabic can be added to alginate in $CaCl_2$ solution to help reduce side-by-side aggregation, which can cause alginate to swell because of the electrostatic repulsive force between carboxylate anions. Additionally, it helps the product retain its water content (Annisa et al., 2022).

3.3 In vitro the release of the total phenolic compound in simulated gastric juice conditions

The total phenolic compound release behavior of the 4 formulas of longan beads was examined in vitro by soaking the longan beads in SGF (pH 2) and SIF (pH 7.5) for 6 hours. It should select suitable materials to prepare the beads to affect the ideal release behavior. This is because the presence of pores in the alginate network is the main factor in its release. Therefore, fillers should be used to delay the release of active compounds (Córdoba et al., 2013). The release of phenolic compounds in SGF is shown in Figure 2. The release occurs rapidly during the first 210 min, which can be observed from the release curve steep during this time and slows down and will eventually reach equilibrium at approximately 270 minutes onwards, as can be seen from the behavior during the graph where the release is relatively constant, parallel to the timeline. After 360 minutes in the simulated gastric situation, the total phenolic compound released from the beads of 100A, 30G/70A, 30GA/70A, and 30P/70A was roughly 60.11, 54.76, 41.35, and 46.77%, respectively. It was discovered from the features that the longan beads had not lost their spherical shape.

This response indicates that in SGF (pH 2) compared to SGF (pH 7.5), longan beads will release fewer total phenolic compounds. This is explained by the ion exchange process, which produces water-insoluble alginic acid when the interchain calcium ions are replaced by H+ during the carboxylic acid group protonation in the alginate chain (Zhou et al., 2018). It causes the alginate hydrogel to shrink in low pH environments and slows down the penetration of water into the particles, which delays the release of the total phenolic compounds (Villaverde et al., 2018). Nevertheless, it was found that the 100% alginate formula (100A) had the maximum amount of the total phenolic compound release after analyzing the release behavior of the total phenolic compounds in all 4 formulae. Due to the porous nature of the alginate structure. The total phenolic compounds within are hence readily diffused to the solution when compared to other formulas. The formula that released the least phenolic substances was the 30GA/70A formula because gum arabic is an ampholytic polymer. Due to this property, gum arabic uses electrostatic forces to draw in negatively charged alginate molecules (Fang et al., 2011). Because gum arabic functions as a barrier in the pores of alginate, this suggests that an appropriate ratio of alginate to gum arabic can prevent the release of the total phenolic compounds (Nayak et al., 2012).

Table 2 Study effect of sodium alginate combined natural polysaccharides on encapsulation efficiency.

sample	Bead diameter (mm)	Encapsulation Efficiency of TPC (%)	Total phenolic compound (mgGAE/g beads)	Antioxidant activity (%)
100A	3.54	65.54 ± 0.048^{d}	3.723 ± 0.241^{d}	50.14 ± 0.264^{c}
30G/70A	3.32	69.69 ± 0.225^{c}	4.136 ± 0.176^{c}	54.67 ± 0.215^{c}
30GA/70A	3.25	74.86 ± 0.171^{a}	4.631 ± 0.131^{a}	60.89 ± 0.169^{a}
30P/70A	3.29	71.35 ± 0.187^{b}	4.325 ± 0.264^{b}	58.36 ± 0.223^{b}

Figure 3 shows the release of the total phenolic compound from longan beads in the simulated intestinal fluid (SIF). It was found that the first 180 minutes saw a fast release slowed down, and started to reach equilibrium around minute 270. After 360 minutes in the

simulated intestinal fluid, the total phenolic compound released from the beads of 100A, 30G/70A, 30GA/70A, and 30P/70A was roughly 90.70, 75.30, 87.31, and 80.06 %, respectively. The release of all formulas of longan beads tends to be similar.

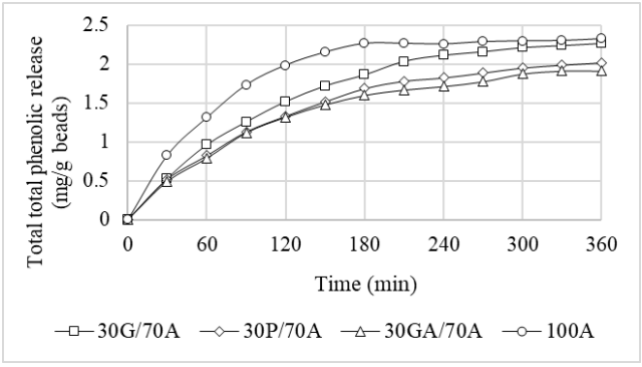

Figure 2 The total phenolic compound release in SGF at 37 °C for 360 min

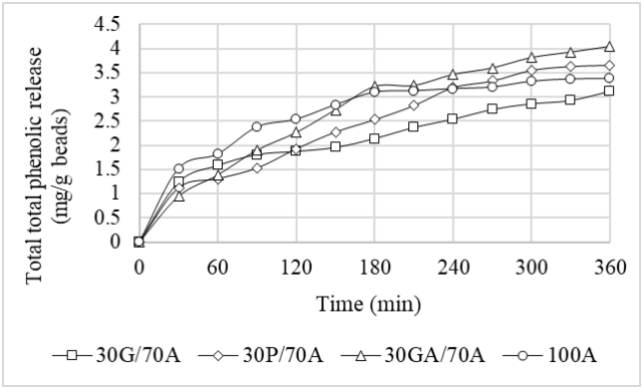

Figure 3 The total phenolic compound release in SIF at 37 °C for 360 min

Longan beads will maintain their spherical shape for the first 90 minutes and after this period will begin to swell. This is because the Na^+ ions in the phosphate buffer solution undertake an ion exchange process with the Ca2+ ions of the beads, which bind to the COO groups present in the alginate beads, causing alginate beads to become unstable in phosphate buffer (pH 7.5). The resultant polymannuronate unit produces chain relaxation, increases the electrostatic repulsion force in the negatively charged COO group, and causes the beads to swell or expand more as they absorb water (Bajpai & Sharma, 2004), it is observed that turbidity appears in the system due to the formation of calcium phosphate as shown in Figure 4.

In addition, the Ca^{2+} ion associated with –COO– the unit of polyguluronate (G block) also begins to be exchanged for Na+ ions in the phosphate buffer. This is because the polygluuronate sequence is very important in binding to calcium ions. This acts as a stable cross-linking structure within the tight gel (egg box). Therefore, the beads begin to lose weight and eventually dissolve (Dallabona et al., 2020). As can be seen, the beads 100A, which are made entirely of alginate, will dissolve in the phosphate buffer after 360 minutes. As for the beads in other formulas that are mixed with polymers in the polysaccharide and protein groups will be seen as swelling because it helps to slow down the release of phenolic substances. Therefore, the rapid release of SGF is thought to be consistent with liberating phenolic compounds in the small intestine for absorption and complete body utilization.

3.4 In vitro release kinetics of total phenolic compound in simulated gastric juice conditions

The characteristics of the polymer and the extract both have an impact on the total phenolic compound that is released from the longan beads. First-order zero-order Higuchi and Korsmeyer-Peppas kinetic models were fitted with experimental data to ascertain the release mechanism of the total phenolic compound released from the four beads formulas. Furthermore, it was discovered that the Higuchi and Korsmeyer models were the most appropriate models for both situations when the phenolic release data of longan beads in SGF and SIF were compared with the model. The zero-order model is a study of constant phenolic release rates and shape-independent release. The first-order model is a concentration-dependent release of phenolic compounds. The Higuchi model is the diffusion of phenolic substances from high concentration to low concentration (Fick diffusion) and finally the Korsmeyer–Peppas model is the release of phenolic substances from the system polymer. This indicates a faster release rate constant.

Based on the longan bead release behavior in gastric conditions (SGF) shown in Table 3, the Higuchi model had a K_H value of approximately 0.17-0.22. This model confirmed the release of total phenolic compound which is a water-soluble substance distributed in a network structure, which in this case is a mixed polymer. The K_p value and the n value in the Korsmeyer-Peppas model are roughly 0.466-0.562 and 0.29-0.36, respectively. The release of concentrated phenolic compound from inside the bead to the solution at a lesser concentration is known as Fick's law diffusion considered from the n value that this is the total phenolic compound release pattern in SGF. It might also mean that phenolic chemicals, which are low molecular weight, can pass right through the beads without interacting with the enclosed polymer material through ionic reactions or adsorption (Puguan et al., 2015). The value of the exponent (n) also indicates that the bead geometry is close to spherical shown in Figure 5.

Based on the longan bead release behavior in the simulated intestinal phase (SIF) shown in Table 4, The k_P value of the Korsmeyer-Peppas model was found to be greater than SGF in the range of 0.71-0.80. This suggests that the release of phenolic compounds from all of the beads in the intestinal condition was faster than in the gastric condition, and the exponent value n is between 0.44-0.57, indicating that the mass transfer typically occurs via diffusion which defies Fick's law. For the spherical geometry, the emission has an exponent value of $0.43 < n < 0.85$. This equation represents what is known as "anomalous" transport and the intricacy of polymeric hydrogel diffusion. The pH may be lower than in intestinal circumstances, which could be the cause of this. To produce the carboxylate anion (COO^-) and hydrogen ions, the carboxyl group deprotons. (H^+)The fast release of phenolic compounds is caused by the alginate polymer swelling (Tsai et al., 2017) due to electrostatic repulsion between carboxylate anions shown in Figure 6. The experiment revealed that whilst there was significant swelling in SIF, the gel beads shrank in SGF. This could have been the main cause of the erosion of the substance's enveloping structure and diffusion of the alginate-based polymer.

Figure 4 Longan beads (100A) were soaked in phosphate buffer for 90 min

Table 1 Constant (k), correlation coefficient (R^2), and release exponent (n) of different kinetic models for phenolic release in SGF

Treatment	Zero-order		First-order		Higuchi		Korsmeyer- Peppas		
	k_0	R^2	k_1	R^2	k_H	R^2	k_p	n	R^2
100A	0.006	0.669	0.002	0.706	0.172	0.936	0.466	0.295	0.962
30G/70A	0.006	0.836	0.001	0.903	0.151	0.979	0.562	0.347	0.977
30GA/70A	0.005	0.814	0.001	0.905	0.223	0.986	0.475	0.324	0.986
30P/70A	0.006	0.887	0.001	0.977	0.206	0.984	0.549	0.368	0.968

Table 4 Constant (k), correlation coefficient (R^2), and release exponent (n) of different kinetic models for phenolic release in SIF

Treatment	Zero-order		First-order		Higuchi		Korsmeyer- Peppas		
	k_0	R^2	k_1	R^2	k_H	R^2	k_p	n	R^2
100A	0.005	0.717	0.001	0.716	0.130	0.915	0.714	0.440	0.882
30G/70A	0.006	0.855	0.001	0.750	0.129	0.933	0.717	0.568	0.967
30GA/70A	0.005	0.849	0.001	0.719	0.107	0.954	0.805	0.538	0.989
30P/70A	0.005	0.859	0.001	0.748	0.114	0.947	0.778	0.545	0.968

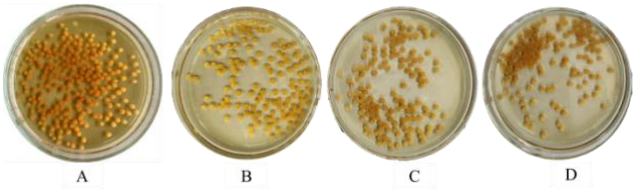

Figure 5 Release of total phenolic compounds from longan beads of 4 formulas (A) 100A, (B) 30G/70A, (C) 30GA/70A, and (D) 30P/70A under SGF at 360 min.

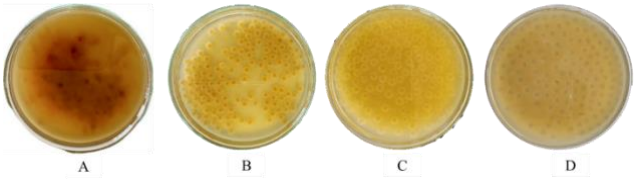

Figure 6 Release of total phenolic compounds from longan beads of 4 formulas (A) 100A, (B) 30G/70A, (C) 30GA/70A, and (D) 30P/70A under SIF at 360 min.

3.5 Enhancing analytical efficiency and environmental sustainability through microwave-assisted extraction

Microwave-assisted extraction (MAE), also known as microwave-assisted solvent extraction (MASE), is recognized as a more environmentally friendly option. The MAE technology minimizes energy wastage and ecological footprint by employing a focused and precise heating approach (Nguyễn et al., 2022). The results of our study show that MAE greatly simplifies the extraction process of bioactive flavonoids by requiring less solvent, achieving higher recoveries, and reducing extraction times compared to previous approaches. The MAE procedure consists of three separate phases that effectively extract flavonoids from the sample matrix. At first, when there is high pressure and temperature, flavonoids break from the matrix and start the extraction process (Cebrián-Lloret et al., 2022). Subsequently, the solvent starts to spread evenly throughout the matrix, so promoting the additional release of the chemicals. Ultimately, the dynamic flavonoids penetrate the solvent, so concluding the extraction procedure. This stepwise methodology guarantees a comprehensive and efficient extraction of bioactive chemicals.

The benefits of MAE were apparent in laboratory experiments, demonstrating decreased extraction durations, lower temperatures, less solvent consumption, increased product quantities, and enhanced specificity. Notwithstanding these obstacles, the increasing enthusiasm for environmentally friendly technology encourages the implementation of MAE as a promising method for extracting valuable substances from plant materials (Sanchez-Prado et al., 2015). The approach provides expedited treatment and enhanced energy economy, while also guaranteeing less quality degradation during extraction. The selection of solvent has been identified as a critical component that significantly affects the production of bioactive compounds. This highlights the importance of carefully choosing the solvent to get optimal results. MAE has superior yield, selectivity, and extraction efficiency compared to conventional techniques such as Soxhlet extraction and maceration. The cost-effectiveness and reduced environmental impact of MAE, achieved by the use of non-toxic solvents and lower energy use, make it a highly appealing choice for contemporary analytical applications.

4 Conclusion

To improve encapsulation effectiveness, alginate is combined with wall materials such as pectin, gum arabic, and gelatin to encapsulate the total phenolic compound using the extrusion process. It was discovered that the wall material and alginate beads together were spherical providing a high yield of the whole phenolic compound and a high encapsulation efficiency. While the kinetic release of the total phenolic compound in gastroparesis is governed by Fickian diffusion, it is governed by non-Fickian diffusion in the intestinal environment, which combines diffusion and chain relaxation. When designing delivery systems for health-critical compounds in the form of functional food products, the concentration of the substances involved, as well as the preparation and cross-linking process, are crucial considerations.

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