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ORIGINAL ARTICLE

Physicochemical properties of heterogeneously acetylated glucomannan of *A. oncophyllus* and its performance for iron encapsulation

Propriedades físico-químicas do glucomanano heterogeneamente acetilado de A. oncophyllus e seu desempenho para encapsulamento de ferro

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Abstract

Well-known as a food additive, glucomannan has excellent biocompatibility and biodegradability properties. However, glucomannan is easily gelled, which limited its use in high concentration. To reduce the gel formation ability of glucomannan, acetylation was conducted. This work aims to study the effect of acetylation on physicochemical properties of glucomannan. Acetylation was performed in heterogeneous system which glucomannan was immersed in ethanol (96%) with various concentrations of glucomannan (5-25%) and acetic acid (5-99%). This modified glucomannan was subsequently used as an encapsulation matrix for producing iron beads. The results showed that higher concentration of acetic acid in acetylation impacted on higher solubility and viscosity of glucomannan. The transmittance intensity of Infrared (IR) spectra and morphology of glucomannan were changed due to the acetylation and encapsulation process. The highest viscosity of the matrix (484.33 cP) led to the highest Encapsulation Yield (EY) (53.3%). Gompertz's model fitted to describe the release profile of iron in all samples (R^2>0.92) that showed the burst phenomena in the initial release. This work found that acetylated glucomannan had higher solubility and has a potency to protect the iron taste during oral consumption as it releases slower in neutral pH solution.

Keywords: Glucomannan modification; Glucomannan acetylation; Gelation encapsulation; Iron release; Encapsulation yield.

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Resumo

Conhecido como aditivo alimentar, o glucomanano possui excelentes propriedades de biocompatibilidade e biodegradabilidade. No entanto, o glucomanano é facilmente gelificado, o que limita seu uso em altas concentrações. Para reduzir a capacidade de formação de gel do glucomanano, procedeu-se à sua modificação, usando acetilação. Este trabalho tem como objetivo estudar o efeito da acetilação nas propriedades físico-químicas do glucomanano. A acetilação foi realizada em reação heterogênea, que foi conduzida em etanol (96%), com várias concentrações de glucomanano (5-25%) e ácido acético (5-99%). Este glucomanano modificado posteriormente foi usado como matriz de encapsulamento para a produção de grânulos de ferro. Os resultados mostram que uma maior concentração de ácido acético na acetilação impactou na maior solubilidade e viscosidade do glucomanano. A intensidade dos espectros de IR e a morfologia do glucomanano foram alteradas devido ao processo de acetilação e encapsulamento. A maior viscosidade da matriz (484,33 cP) levou ao maior rendimento de encapsulamento (53,3%). O modelo de Gompertz ajustou-se para descrever o perfil de liberação do ferro em todas as amostras (R^2>0,92) que apresentaram os fenômenos de explosão na liberação inicial. Este trabalho verificou que o glucomanano acetilado apresentou maior solubilidade e poder de proteção do sabor do ferro durante o consumo oral, pois é liberado mais lentamente em solução de pH neutro.

Palavras-chave: Modificação de glucomanano; Acetilação; Encapsulamento por gelificação; Liberação de ferro; Rendimento de encapsulamento.

Highlights

- Acetylation on glucomannan had successfully conducted using acetic acid in a heterogenous reaction
- Acetylation facilitated iron encapsulation ability of glucomannan using gelation method
- Gompertz's model fitted to describe the release profile of iron in all samples that showed a burst phenomenon in initial release

1 Introduction

Iron is naturally presented in the red blood cell in enzymes, hemoglobin, and myoglobin, mainly stored in the liver and bone marrow. Insufficient iron intake causes iron deficiency anemia in humans, which has the highest number of micronutrient deficiency cases globally. This deficiency affects human immunity, cell development, and human productivity of more than 2 billion people worldwide (Scott et al., 2014). The iron fortification helps in fulfilling the iron intake as recommended (Naktinienė et al., 2021). However, direct addition of iron in the food fortification method comes with an unacceptable flavor and taste. Moreover, iron deficiency is also affected by the reduction of iron bioavailability and iron loss during food processing (Shubham et al., 2020). The presence of absorption inhibitors of iron in meals, such as phytic acid and polyphenols, can cause iron degradation which decreases its bioavailability (He et al., 2018; Hurrell, 2021). The iron encapsulation prevents direct contact of iron to its unsupported environment (Naktinienė et al., 2021).

Encapsulation is a method to cover and protect iron using an encapsulant matrix that limits the iron contact with other components. The undesirable sensorial changes can be prevented as the iron is protected (Bryszewska et al., 2019). Encapsulation using polysaccharides as the matrix improves the bioavailability of active substances as it increases the solubility of the components encapsulated in particles. Suitable polysaccharides also protect the active substances in the digestive tract conditions and increase the residence time of the active substances (Fathi et al., 2014). In drug-delivery use, the properties of matching matrix allow to support the drug-targeted delivery, which maintains and releases the active substances in specified organs (Wang et al., 2019). Chean et al. (2021) used chitosan-alginate matrix to protect the *Lactiplantibacillus plantarum* against simulated gastrointestinal conditions.

Glucomannan, a natural polysaccharide extracted from *Amorphophallus oncophyllus* Prain ex Hook. f., shows excellent biocompatibility and biodegradability properties which suitable for manufacturing drugs and medical dressing (Liu et al., 2012). However, glucomannan has low solubility as hydrogen bond formation during purification and drying treatment (Alonso-Sande et al., 2009). In addition, glucomannan's high molecular weight and viscosity limit its application. Glucomannan with specific molecular weight could have specified biological functions, such as anti-tumor, immunoregulation, and cytothesis (Liu et al., 2012). Thus, glucomannan should be modified to conform its use and broaden its application (Wardhani et al., 2019; Zhu, 2018).

For drug excipient use, lower solubility in neutral pH is preferred to cover the drug taste. Glucomannan solubility is depended on its acetyl group, as it prevents the glucomannan self-aggregation and promotes the water penetration to amorphous phase (Wani et al., 2012; Wardhani et al., 2022). Acetylation is a proven method to increase glucomannan solubility. Liu et al. (2011) produced more soluble glucomannan with a degree of acetylation of 0.8-0.9. Wang et al. (2020) used acetic acid to produce acetylated glucomannan which has solubility improvement in organic solvents. In previous research, Wardhani et al. (2016) conducted glucomannan acetylation homogenously using acetic acid in various concentrations. However, in that work only 3% maximum of glucomannan can be reacted with acetic acid as glucomannan has high gelation properties in water. Heterogeneous acetylation can be an alternative that allow to conduct the reaction in the presence of non-solvent. Quintana et al. (2018) performed heterogenous acetylation of chitosan.

Hence, in this work heterogenous acetylation of glucomannan was conducted in ethanol using acetic acid. The acetylated glucomannan was subsequently used for iron encapsulation using a gelation method. Physicochemical properties of the acetylated glucomannan and performance on the iron encapsulation were studied.

2 Materials and methods

2.1 Materials

Crude flour of *A. oncophyllus* tube was bought from a local farmer at Nganjuk, East Java, in Indonesia. The glucomannan was extracted based on previous method using isopropyl alcohol (IPA) (Wardhani et al., 2020). The extraction found that the flour contained 76.3% glucomannan. Ethanol (96%) was purchased from PT. Indoacidatama Tbk, (Surakarta, Central Java, Indonesia). Ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$), HCl, 1,10-phenanthroline monohydrate ($C_{12}H_8N_2.H_2O$), acetic acid glacial and other reagents were pro analysis grade from Merck Chemical Co. (Darmstadt, Germany).

2.2 Modification of glucomannan

Glucomannan was dispersed in acetic acid-ethanol solution (100 mL) and stirred for 1 h in ambient conditions. The concentration of acetic acid and glucomannan were varied for 5, 10, 25, 75, 99% and 5, 10, 15, 20, 25%, respectively. The acetylated glucomannan was obtained by filtering using filter paper and subsequently oven-drying at 80 °C for 30 min.

2.3 Iron encapsulation

Glucomannan matrix solution was prepared by dissolving acetylated glucomannan powder (3 g) in distilled water (100 mL) under constant stirring for 10 min. After addition of ferrous sulfate (0.3 g), the solution was continuously stirred for 15 min. Subsequently, the solution was dropped to ethanol (96%, 100 mL) to form iron beads. The mixing and beading process were conducted at ambient temperature (~25 °C). The beads were immersed in the ethanol solution for 3 h before being filtered and oven-dried at 105 °C for 120 min.

2.4 Functional group and morphological analysis

Functional groups of native glucomannan, acetylated glucomannan, and encapsulated iron were obtained by Infrared (IR) spectra using a Fourier-transform infrared (FTIR) spectroscopy (Perkin Elmer Spotlight 200, Perkin Elmer Inc., Waltham, MA, USA) at a range of wave number between 4000-400 cm^{-1}. The surface morphology of the samples was observed using a Scanning Electron Microscope (SEM) instrument (JEOL JSM-6510 LA, JEOL Ltd., Akishima, Tokyo, Japan).

2.5 Viscosity

The viscosity of glucomannan powder was determined using Cannon Fenske Viscometer size 100 (Schott AG, Mainz, Rhineland-Palatinate, Germany) (Wardhani et al., 2018). Glucomannan solution was prepared by dissolving and stirring the glucomannan (1 g) in distilled water (40 mL) at 45 °C for 90 min. After centrifuging at 2300xg (EBA 21 centrifuge, Hettich®, Kirchlengern, North Rhine-Westphalia, Germany) for 15 min, the supernatant was transferred to the viscometer and compared with the data of water.

2.6 Solubility

Solubility determination was conducted following the method of Wang et al. (2014) with slight modification. Glucomannan solution (1%) was prepared and heated in a water bath at 60 °C for 30 min. The mixture was centrifuged at 2300xg for 20 min to obtain the supernatant. The supernatant was weighed and oven-dried at 105 °C until constant-weighted. The weight of supernatant and its oven-dried precipitate was determined for solubility calculation (Equation 1).

$$Solubility\ (\%) = \frac{Dried\ supernatant\ weight}{initial\ supernatant\ weight} \text{x } 100\% \quad (1)$$

2.7 Encapsulation yield

Iron bead (0.4 g) was dispersed in HCl solution (6 M, 10 mL) and stirred for 1 h in ambient conditions. The mixture was subsequently filtered, and the filtrate was diluted to 10 mL using distilled water. The solution (0.1 mL) was added by sodium thiosulphate solution (1.1 mL, 100 ppm), 1,10-phenanthroline (1.5 mL, 1000 ppm), acetate buffer (pH 4.5, 1.5 mL) and acetone (5 mL). After diluting to 10 mL, the solution was stirred for 120 min. The absorbance of the solution was obtained by Ultraviolet-visible (UV-Vis) spectrophotometer (Shimadzu UV Mini 1240, Shimadzu Asia Pacific Pte Ltd, Singapore, Central Region, Singapore) at 520 nm. The iron content was obtained by plotting the absorbance data to the iron standard curve. The encapsulation yield was calculated using Equation 2.

$$Encapsulation\ yield\ (EY, \%) = \frac{concentration\ of\ iron\ in\ bead}{concentration\ of\ iron\ added} x100\% \quad (2)$$

2.8 Iron release and its kinetics

The iron release was determined by an in-vitro test in 2 pH solutions. Dried iron bead (0.5 g) was added to either 150 mL of HCl solution (0.1 M, pH 1.2) or phosphate buffer solution (0.1 M, pH 7.4) under constant stirring. Sample solutions were taken every 30 min for the iron concentration determination as described in the previous section.

The iron release at a certain time t (C_t) per total iron content (C_{total}) was mathematically modeled using four equations, *i.e.*, Weibull, Hopfenberg, and Gompertz models (Equation 3, 4, and 5, respectively) using linear regression (Ramteke et al., 2014; Shah & Rajput, 2019).

$$C_t = C_{total}\left[1 - exp\left(\frac{-(t-Ti)^b}{a}\right)\right] \quad (3)$$

$$\frac{C_t}{C_{total}} = 1 - [1 - k_1 t(t-l)]^n \quad (4)$$

$$\frac{C_t}{C_{total}} = \exp\left[-\alpha\, e^{\beta \log t}\right] \quad (5)$$

where:

T_i or l = lag time for dissolution process. There was no lag time occurred in this dissolution process ($T_i = l = 0$)

a = time-dependent parameter

b = the shape of dissolution curve progression

k_1 = erosion rate constant

α = the undissolved iron at time =1

β = dissolution rate per unit of time.

3 Results and discussion

This research focused on acetylation of glucomannan to modify its properties and subsequently, applied it for encapsulation iron using gelation method. Impacts of acid-glucomannan ratio and concentration of glucomannan on the viscosity and solubility of acetylated glucomannan were studied. The modification was conducted heterogeneously in ethanol to prevent the gel formation. Performance of the encapsulated iron using acetylated glucomannan, including its release studies in acid and neutral conditions, was observed.

3.1 Acetylation

Homogenous acetylation had successfully modified the physicochemical characteristics of 3% glucomannan solution (Wardhani et al., 2016). However, high gelation capability of glucomannan limited diffusivity of reactants that reduced the effectiveness of the homogeneous reaction. Only low glucomannan concentration involved in the reaction. In this research, glucomannan acetylation was performed heterogeneously in ethanol to increase its yield. The heterogeneous reaction might hinder glucomannan gelation, allowing more glucomannan to contact with the acid. In this works, up to 25% glucomannan was used in the heterogeneous acetylation, higher concentration than that of the homogenous one.

The viscosity and solubility of glucomannan were affected by its acetyl group (Mehboob et al., 2020). Hydroxyl group of glucomannan forms hydrogen bonds with water, leading to gel formation (Impaprasert et al., 2017). In acetylation, the hydroxyl groups of glucomannan were replaced with the acetyl ones. This latest group inhibited the inter-chain hydrogen bonds between adjacent glucomannan chains as intramolecular and intermolecular hydrogen bonds weakened (Adeyanju et al., 2016; Colussi et al., 2015; Wardhani et al., 2016). Moreover, the presence of acetyl group reduced the molecular bond strength and eased the water diffusion. This condition led to increase the swellness (Hoover & Sosulski, 1985). The less association of glucomannan chains eased the water penetration and increased the glucomannan solubility. Hence, the viscosity and solubility of glucomannan tended to increase after modification when there is more acetyl group involved in the reaction (Figure 1b). A similar result of increasing viscosity and solubility after acetylation was also reported by Shubeena et al. (2015) on chestnut starch and Siroha et al. (2019) on pearl millet starch, respectively.

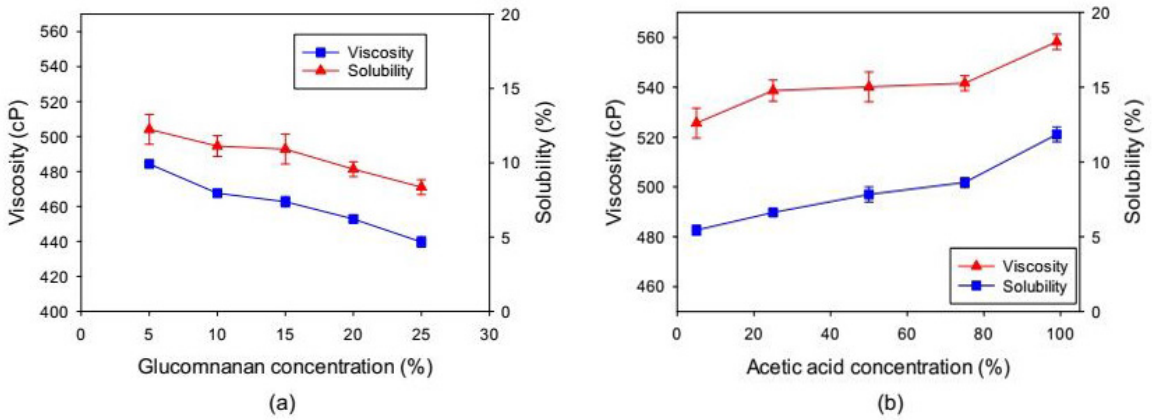

Figure 1. Effect of (a) glucomannan concentration and (b) acetic acid concentration on viscosity, solubility, and encapsulation yield of acetylated glucomannan.

3.2 Iron encapsulation

The gelation method was used for iron encapsulation by dropping glucomannan-iron solution into ethanol which acted as an anti-solvent for glucomannan and formed iron beads (Wardhani et al., 2019). The matrix ability to entrap the active agent was represented by the value of Encapsulation Yield (EY). Figure 2 shows that higher viscosity of glucomannan performed higher Encapsulation Efficiency (EE). Matrix solution with high viscosity entrapped more iron and prevented leaching process during encapsulation process (El-Say, 2016). Moreover, the viscous solution also prevented harsh solidification. Xin et al. (2008) suggested that the EE of the dropping method was related to the molecular structure of matrix compound, *i.e.*, the length of the chain and molecular weight. Better encapsulation performance of higher viscosity materials was also obtained by Silva Carvalho et al. (2019) on anthocyanin bead formation.

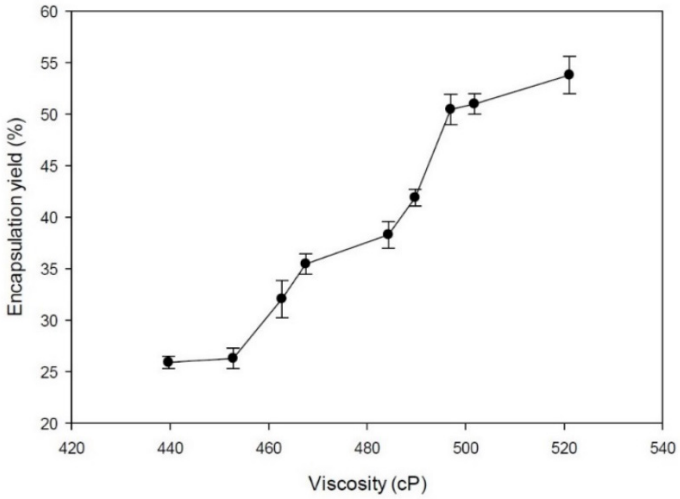

Figure 2. Correlation between viscosity and encapsulation yield.

The study of iron release of all samples was determined at acidic (pH 1.2) and neutral conditions (pH 7.4) for 180 min. These solutions represented the condition of non-enzymatic human gastric and saliva, respectively. Figure 3 shows the iron release fraction from iron beads encapsulated by acetylated glucomannan with different degrees of acetylation (high DA=AA99; low DA=GM25). Acetylation accelerated the iron release from the beads as the matrix was more soluble. Initial burst releases were observed in all iron bead due to the surface iron dissolution. Gelation method of encapsulation produced glucomannan bead with equally distributed iron around the bead, including on bead surface. This iron was instantly dissolved as the bead immersed in water.

Moreover, the release was lower in neutral pH immersion. The gelled glucomannan bead maintained its form at neutral pH as described by Wardhani et al. (2022) and Cui et al. (2013). This release profile was preferable to avoid the unpleasant flavor of iron during chewing process. However, the release pattern of the iron in both pH solutions was insignificantly different.

Four mathematical models were fitted into the release profiles from iron-glucomannan beads, as shown in Figure 3, and the constants for their regression analysis were summarized in Table 1. Judging from the coefficient of determination (R^2), Gompertz model was the most suitable model to describe the iron release. This model started with a steep increase and converged slowly to the asymptotic maximal dissolution. Gompertz's model described the good solubility with intermediate release rate of iron from acetylated glucomannan beads (Dash et al., 2010).

Table 1. Linear regressions of the release modelling data.

Variables	Weibull			Hopfenberg			Gompertz		
	a	*b*	R^2	k_1	*n*	R^2	*α*	*β*	R^2
AA99 1.2	1.03 ± 0.005	0.025 ± 0.002	0.567 ± 0.005	0.003 ± 0.001	-0.14 ± 0.021	0.93 ± 0.009	0.973 ± 5.27	-0.45 ± 0.94	0.99 ± 0.057
AA99 7.4	1.04 ± 0.001	-0.03 ± 0.003	0.537 ± 0.002	0.004 ± 0.001	-0.11 ± 0.043	0.93 ± 0.012	0.979 ± 5.31	-0.28 ± 0.94	0.98 ± 0.062
GM25 1.2	1.12 ± 0.001	-0.03 ± 0.002	0.127 ± 0.001	0.004 ± 0.001	-0.10 ± 0.032	0.96 ± 0.015	1.043 ± 1.79	-0.27 ± 0.94	0.92 ± 0.032
GM25 7.4	1.07 ± 0.001	-0.01 ± 0.003	0.069 ± 0.002	0.004 ± 0.001	-0.11 ± 0.027	0.95 ± 0.010	1.006 ± 5.45	-0.31 ± 0.94	0.99 ± 0.053

The constants and their definitions are followed: a=time-dependent parameter; b=the shape of dissolution curve progression; k_1=erosion rate constant; α=the undissolved iron at time=1; β=dissolution rate per unit of time.

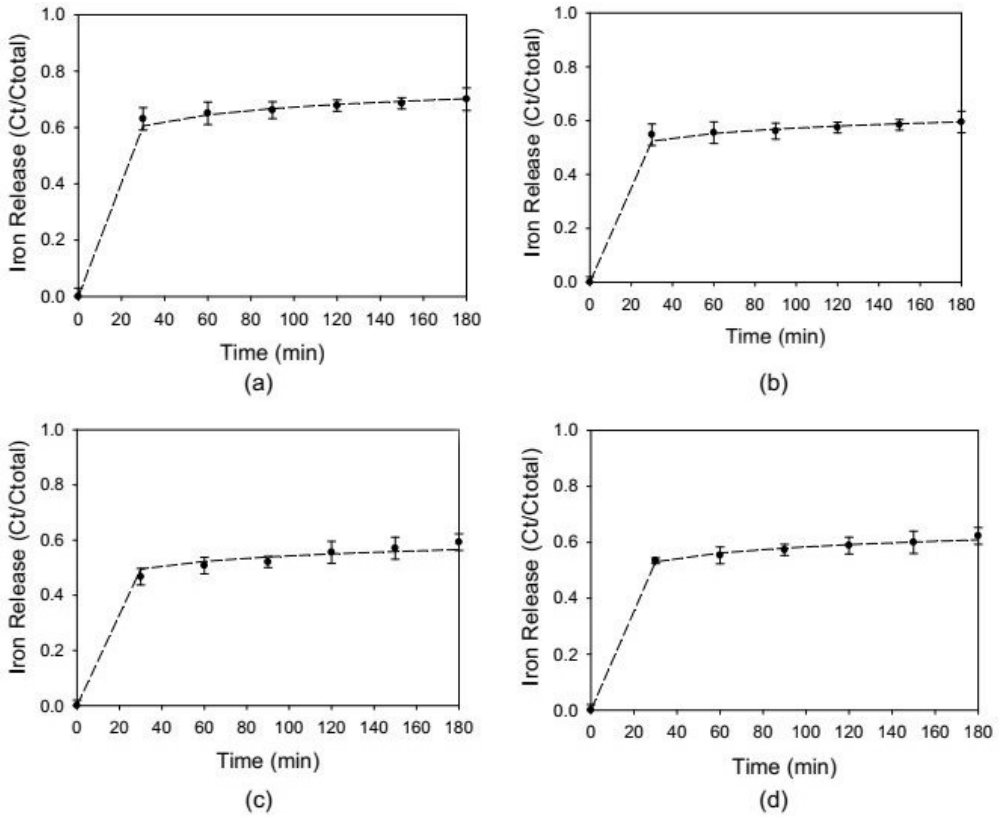

Figure 3. Profile of iron release and the Gompertz model fitting: (a) AA99 pH 1.2; (b) AA99 pH 7.4; (c) GM25 pH 1.2; and (d) GM25 pH 7.4.

3.3 Functional groups and morphology

The IR spectra of native glucomannan, acetylated glucomannan, and iron bead are shown in Figure 4, which described that these samples had similar peaks but in different transmittance intensities. The hydroxyl and acetyl groups of glucomannan were found at ~3430 and ~1620 cm^{-1}, respectively (Asghari-Varzaneh et al., 2017). A broad peak around ~3430 cm^{-1} of native glucomannan and encapsulated iron spectra was due to O-H stretching vibration. High intensity of hydroxyl group was detected in the dried beads of iron encapsulation that could be contributed by water owing to the crystallization of the iron. The C=O bond became a parameter to analyze acetyl groups in glucomannan spectra at ~1620 cm^{-1}. The iron ($FeSO_4.7H_2O$) addition in iron beads caused the broader peak of O-H bond identified around ~3430 cm^{-1}, which was also found by Asghari-Varzaneh et al. (2017).

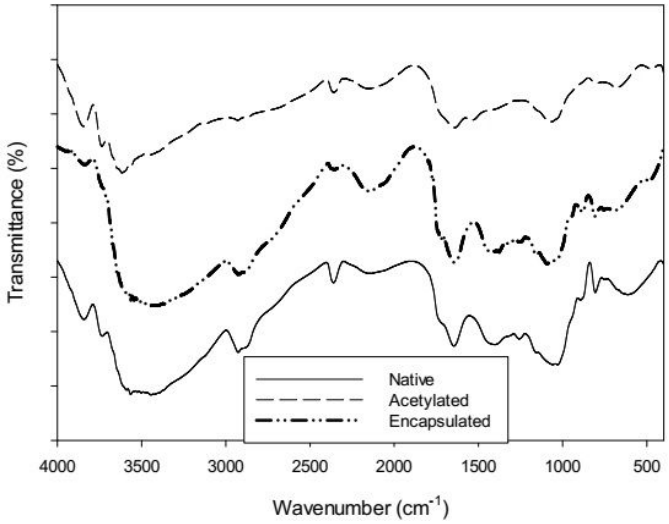

Figure 4. IR spectra of native glucomannan, acetylated glucomannan using 99% acetic acid, and dried encapsulated iron.

The change of surface morphology due to the acetylation and encapsulation is shown in Figure 5. Acetic acid eroded the glucomannan and produced a rougher surface of the acetylated glucomannan. Shah & Rajput (2019) showed that the acid attack on polysaccharide surfaces during acetylation. Cuenca et al. (2020) found that internal damage after acetylation led to starch aggregation. Furthermore, the iron bead showed a wrinkled surface due to water diffusion during bead drying. This water loss also led to an agglomeration of the beads. Wang et al. (2022) also found the rough and cracked surface on their acetylated starch granules.

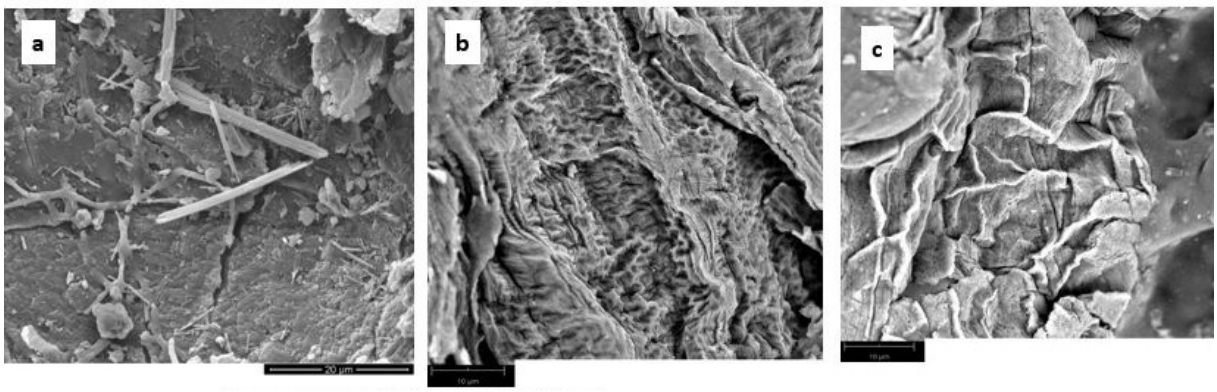

Figure 5. Surface appearances of (a) native glucomannan; (b) acetylated glucomannan; and (c) dried encapsulated iron in a magnification of 5000x.

4 Conclusions

Heterogeneous acetylation in ethanol changed the physicochemical properties of glucomannan. Higher concentration of acetic acid as the acetylation agent promoted the acetylation process of glucomannan, that led to improve its solubility and viscosity. The iron encapsulation produced more yield when higher viscosity of acetylated glucomannan was used. The acetylation and gelation process influenced the glucomannan surface. Gompertz's model fitted to describe the release profile of iron in all samples that showed the burst release phenomena.

References

Adeyanju, O., Nwanta, U. C., Shuaibu, Y., & Hussaini, Y. (2016). Effect of acetylation on physicochemical characteristics of cashew exudate gum (*Anacardium occidentale*): A potential excipient. *Journal of Pharmaceutical and Applied Chemistry*, *2*(3), 201-204. http://dx.doi.org/10.18576/jpac/020311

Alonso-Sande, M., Teijeiro-Osorio, D., Remuñán-López, C., & Alonso, M. J. (2009). Glucomannan, a promising polysaccharide for biopharmaceutical purposes. *European Journal of Pharmaceutics and Biopharmaceutics*, *72*(2), 453-462. PMid:18511246. http://dx.doi.org/10.1016/j.ejpb.2008.02.005

Asghari-Varzaneh, E., Shahedi, M., & Shekarchizadeh, H. (2017). Iron microencapsulation in gum tragacanth using solvent evaporation method. *International Journal of Biological Macromolecules*, *103*, 640-647. PMid:28528002. http://dx.doi.org/10.1016/j.ijbiomac.2017.05.047

Bryszewska, M. A., Tomás-Cobos, L., Gallego, E., Villalba, M. P., Rivera, D., Taneyo Saa, D. L., & Gianotti, A. (2019). In vitro bioaccessibility and bioavailability of iron from breads fortified with microencapsulated iron. *Lebensmittel-Wissenschaft + Technologie*, *99*, 431-437. http://dx.doi.org/10.1016/j.lwt.2018.09.071

Chean, S. X., Hoh, P. Y., How, Y. H., Nyam, K. L., & Pui, L. P. (2021). Microencapsulation of *Lactiplantibacillus plantarum* with inulin and evaluation of survival in simulated gastrointestinal conditions and roselle juice. *Brazilian Journal of Food Technology*, *24*, e2020224. http://dx.doi.org/10.1590/1981-6723.22420

Colussi, R., El Halal, S. L. M., Pinto, V. Z., Bartz, J., Gutkoski, L. C., Zavareze, E. R., & Dias, A. R. G. (2015). Acetylation of rice starch in an aqueous medium for use in food. *Lebensmittel-Wissenschaft + Technologie*, *62*(2), 1076-1082. http://dx.doi.org/10.1016/j.lwt.2015.01.053

Cuenca, P., Ferrero, S., & Albani, O. (2020). Preparation and characterization of cassava starch acetate with high substitution degree. *Food Hydrocolloids*, *100*, 105430. http://dx.doi.org/10.1016/j.foodhyd.2019.105430

Cui, S. W., Wu, Y., & Ding, H. (2013). The range of dietary fibre ingredients and a comparison of their technical functionality. In J. A. Delcour & K. Poutanen (Eds.), *Fibre-rich and wholegrain foods: Improving quality* (pp. 96-119). Cambridge: Woodhead Publishing. http://dx.doi.org/10.1533/9780857095787.1.96

Dash, S., Murthy, P. N., Nath, L., & Chowdhury, P. (2010). Kinetic modeling on drug release from controlled drug delivery systems. *Acta Poloniae Pharmaceutica*, *67*(3), 217-223. PMid:20524422.

El-Say, K. M. (2016). Maximizing the encapsulation efficiency and the bioavailability of controlled-release cetirizine microspheres using Draper-Lin small composite design. *Drug Design, Development and Therapy*, *10*, 825-839. PMid:26966353. http://dx.doi.org/10.2147/DDDT.S101900

Fathi, M., Martín, Á., & McClements, D. J. (2014). Nanoencapsulation of food ingredients using carbohydrate based delivery systems. *Trends in Food Science & Technology*, *39*(1), 18-39. http://dx.doi.org/10.1016/j.tifs.2014.06.007

He, W., Li, X., Ding, K., Li, Y., & Li, W. (2018). Ascorbic acid can reverse the inhibition of phytic acid, sodium oxalate and sodium silicate on iron absorption in Caco-2 cells. *International Journal for Vitamin and Nutrition Research*, *88*(1-2), 65-72. PMid:31119995. http://dx.doi.org/10.1024/0300-9831/a000503

Hoover, R., & Sosulski, F. (1985). A comparative study of the effect of acetylation on starches of phaseolus vulgaris biotypes. *Stärke*, *37*(12), 397-404. http://dx.doi.org/10.1002/star.19850371202

Hurrell, R. F. (2021). Iron fortification practices and implications for iron addition to salt. *The Journal of Nutrition*, *151*(Suppl.1), 3S-14S. PMid:33582781. http://dx.doi.org/10.1093/jn/nxaa175

Impaprasert, R., Piyarat, S., Sophontanakij, N., Sakulnate, N., Paengkanya, S., Borompichaichartkul, C., & Srzednicki, G. (2017). Rehydration and textural properties of dried konjac noodles: Effect of alkaline and some gelling agents. *Horticulturae*, *3*(1), 20. http://dx.doi.org/10.3390/horticulturae3010020

Liu, J. Y., Wang, H. C., Yin, Y., Li, N., Cai, P. L., & Yang, S. L. (2012). Controlled acetylation of water-soluble glucomannan from *Bletilla striata*. *Carbohydrate Polymers*, *89*(1), 158-162. PMid:24750618. http://dx.doi.org/10.1016/j.carbpol.2012.02.065

Liu, J., Zhang, Y., Yin, Y., Peng, F., Cai, P., & Yang, S. (2011). Controlled acid hydrolysis and acetylation of glucomannans as drug carriers with designed pharmacokinetic behaviors. *Journal of Controlled Release*, *152*(Suppl.1), e61-e62. PMid:22195928. http://dx.doi.org/10.1016/j.jconrel.2011.08.123

Mehboob, S., Ali, T. M., Sheikh, M., & Hasnain, A. (2020). Effects of cross linking and/or acetylation on sorghum starch and film characteristics. *International Journal of Biological Macromolecules*, *155*, 786-794. PMid:32194109. http://dx.doi.org/10.1016/j.ijbiomac.2020.03.144

Naktinienė, M., Eisinaitė, V., Keršienė, M., Jasutienė, I., & Leskauskaitė, D. (2021). Emulsification and gelation as a tool for iron encapsulation in food-grade systems. *Lebensmittel-Wissenschaft + Technologie*, *149*, 111895. http://dx.doi.org/10.1016/j.lwt.2021.111895

Quintana, E., Ago, M., Valls, C., Roncero, M. B., & Rojas, O. J. (2018). Alternative chemo-enzymatic treatment for homogeneous and heterogeneous acetylation of wood fibers. *Cellulose*, *25*(9), 5323-5336. http://dx.doi.org/10.1007/s10570-018-1947-4

Ramteke, K. H., Dighe, P. A., Kharat, A. R., & Patil, S. V. (2014). Mathematical models of drug dissolution: A review. *Scholars Academic Journal of Pharmacy*, *3*(5), 2320-4206.

Scott, S. P., Chen-Edinboro, L. P., Caulfield, L. E., & Murray-Kolb, L. E. (2014). The impact of anemia on child mortality: An updated review. *Nutrients*, *6*(12), 5915-5932. PMid:25533005. http://dx.doi.org/10.3390/nu6125915

Shah, P., & Rajput, S. J. (2019). Amine decorated 2d hexagonal and 3d cubic mesoporous silica nanoparticles: A comprehensive dissolution kinetic study in simulated and biorelevant media. *Journal of Dispersion Science and Technology*, *40*(1), 55-73. http://dx.doi.org/10.1080/01932691.2018.1464467

Shubeena, G., Wani, I. A., Gani, A., Sharma, P., Wani, T. A., Masoodi, F. A., Hamdani, A., & Muzafar, S. (2015). Effect of acetylation on the physico-chemical properties of Indian Horse Chestnut (*Aesculus indica* L.) starch. *Stärke*, *67*(3-4), 311-318. http://dx.doi.org/10.1002/star.201400156

Shubham, K., Anukiruthika, T., Dutta, S., Kashyap, A., Moses, J. A., & Anandharamakrishnan, C. (2020). Iron deficiency anemia: A comprehensive review on iron absorption, bioavailability and emerging food fortification approaches. *Trends in Food Science & Technology*, *99*, 58-75. http://dx.doi.org/10.1016/j.tifs.2020.02.021

Silva Carvalho, A. G., Costa Machado, M. T., Freitas Queiroz Barros, H. D., Cazarin, C. B. B., Maróstica Junior, M. R., & Hubinger, M. D. (2019). Anthocyanins from jussara (*Euterpe edulis* Martius) extract carried by calcium alginate beads pre-prepared using ionic gelation. *Powder Technology*, *345*, 283-291. http://dx.doi.org/10.1016/j.powtec.2019.01.016

Siroha, A. K., Sandhu, K. S., Kaur, M., & Kaur, V. (2019). Physicochemical, rheological, morphological and in vitro digestibility properties of pearl millet starch modified at varying levels of acetylation. *International Journal of Biological Macromolecules*, *131*, 1077-1083. PMid:30926488. http://dx.doi.org/10.1016/j.ijbiomac.2019.03.179

Wang, C., Li, B., Chen, T., Mei, N., Wang, X., & Tang, S. (2020). Preparation and bioactivity of acetylated konjac glucomannan fibrous membrane and its application for wound dressing. *Carbohydrate Polymers*, *229*, 115404. PMid:31826490. http://dx.doi.org/10.1016/j.carbpol.2019.115404

Wang, J., Liu, C., Shuai, Y., Cui, X., & Nie, L. (2014). Controlled release of anticancer drug using graphene oxide as a drug-binding effector in konjac glucomannan/sodium alginate hydrogels. *Colloids and Surfaces. B, Biointerfaces*, *113*, 223-229. PMid:24096158. http://dx.doi.org/10.1016/j.colsurfb.2013.09.009

Wang, L. H., Huang, G. Q., Xu, T. C., & Xiao, J. X. (2019). Characterization of carboxymethylated konjac glucomannan for potential application in colon-targeted delivery. *Food Hydrocolloids*, *94*, 354-362. http://dx.doi.org/10.1016/j.foodhyd.2019.03.045

Wang, R., Wang, J., Liu, M., Strappe, P., Li, M., Wang, A., Zhuang, M., Liu, J., Blanchard, C., & Zhou, Z. (2022). Association of starch crystalline pattern with acetylation property and its influence on gut microbota fermentation characteristics. *Food Hydrocolloids*, *128*, 107556. http://dx.doi.org/10.1016/j.foodhyd.2022.107556

Wani, I. A., Sogi, D. S., & Gill, B. S. (2012). Physicochemical properties of acetylated starches from some indian kidney bean (*Phaseolus vulgaris* L.) cultivars. *International Journal of Food Science & Technology*, *47*(9), 1993-1999. http://dx.doi.org/10.1111/j.1365-2621.2012.03062.x

Wardhani, D. H., Abdullah, Azizah, A. N., & Ananta, M. Y. (2016). Physicochemical properties of acetylated glucomannan of *Amorphophallus onchophillus* as excipient of drug controlled release. *AIP Conference Proceedings*, *1746*, 020039. http://dx.doi.org/10.1063/1.4953964

Wardhani, D. H., Aryanti, N., Etnanta, F. N., & Ulya, H. N. (2019). Modification of glucomannan of *Amorphophallus oncophyllus* as an excipient for iron encapsulation performed using the gelation method. *Acta Scientiarum Polonorum. Technologia Alimentaria*, *18*(2), 173-184. PMid:31256545. http://dx.doi.org/10.17306/J.AFS.2019.0651

Wardhani, D. H., Etnanta, F. N., Ulya, H. N., & Aryanti, N. (2022). Iron encapsulation by deacetylated glucomannan as an excipient using the gelation method: Characteristics and controlled release. *Food Technology and Biotechnology*, *60*(1), 41-51. PMid:35440881. http://dx.doi.org/10.17113/ftb.60.01.22.7130

Wardhani, D. H., Hapsari, F. D., Suryana, K. M., Aryanti, N., & Cahyono, H. (2018). Physicochemical properties of glucomannan-alginate as vitamin C excipient. *Evergreen*, *5*(2), 6-10. http://dx.doi.org/10.5109/1936211

Wardhani, D. H., Rahayu, L. H., Cahyono, H., & Ulya, H. L. (2020). Purification of glucomannan of porang (Amorphophallus oncophyllus) flour using combination of isopropyl alcohol and ultrasound-assisted extraction. *Reaktor*, 20(4), 203-209. https://doi.org/10.14710/reaktor.20.4.203-209

Xin, M., Li, M., Liao, Y., Deng, J., & Qiao, Z. (2008). Novel biomaterial study II: O, O-dilong chain acyl chitosan (OCS) for selfassembled nanovesicle and OCS /PLLA blend for tissue engineering scaffold. In *BioMedical Engineering and Informatics: New Development and the Future - Proceedings of the 1st International Conference on BioMedical Engineering and Informatics (BMEI 2008)* (pp. 751-754). New York: IEEE. http://dx.doi.org/10.1109/BMEI.2008.296

Zhu, F. (2018). Modifications of konjac glucomannan for diverse applications. *Food Chemistry*, *256*, 419-426. PMid:29606469. http://dx.doi.org/10.1016/j.foodchem.2018.02.151

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