Properties of cellulose and modified cellulose-alginate for rifampicin drug delivery

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Properties of cellulose and modified cellulose-alginate for rifampicin drug delivery

R J D Arianto[1] and Sunardi[1,2]*

[1]Department of Chemistry, Mathematics and Natural Science Faculty, Lambung Mangkurat University, Banjarbaru 70714, Indonesia
[2]Wetland-Based Materials Research Center, Lambung Mangkurat University, Banjarbaru 70714, Indonesia

Email: sunardi@ulm.ac.id

Abstract. Oral drug delivery of rifampicin as tuberculosis healing treatment has several challenging issues such as poor solubility in water and short biological half-life resulting in some unfavorable side effects. Various polymeric materials have the prospective to overcome the obstacles correlated with rifampicin oral drug delivery to deliver controlled release and protect this drug from the severe gastric environment. In this study, alginate (Alg), alginate-cellulose (Alg-Cel), and alginate-C_{16}TMABr modified cellulose (Alg-MCel) beads were prepared and evaluated as a potential agent for drug delivery of rifampicin. Numerous parameters were investigated, such as beads size, gel fraction, swelling ratio, encapsulation efficiency, and release percentage. The results showed that the addition of cellulose and C_{16}TMABr modified cellulose into the alginate improves the encapsulation efficiency and controlled release of rifampicin.

1. Introduction

As the first treatment of Tuberculosis, rifampicin application is convinced to be the most effective way. It is related to anti-bacterial activity on the macrocyclic functional group of rifampicin molecules, which able to binding RNA polymerase enzyme of bacteria inhibiting the initiation of the Bacterial RNA synthesis process [1]. However, rifampicin has a short biological half-time (2-5 hours) and poor solubility in an aqueous environment [2]. Both necessitate a long-term (6-8 months) consumption of rifampicin on a high dose continuously to avoid bacterial resistance to the drug and maintain the drug concentration within a therapeutic range [3]. Furthermore, this consumption design has been resulting in some unfavorable side effects.

In attempts to decreasing the side effects, various controlled delivery systems have been developed. Drug encapsulation method by beads made from natural polymers, such as alginate, as one of the drug delivery systems has been developed numerously because of its advantages on biodegradability, biocompatibility, and non-toxic properties. Alginates is a polysaccharide consisting of β-D-mannuronic acid and α-L-guluronic acid copolymer. Alginate has a nano-porous structure and swelling ability at certain pH conditions, which suitable to use as a drug preparation with a controlled-release system [4]. However, the high number of alginate porosity conduces an attenuation of endurance and mechanical stability that leads to the increasing of the drug diffusion rate [5].

In order to enhance the mechanical properties of alginate beads, several developments have been focused on composite synthesis processes of alginate with other polymers such as chitosan [6], clay

[7], and cellulose [8]. Compared with other composite materials, cellulose is a biopolymer with the highest abundance and availability also requires a relatively low cost on the preparation [9]. Based on the report by Ooi et al., cellulose was able to enhance the mechanical properties of hydrogel up to around four times [10]. The enhancement of alginate mechanical properties by cellulose has been resulting in a more rigid structure of hydrogel and preventing drug release before the requiring time.

However, the hydrophilic nature of cellulose could weaken the interaction between beads and drugs that have a hydrophobic nature. Therefore, the surface modification of cellulose is needed to alter the cellulose into a hydrophobic material. The modification could be done with a chemical approach like a cationic surfactant, such as cetyltrimethylammonium ($C_{16}TMA^+$), adsorption at the surface of cellulose [11]. In this research, the effects of cellulose and C_{16}TMABr modified cellulose addition on the preparation of alginate beads are studied regarding rifampicin encapsulation and release ability of beads.

2. Materials and methods

2.1. Materials

Sodium Alginate was purchased from Kanto Chemical (Japan). Cetyltrimethylammonium bromide (C_{16}TMABr), calcium chloride dihydrate, acetic acid glacial, and rifampicin were purchased from Merck (Germany). Cellulose was isolated from nypa (*Nypa fruticans*) frond by alkaline hydrogen peroxide treatment with some modification.

2.2. Cellulose modification with C_{16}TMABr

Cellulose was modified by suspending 1 g of cellulose into 250 mL of water (0,4 wt % suspension). The suspension was slowly added into 4.0 mM C_{16}TMABr solution, and the mixture was stirred at 60°C for 3 hours. The process was continued by stirring at room temperature overnight. The suspension obtained was filtered by Whatman No. 42 Filter paper, then the residue was washed with distilled water to remove bromide ion and dried to a constant weight at 65°C for 20 hours.

2.3. Beads preparation

Beads were prepared with three different compositions, which were alginate beads (Alg), alginate-cellulose beads (Alg-Cel), and alginate-modified cellulose bead (Alg-MCel). The staple solution of beads was prepared by adding 0.1 g of cellulose or modified cellulose into 20 mL of 3% sodium alginate solution and stirred at room temperature for 1 hour. Then, 20 mL of 0.5 mg/mL rifampicin solution was added to the mixture under stirring for 10 minutes. The homogenous mixture then added dropwise into a 1.5% solution of calcium chloride ($CaCl_2$) through a syringe device. The spherical beads obtained were cured for 1 hour, then washed and dried at 45°C for 15 hours.

2.4. Characterization

2.4.1. FTIR Spectroscopy. The structural changes of cellulose modification products were analyzed as FTIR spectra using a Bruker Alpha ATR/FTIR. The spectra were recorded in the range of 4000–500 cm^{-1}.

2.4.2. Beads size measurement. The size of dried alginate beads from each formula was measured as the average value of 25 beads' size using a digital caliper.

2.4.3. Gels fraction. The dried beads were first extracted in 5 % acetic acid solution using autoclave for 2 hours at 120°C and 1 bar pressure. After this, the extracted beads were dried at 45°C to a constant weight. The gel fraction (G%) than was determined as the ratio of the dry gel before (W_i) and after (W_F), using the equation 1.

$$G\,\% = \frac{W_f}{W_i} \times 100\% \quad (1)$$

2.4.4. Swelling behavior. The swelling behavior was studied by suspending 40 mg (W_d) dried alginate-cellulose beads in 4 mL simulated gastric fluid (SGF) pH 1.2 for 2 hours followed by suspension in 4 mL simulated intestinal fluid (SIF) pH 6.8 during 4 hours. The weight of beads was measured at one-hour intervals after removing the liquid from the surface of the beads using filter paper (W_s). This analysis was done in triplicate. The swelling ratio of beads (S%) was calculated using the equation 2.

$$S\,\% = \frac{W_s - W_d}{W_d} \times 100\% \quad (2)$$

2.4.5. Encapsulation efficiency. The concentration of rifampicin before (W_a) and after (W_b) beads gelation process was determined by measuring the absorbance of rifampicin that dissolved at $CaCl_2$ solution after the gelation process using UV-Vis spectrophotometer (Jenway 7315 Model) at 475 nm (Thomas *et al.*, 2018). The method for rifampicin concentration determination used calibration curve arranged from a series of solutions with a known concentration of rifampicin. The encapsulation efficiency value (EE%) then calculated using the equation 3.

$$EE\,\% = \frac{W_a - W_b}{W_b} \times 100\% \quad (3)$$

2.4.6. In-Vitro release of rifampicin. Thirty milligrams (30 mg) of rifampicin loaded beads were placed into a dialysis bag with MW cut off of 12,000 Da. Then, the beads were soaked into 9 mL of release medium at 37°C under stirring. The first release medium was SGF for 2 hours, followed by SIF for 4 hours. At one-hour intervals, 3 mL of medium was withdrawn for analysis and replaced by the fresh medium with an equal volume. The amount of rifampicin in the release medium was calculated using spectrophotometry method at 475 nm by UV-Vis spectrophotometer (Jenway 7315 Model). This analysis was done in duplicate.

3. Results and Discussion

3.1. Cellulose and modified cellulose analysis using FTIR spectroscopy

The FTIR Spectra analyzed by FTIR instrument was used to investigate the structural changes of cellulose due to the surface modification with C_{16}TMABr. Figure 1 shows the spectra of unmodified cellulose and modified cellulose. A new modest peak at 1455 cm^{-1} was found in modified cellulose, which corresponded to the trimethyl group of the quaternary ammonium [12]. This peak proved the appearance of quaternary ammonium in cellulose as the surfactant is a quaternary ammonium salt. There are also two small peaks at 2897 & 2858 that correspond to asymmetrical and symmetrical CH_2 stretches of the long alkyl chain as an attribute of C_{16}TMABr surfactant [13]. Moreover, the peak intensity at 1052 cm^{-1} had a slight increase as an indication of the long alkyl chain attached to the hydroxyl groups of cellulose [14].

However, the low amount of changes that were shown in spectra indicated the poor condition of C_{16}TMABr adsorption on the cellulose surfaces (figure 2). Based on the report by Zainuddin et al. [16], C_{16}TMABr's groups depicted by FTIR spectra might show a low intensity as the concentration of C_{16}TMABr used was lower or even higher than the concentration needed to construct the material with the surfactant critical micelle concentration on its surfaces. At the higher concentration, the aggregation between surfactant molecules on the cellulose surface could be conducted. This condition was caused by the increase of surface hydrophobicity, which led to the adsorption of excess surfactant

through the hydrophobic interaction between surfactants [15]. The aggregated condition of surfactant may lead to the desorption of C_{16}TMABr from the cellulose surfaces during the rinsing step [16].

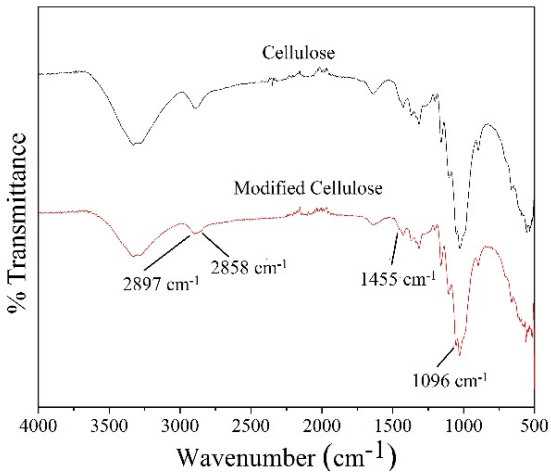

Figure 1. FTIR spectra of unmodified and modified cellulose.

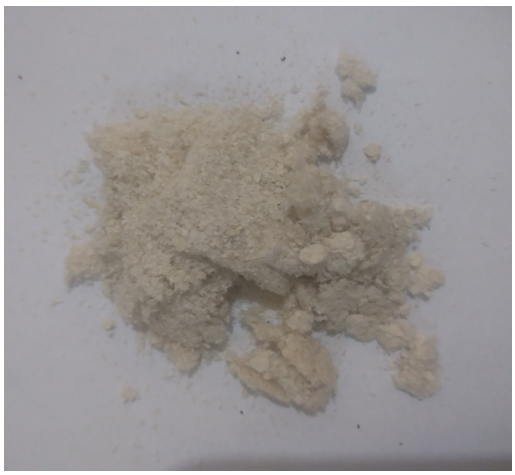

Figure 2. C_{16}TMABr modified cellulose product.

3.2. Morphology and size

All beads obtained were orange as the color of rifampicin as shown by figure 3.Alg-Cel and Alg-MCel beads were darker than Alg beads because of the existence of cellulose which was increasing the crosslinking density. Based on the data in table 1, the diameter of Alg-Cel and Alg-MCel beads was considerably bigger than Alg beads. Overall, the beads from each formula were relatively homogenous in size, as shown by the coefficient of variation between standard deviation and mean size that was less than 0.33 [6].

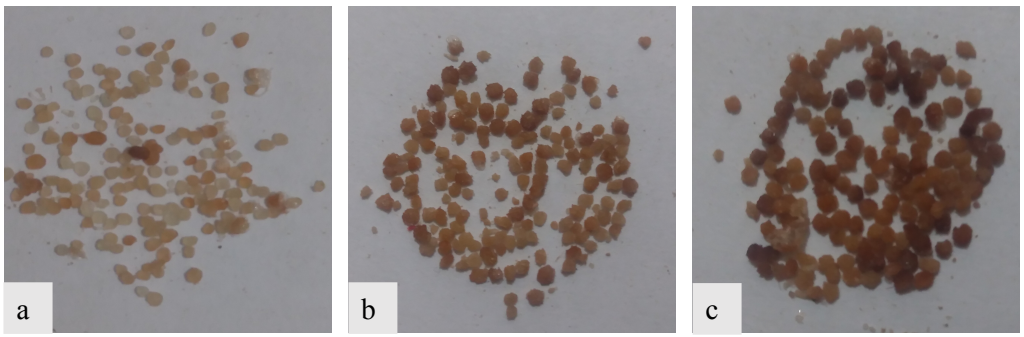

Figure 3. The photographs of Alg beads (a), Alg-Cel beads (b), & Alg-MCel beads (c).

3.3. Gel fraction

The result of the gel fraction analysis of the beads is shown in table 1. The gel fraction of the beads represented the amount of insoluble part of the polymer due to the formation of crosslinking between the polymer chains [17]. The obtained result showed that the presence of cellulose affected the gel fraction of the beads. The cellulose conduced the amount of crosslinking that was formed through hydrogen bonding interaction between alginate and cellulose molecules. These interactions could enhance the chemical resistance and stability of the beads in the acidic environment

However, the gel fraction of Alg-MCel beads was slightly lower than Alg-Cel beads. The adsorption of C_{16}TMABr surfactant by hydroxyl groups as anionic sites on the cellulose surface led to the decline of Alg-MCel beads gel fraction. The presence of surfactant might disrupt the hydrogen

bonding interaction between cellulose and alginate materials. It led to the reduction of crosslinking formation and lowering the amount of insoluble fraction.

Table 1. Characteristic of beads with three different formulation.

Beads Formulation	Average size	Gel Fraction	Encapsulation efficiency
Alg	0,89 ± 0,05 mm	30 %	47,37 %
Alg/Cel	1,13 ± 0,09 mm	36 %	61,20 %
Alg/Mcel	1.31 ± 0,07 mm	32 %	60,83 %

3.4. Encapsulation efficiency

The presence of cellulose in the beads provided a significant effect in the drug encapsulation, as shown in table 1. The encapsulation value of Alg/Cel and Alg/MCel beads attained over 60 % of total rifampicin that was added, which is higher than Alg beads that just attained 47,374 %. The encapsulation efficiency was calculated as the ratio between the weight of the encapsulated drug and the drug fed. The appearance of free rifampicin in $CaCl_2$ solution was occurred due to the diffusion of the drug while the gelation process of alginate that was forming pores on the surface of the beads [18]. The appearance of cellulose seemed to influence the amount of non-encapsulated drugs as cellulose was able to enhance the structural stability of the beads. Thus the pores formed on the surface of the beads could be decreased.

Meanwhile, the encapsulation efficiency of Alg/MCel Beads was relatively constant compared to Alg/Cel beads. These results might happen because of the presence of surfactant on the cellulose surface that was higher than the surfactant critical micelle concentration [16]. The presence of surfactant on the surfactant critical micelle concentration would increase the hydrophobicity of the cellulose surfaces. While at the higher concentration, above its critical micelle concentration, the surfactant might aggregate and formed positive hydrophilic sites on the cellulose surfaces [15]. The formation of hydrophilic sites led to the decrease of rifampicin binding on the cellulose surface.

3.5. Swelling behavior

The swelling ratios of the beads on the SGF and SIF medium are shown in figure 4. There was a soar for all variation from 135 – 210 % in the second hour of SGF treatment to more than 2000 % in the first hour of SIF treatment. This increase showed the swelling behavior of the alginate beads was depended on the pH condition of medium.

The swelling in SGF was occurred due to the absorption of water into the beads. However, at low pH value, alginate beads were able to maintain the structure because of the change of carboxylate groups (-COO) of alginate that was protonated and generating alginate acid, thus strong hydrogen bonding interactions between the carboxylate group of alginate molecules was formed [19]. The swelling ratio values of Alg, Alg-Cel, Alg-MCel beads in SGF were up to 134,96%, 126,09, and 209,76%, respectively. The swelling ratio of Alg-Cel beads that was the lowest showed that cellulose enhances the network structure of alginate in acidic medium. However, the swelling ratio of Alg-MCel that was the highest might occur due to the presence of surfactant that interfered the hydrogen bonding interactions of cellulose and loosened up the polymer composite structure.

Meanwhile, the significant rise of the swelling ratio of the beads in SIF was resulted by the partial ionization of carboxylate groups of alginate molecules along with the ionic exchange between the Ca^{2+} ion as the crosslinking agent of alginate structure and the Na^{+} ion present in SIF. Both led to the partial degradation of the beads due to sodium alginate salt formation, which is soluble in water and could cause the release of the drug [8]. The swelling ratio values of Alg, Alg-Cel, Alg-MCel beads in SGF were up to 134,96%, 126,09, and 209,76%, respectively. The ratios of Alg-Cel and Alg-MCel in this medium were relatively lower than Alg beads, which showed that the appearance of cellulose might able to enhance the chemical stability of the beads.

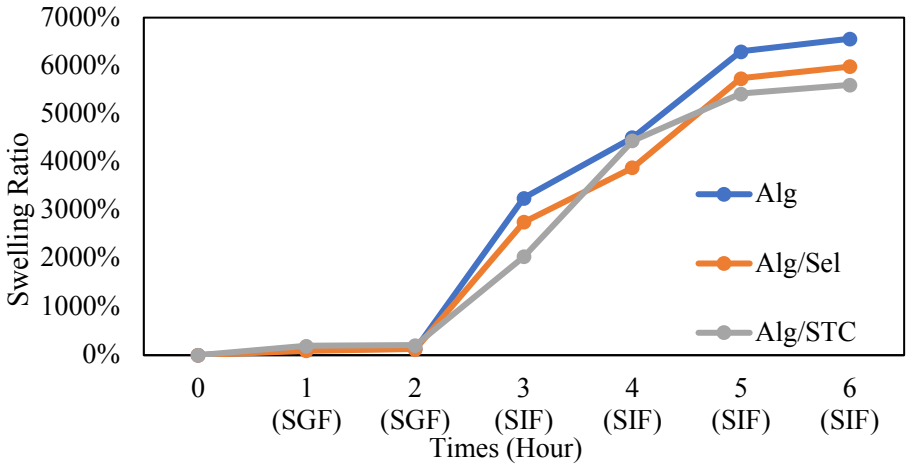

Figure 4. The swelling ratio of the beads in SGF and SIF.

3.6. In-vitro release of rifampicin

The rifampicin percentage value of the beads is shown in figure 5. The number of drugs found in the release medium could depict of drug release behavior in the gastrointestinal tract. The dissolution rate of drug, which is a kinetic property of the drugs, could be controlled by the diffusion process of the drug [20]. That is, the drug delivery system might control the dissolution rate through the control of drug diffusion.

In the SGF medium, the drug release process occurred because of bead swelling, which led to drug diffusion into the SGF solution. The release percentage values of Alg, Alg-Cel, Alg-MCel beads in SGF were up to 3,22%; 1,23%; and 1,57%, respectively. The release percentage value of Alg-Cel in SGF was the lowest among the others, which was appropriate with the swelling ratio of Alg-Cel in SGF that was lowest compared to the other beads. Meanwhile, the release percentage value of Alg/MCel beads was considerably lower than Alg beads, which showed the discrepancy with the swelling ratio value of both beads. This result indicated the effect of cellulose modification by the surfactant, which could maintain the drug binding in the drug system due to the increase of hydrophobicity on cellulose surface [16].

The drug release into solution also occurred in SIF with the release percentage value of Alg, Alg-Cel, Alg-MCel beads in SGF were up to 4,85%; 2,60%; and 3,34%, respectively. The release percentage value of Alg beads was the highest among the others, which was appropriate with the swelling ratio result. Generally, the addition of cellulose into alginate beads decreased the release percentage of rifampicin in both of release medium. These declines had resulted in the presence of cellulose that enhanced the chemical stability of the beads. Thus, the swelling of the beads was decreased, and the diffusion of the drug from the system was controlled. However, the results of Alg/MCel beads which did not show the increase of release percentage could be led by the set on the hydrophobic site formation process was not in optimum condition. Therefore, the beads ability to maintain drugs during the diffusion process decreased. Overall, the lower result in acidic medium and the higher result for all beads in pH-neutral medium indicated the ability of the system to protect drug in the gastric environment as well as the desirable release behavior in the intestinal fluid [21], which was the main criteria for oral drug delivery system.

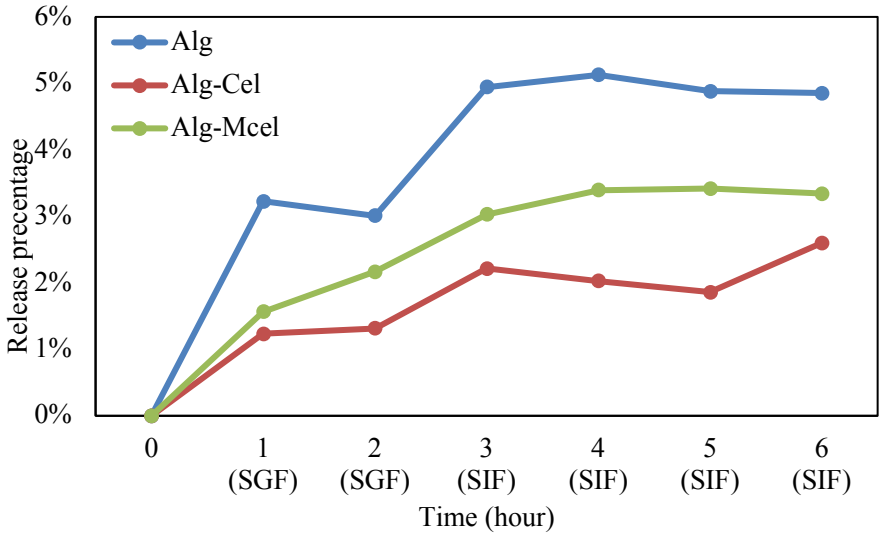

Figure 5. The drug release percentages of the beads in SGF and SIF.

4. Conclusion

In this study, alginate beads with three different formulations of cellulose addition were prepared and characterized. Based on the results, the addition of cellulose and modified cellulose was revealed that it induced the improvement in bead properties such as beads size, gel fraction, swelling behavior, encapsulation efficiency, and drug release behavior. The addition of modified cellulose provided the best results in the size and swelling ratio of the beads. However, the gel fraction, encapsulation efficiency, and release percentage value of Alg/MCel beads showed relatively homogenous results compared to Alg/Cel beads. These results indicated that Alg-Cel beads & Alg-MCel beads had a prospect to provide a controlled release of rifampicin oral delivery system.

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References

[1] Singh G, Raghuvanshi H K, Anand A, Pundir R, and Dwivedi H 2010 Targeted Delivery of Rifampicin by Niosomal Drug Delivery System *JPR* **3** 1152-54

[2] Sabitha P, Ratna J V, and Reddy K R 2010 Design and Evaluation of Controlled Release Chitosan-Calcium Alginate Microcapsules of Antitubercular Drugs for Oral Use *Int. J. Chem. Technol. Res.* **2** 88-98

[3] Kasim N A, Whitehouse M, Ramachandran C, Bermejo M, Lennernäs H, Hussain A S, Junginger H E, Stavchansky S A, Midha K K, and Shah V P 2004 Molecular Properties of Who Essential Drugs and Provisional Biopharmaceutical Classification *Molecular pharmaceutics* **1** 85-96

[4] Lin N, Huang J, Chang P R, Feng L, and Yu J 2011 Effect of Polysaccharide Nanocrystals on Structure, Properties, and Drug Release Kinetics of Alginate-Based Microspheres *Colloids and Surfaces B: Biointerfaces* **85** 270-79

[5] Moebus K, Siepmann J, and Bodmeier R 2009 Alginate–Poloxamer Microparticles for Controlled Drug Delivery to Mucosal Tissue. *European Journal of Pharmaceutics and Biopharmaceutics* **72** 42-53

[6] Tahtat D, Mahlous M, Benamer S, Khodja A N, Oussedik-Oumehdi H, and Laraba-Djebari F 2013 Oral Delivery of Insulin from Alginate/Chitosan Crosslinked by Glutaraldehyde *International journal of biological macromolecules* **58** 160-68
[7] Uyar G, Kaygusuz H, and Erim F B 2016 Methylene Blue Removal by Alginate–Clay Quasi-Cryogel Beads *Reactive and Functional Polymers* **106** 1-7
[8] Thomas D, Latha M, and Thomas K K 2018 Synthesis and in Vitro Evaluation of Alginate-Cellulose Nanocrystal Hybrid Nanoparticles for the Controlled Oral Delivery of Rifampicin *Journal of Drug Delivery Science and Technology* **46** 392-99
[9] Yu X, Tong S, Ge M, Wu L, Zuo J, Cao C, and Song W 2013 Adsorption of Heavy Metal Ions from Aqueous Solution by Carboxylated Cellulose Nanocrystals *Journal of Environmental Sciences* **25** 933-43
[10] Ooi S Y, Ahmad I, and Amin M C I M 2016 Cellulose Nanocrystals Extracted from Rice Husks as a Reinforcing Material in Gelatin Hydrogels for Use in Controlled Drug Delivery Systems *Industrial Crops and Products* **93** 227-34
[11] Qing W, Wang Y, Wang Y, Zhao D, Liu X, and Zhu J 2016 The Modified Nanocrystalline Cellulose for Hydrophobic Drug Delivery *Applied Surface Science* **366** 404-09
[12] Abitbol T, Marway H, and Cranston E D 2014 Surface Modification of Cellulose Nanocrystals with Cetyltrimethylammonium Bromide *Nordic Pulp & Paper Research Journal* **29** 46-57
[13] Salajková M, Berglund L A, and Zhou Q 2012 Hydrophobic Cellulose Nanocrystals Modified with Quaternary Ammonium Salts *Journal of Materials Chemistry* **22** 19798-805
[14] Song Y, Zhang L, Gan W, Zhou J, and Zhang L 2011 Self-Assembled Micelles Based on Hydrophobically Modified Quaternized Cellulose for Drug Delivery *Colloids and Surfaces B: Biointerfaces* **83** 313-20
[15] Hu Z, Ballinger S, Pelton R, and Cranston E D 2015 Surfactant-Enhanced Cellulose Nanocrystal Pickering Emulsions *Journal of colloid and interface science* **439** 139-48
[16] Zainuddin N, Ahmad I, Kargarzadeh H, and Ramli S 2017 Hydrophobic Kenaf Nanocrystalline Cellulose for the Binding of Curcumin *Carbohydrate polymers* **163** 261-69
[17] Mozalewska W, Czechowska-Biskup R, Olejnik A K, Wach R A, Ulański P, and Rosiak J M 2017 Chitosan-Containing Hydrogel Wound Dressings Prepared by Radiation Technique *Radiation Physics and Chemistry* **134** 1-7
[18] Sankalia M G, Mashru R C, Sankalia J M, and Sutariya V B 2005 Papain Entrapment in Alginate Beads for Stability Improvement and Site-Specific Delivery: Physicochemical Characterization and Factorial Optimization Using Neural Network Modeling *Aaps pharmscitech* **6** E209-E22
[19] Deepathomas D, Latha M, and Kurienthomas K 2018 Zinc Alginate Beads for the Controlled Release of Rifampicin *Orient. J. Chem* **34** 428-33
[20] Siegel R A, and Rathbone M J 2012 Fundamentals and Applications of Controlled Release Drug Delivery (Vol. 3) ed J Siepmann*, et al* (New York: Springer) p 30
[21] Thomas D, Latha M, and Thomas K K 2017 Synthesis and in Vitro Evaluation of Iron Cross Linked Alginate Nano Particle for Controlled Drug Release *Lung Pulm Respir Res J* **1** 111-17.