ADVANCEMENTS IN CARBOXYMETHYL CELLULOSE APPLICATIONS IN FOOD INDUSTRY AND WASTEWATER TREATMENT

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Abstract:
Carboxymethylcellulose (CMC) is a water-soluble cellulose derivative that can produce robust and durable films for a variety of uses as well as control the rheology and viscosity of aqueous systems. Initially, CMC was introduced as a substitute for starch and natural gums but frequently CMC emerged as a promising derivative with characteristic surface properties for various advanced applications. The use of this cellulose derivative is thus widespread in the production of paper, the processing of detergents, textiles, protective coatings and drilling fluids. The food, drug, and cosmetic sectors all frequently employ the refined variety, commonly known as cellulose gum. Currently, CMCs are also used in biomedical engineering, as diverse conductive agents in the textile, pharmaceutical, and food industries. Moreover, CMCs are effectively used in wastewater treatment to remove heavy metal contaminants, radionuclides, dyes, etc. which is also an emerging area of research. Additionally, several hybrid materials including a particular variety of super-absorbents based on CMC has been reported and there is still a great opportunities that more will be created in the future .Based on these significant updates, this review covers advancement in CMC applications with major focus on food industry and wastewater treatment.

Keywords: CMC, Application of CMC, CBHs, Food Industries, Wastewater Treatment

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Introduction

CMC is an anhydro-glucose linear polysaccharide. Through -1,4-glycosidic bonds, the repeating units are joined. At the molecular level, the only significant distinction between CMC and cellulose is the presence of a few anionic carboxymethyl groups (i.e., $-CH2COOH$) in the CMC structure, which take the place of some hydroxyl groups that were present in the original cellulose structure. 1918 saw the invention of CMC in Germany and introduced as a substitute for gelatin [1]. However, the discovery of commercial polymeric materials was promoted on a large scale in Germany in the early 1920s [2].

Carboxymethyl cellulose was produced primarily by extracting cellulose from wood and other plant-based progenitors. These plants contained a lot of cellulose fibers that were essential for the production process. Therefore, the final factor influencing CMC production was the availability of these specific wood-based plants. As such, CMC production was largely limited by the availability of these plants and their connection to the process [3, 4].

However, daily cellulose-containing products have been proposed in the literature by numerous researchers as effective substitute alternatives in this situation.

The several precursors based on plant (e.g., banana pseudo-stem [5], sago palm [6], corn stalks [8], corn husk [7], corn cobs [9], cacao pod husks [10], durian rind [11], maize stalks [12], the pulp of Eucalyptus globules [13], bagasse of sugarcane [14], the stalk of asparagus officinalis [15], pineapple peel [16], orange peel [17] etc.), additionally to some waste products (like as cotton gin wastes [18], wastepaper [19], waste paper sludge [20], textile waste [21], knitted rags [22] and cotton linter waste from the textile industry [23], etc.) for use in industrial-CMC manufacture, have attracted the interest of researchers.

There are numerous applications for CMC and CMC-composites in the fields of biotechnology, pharmaceuticals, building materials, textiles, polymers, food, energy and cosmetics, because of the abundance of raw materials, straightforward, inexpensive method of procedure, the distinctive characteristics of surface [24], various formability [26], mechanical strength [25], tuneable hydrophilicity [27], viscosity [28], and rheological properties [29], as well as hundreds of other. For instance, CMC and its composites are frequently used in biomedical fields for a variety of purposes, including tissue engineering [30], bone-tissue engineering [31], wound dressing [32], Creating artificial organs or extracellular polymeric matrix mimics [33], manufacturing 3D-scaffolds for biocompatible implants [34] and producing absorbent nonwovens are a few examples. Because of their exceptional biocompatibility, binding ability to pharmaceutically active substances such as enzymes and medicines, pH sensitivity and high stability, CMC hybrid materials, films and CMC-based hydrogels have attracted significant interest in the past few years for potential use in pharmaceuticals, particularly for drug delivery [35], drug emulsification [36], and drug stabilization [37].

Additionally, CMC hybrid materials are employed as sizing and finishing agents in textile weaving [38], used for digital printing on textiles because of their qualities that thicken and sharpen colors [39], and as antioxidant, antiradical, absorbent textiles or antimicrobial because of their thermo sensitivity, pH, hygroscopic, and hygienic features [40-42].

Due to their lack of flavor, caloric content, and physiological inertness, CMCs are utilized as a variety of auxiliary agents in food items and their packaging, including thickeners, emulsion stabilizers, adhesive stabilizers, and moisture binders. In addition, many researchers have so far shown how important CMC is in the wastewater treatment and production of ecologically friendly energy and its storage.

CMC and its different composites have garnered a lot of attention recently as an affordable binding agent in biomass pellets (to cut down on excessive fuel loss), supplementary electrode material in batteries, and supercapacitor aerogels for effective energy storage [43, 44].

Over the past years, CMC-hybrid compounds, particularly their hydrogels, have shown a few encouraging outcomes in the removing dye contaminants [45], numerous inorganic metal ions [46], and even certain radionuclides [47] from contaminated waters.

CMC has also been suggested as a potential application in a number of other sectors, like in the paper industries. CMC helps in strengthening properties, color stability, ink retention or good printability, fire retardancy features [48, 49] improve adhesion properties [50], and also improve binding ability and cyclic performance of Si anode electrodes [51].

CMC has also been used in the oil business, the cosmetics industry, the dental industry, liquid detergent, the fertilizer industry and the building industry [52]. In order to visualize this, we discuss and compile the published CMC research here based on its applicability in a variety of food industries and water treatment methods.

Application of Carboxymethyl Cellulose (CMC)

Application in Food Industries

Food-grade CMC (cellulose gum) is widely used because of its ability to thicken water, act as a moisture binder, dissolve rapidly in both hot and cold aqueous systems, and texturize a wide range of food products (**Figure 1**) and because it is tasteless, odorless, and forms clear solutions without cloudiness or opacity.

Because it is physiologically inert and non-caloric, cellulose gum is particularly useful in dietetic foods. Cellulose gum serves as an extrusion aid, acts as a binder, helps to stabilize emulsions, and retards sugar crystal growth.

In frozen products, it controls ice crystal growth and phase separation. It is compatible with a wide range of food ingredients, including proteins, sugars, and more hydrocolloids.

The extensive acceptance of cellulose gum in so many culinary applications can be attributed to the variety of varieties that allow it to be customized to the various needs of the food industry.

The provision of food for human society is a crucial function of the food industry. The food industry uses a variety of auxiliary agents, such as hydrocolloids such as xanthan gum powder, sugar beet pectin, and soluble soybean polysaccharide (SSPS) [53, 54], as well as different alginates, gums, agar, a little amount of galactomannans and pectin , modified cellulose or starches CMC, and other polysaccharides to make high-quality foods.

Due to some of its exceptional qualities, including being tasteless, odorless, non-caloric, medically inert, creating a transparent solution without opacity, impeding the ability of suspended particles to be gravitationally separated, etc. These CMC characteristics aid in enhancing the quality of food and the required pleasant texture to guarantee safety of food. CMC is frequently used in the food industry as emulsion stabilizers, thickeners, moisture binders, additive stabilizers, texture-improving and suspending agents, and other auxiliary agents. The structure, rheological properties, flavor, and the way products look as well as their pseudo plastic characteristics are also fine-tuned using CMC.

In order to assure the food products' long-term safety, it is also employed as a packaging or coating material. On the usage of CMC in food products, numerous researches have been published in the literature. By regulating particle size, concentration, and texture, CMC, for instance, is employed like a thickening in olive oil-based nano-emulsions to enhance the stability and physical properties [55].

On the basis of different viscosity of CMC, it serves as moisture binder (low viscosity) and gelation agent (high viscosity) in food industries. . Additionally, it serves as a thickening in fruit syrup, salad dressing, and semisolid dairy products [56]. In order to maintain food safety, CMC is now employed as a hydrogel (dewatering agent) in fruit syrup or juice. Heat is necessary for the traditional thickening process, but it is not necessary for the super absorbing or dewatering processes when heat is present [57].

As an emulsifier, CMC is used in wine, spreads, acidic beverages, dairy products like ice cream and milk, sauces, and bread goods. To make ice cream of the highest quality, 0.5% CMC is added as a stabilizer. By preventing the over-crystallization of lactose in cream, medium viscosity CMC improves the creamy mouthfeel [58].

In the recent past, consuming CMCs in food industries has grown from a normal level to an advanced one because to their sanitary, biocompatible, and potential for preventing or managing human disease through diet. For instance, Dafe *et al.* [59] created a vehicle for CMC/k-carrageenan mixed foods to deliver probiotic-based food in the colon in order to avoid gastrointestinal illness.

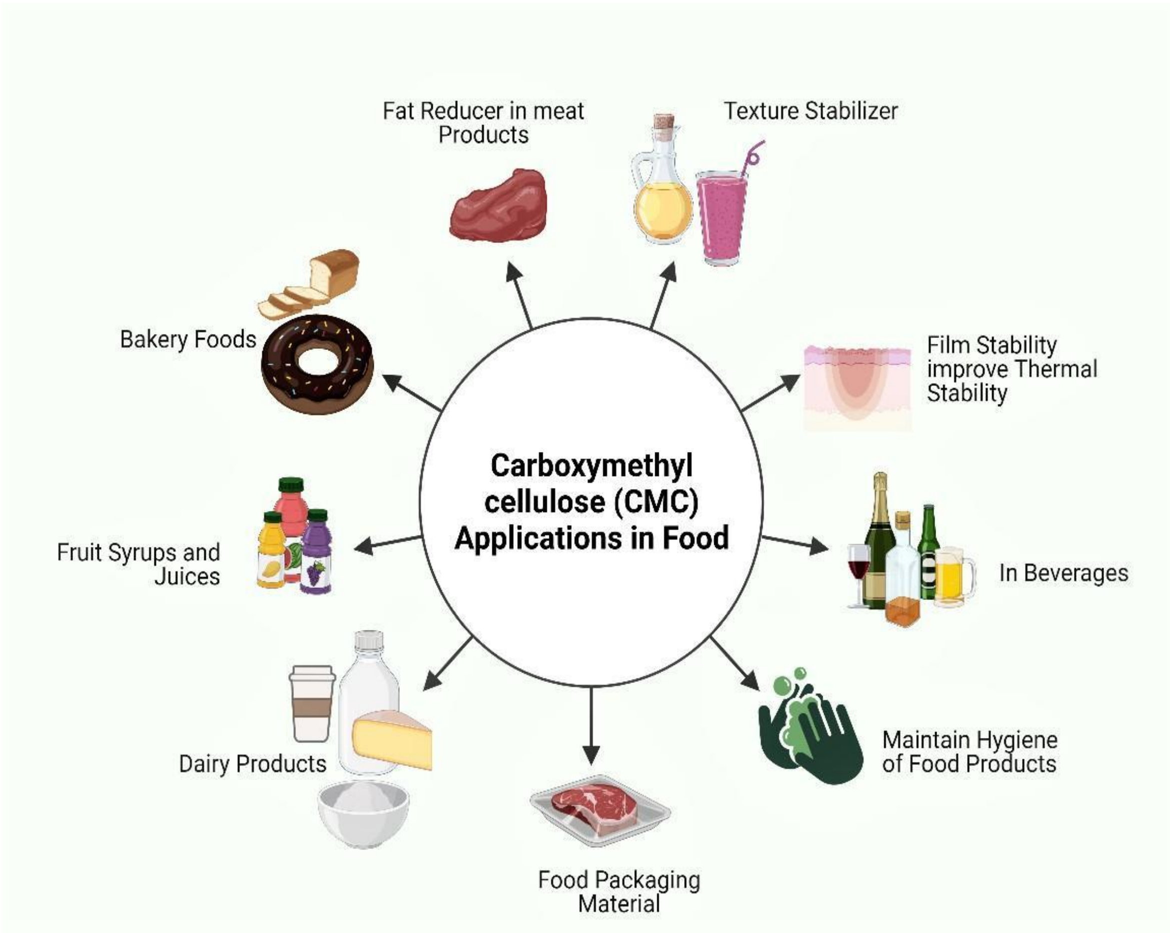

Figure 1: Different applications of CMC in Food industries

Drinks containing cocoa and acid are typically stabilized with CMC, which lessens layer formation and sedimentation at both high and low temperatures. Therefore, owing to the stabilization of minerals in fruit-based beverages or nutritional fiber, in the recent time combined form of CMC and gum tragacanth has been utilized as a stabilizer in drinks [60]. The immune system was strengthened and the gastrointestinal tract or mucosa's health was controlled by food, as advised. A similar coating material was suggested by Ngamekaue *et al.* [61] in 2019 for transporting a herbal-infused microcapsule oil (a combination of oil of holy basil with gelatin) to the intestine. The microcapsule is protected from acid, moisture, or oxidative effects by a CMC/beeswax covering composite while also assisting in the management of the herbal product once it reaches the gut.

The body responds favorably to the suggested herbal items as effective antioxidants, anticancer agents, etc., hence reducing the risk of non-communicable diseases. As a result, bio-based CMC coatings made of grape seed extract and essential oils have also been used on fish [62]. Making nutritious food items is significantly hampered by the high fat content of the food (meat). CMC compounds are utilized as fat substitutes or reducers to address this issue. Gibis and coworkers [63] utilized MCC (microcrystalline cellulose) and CMC as fat substitutes for manufacturing fried patties of beef, CMC with 0.5% concentration being selected as a superior source of flavor, texture, and juiciness. Han *et al.* [64] on the other hand, created healthier beef products with a focus on high nutrition and low fat. To lessen the risk of colon cancer, cardiovascular disease, and other conditions, CMC and other food fibers (such as chitosan cellulose, pectin, inulin, and so on) are used in the processing of meat as texture modifiers, nutrition enhancers and fat reducers.

In the last ten years, CMC has been used as a food packaging material, according to many researchers. Khezrian *et al.* [65] created a packaging material based on nanocomposite with an essential oil doped chitosan/ montmorillonite/ CMC for increasing the shelf life of camel meat. Furthermore, biodegradable and environmentally friendly PVP-CMC hydrogel film is frequently employed as a principal packaging material for food commodities [66]. A biodegradable and antibacterial packaging material made of the combination of a metal cation-based film and CMC/PVA/zeolite has been disclosed. This antibacterial property keeps food from rotting and extends product shelf life. In packaging materials, films made from CMC-CHPS (chickpea husk polysaccharides) have antioxidant and antibacterial properties. Combination of CMC, montmorillonite and dopamine has recently resulted in the development of high stiffness and high thermal stability-based packaging materials [67].

Application in the Water Treatment Process

Water is the world's most abundant natural resource; however, only about 3% of existing water reserves are freshwater, and less than one-third of this freshwater is usable for various domestic, agricultural, and industrial uses [68]. While water consumption is increasing dramatically, the availability of freshwater is being depleted due to an increase in pollution, resulting in water shortages for modern society [69]. Rapid industrialization, uncontrolled urbanization, and a variety of human activities, combined with inefficient waste management, all contribute to this growth in wastewater. Water contamination has recently emerged as one of the world's most pressing challenges. Every day, a massive amount of contaminants enter aquatic habitats from various industries and household activities, causing a variety of illnesses in various living things and humans. The amount of contaminants and toxins that can be found in wastewater from several businesses or household activities has no set upper limit. The two most frequent contaminants found in industrial effluent are dyes and heavy metals, both of which are detrimental to ecosystem sustainability [70, 71]. Even at low concentrations, the presence of dyes restricts penetration of sunlight into water, resulting in a prominent loss of dissolved oxygen, posing severe health dangers to aquatic living entities. In many situations, dyes cause anaerobic digestion, resulting in the formation of several carcinogenic chemicals that can penetrate in the food chain by aquatic creatures.

On the other hand, the dye concentration disposed of into various water bodies remains large. For example, about 7×10^5 tonnes of various reactive dyes are generated each year, with approximately 5-10% of these dyes ending up in the environment. Effluents from industry, heavy metals, on the other hand, pose major health risks due to their high carcinogenic and poisonous potential. Chronic arsenic (As) exposure, for example, can result in severe disorders like bladder, kidney, liver cancer or prostate. Chromium (Cr) is another very hazardous metal that has a negative impact on both human bodies and aquatic creatures [72]. The dangers of heavy metals and dyes to the health of humans and the normal environment underline the importance of industrial wastewater treatment. Distillation, adsorption, coagulation, membrane filtration, redox, electrochemical treatment, are some common physical and/or chemical processes. The most popular and efficient technique for treating contaminated water is adsorption. Although activated carbon is an extremely effective adsorbent, its widespread use for wastewater treatment is constrained by its high cost and labor-intensive regeneration process. Although numerous adsorbents have been found in recent studies to remove heavy metals and dyes from polluted industrial water, treatment of bulk wastewater by using these adsorbents is still difficult [73, 74]. Due to their great removal effectiveness, hydrogels, which are three-dimensional polymer networks, have recently gained a lot of attention in the fight to remove contaminants from waste streams [75]. The high porosity and abundance of hydrophilic functional groups in hydrogels (such as -OH, -COOH, $-NH_2$, $-SO_3H$, $-CONH_2$, etc.) allow for the retention and adsorption of a significant amount of water during the treatment process, leading to the eventual removal and recovery of all aqueous dyes and heavy metals [76].The majority of the hydrogels that are currently in use, however, are made from materials that are neither renewable nor biodegradable, such as petrochemicals. The most prevalent polymer in nature, cellulose, is the source of carboxymethyl cellulose-based hydrogels (CBHs), which are extremely absorbent, long-lasting, non-toxic, biocompatible and biodegradable[77].

Analysts have recently explored employing various CBHs to virtually completely remove heavy metals and colors from polluted water. In this series three-dimensional polymer networks of carboxylated hydrogels have been employed by Zhou *et al.* [78] to remove Pb^{+2} with 90% removal efficiency within four hours. Using various kinds of CBHs, such high adsorption values were also attained for Cu^{2+} (182-230 mg/g), Ni^{2+} (200 mg/g), and Hg^{2+} (140 mg/g) [79]. Recently, Deng *et al.* [80] used chitosan and cellulose to remove nearly 100% of Congo Red dyes with 166.1 mg/g saturation adsorption. There are still many potential applications for CBHs since the modification of HG functional groups improves their adsorption efficiency (**Figure 2**).

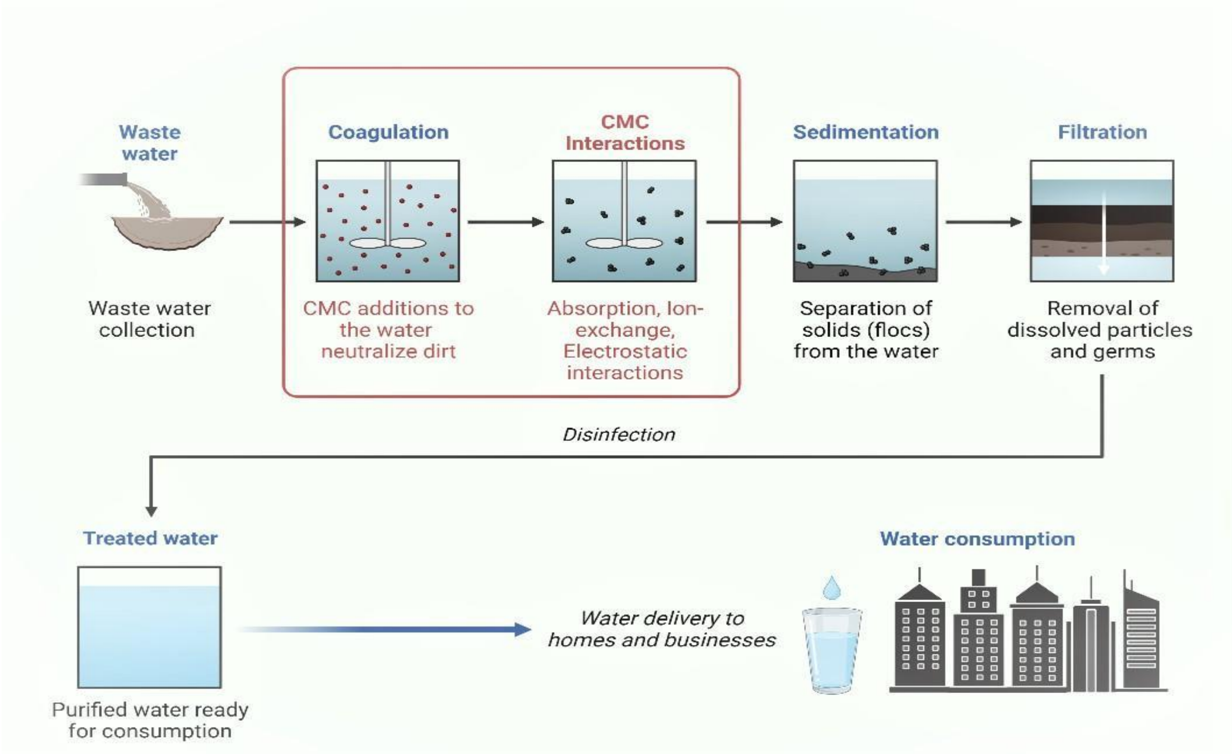

Figure 2: Application of CMC in wastewater treatment based on different interactions.

The impetus behind the current work is the paucity of reviews in this particular field, despite the fact that many research studies employed CBHs to treat contaminated water sources. The different interactions that result in the typical adsorption by CBHs are strongly influenced by the adsorbent characteristics, functional groups present in the HG, , the chemical composition of pollutants, and experimental parameters (like as solution pH, the coexistence of metal ions, initial pollutant concentration, temperature, etc.) [81].

Electrostatic interactions are the primary adsorption process used by CBHs to remove heavy metals and dyes, while various adsorption processes have also been found to combine electrostatic interactions with other interactions [82,83].

CMC-based composites will naturally show a larger adsorption tendency towards metal ions and other cationic pollutants than anionic contaminants because they have electronegative carboxymethyl groups (COOH) on their surface. Adsorbents struggle to effectively bind negatively charged impurities for a sustained period of time due to electrostatic repulsion between anionic contaminants and opposing surface charges. Probably, this is the only cause of scarcity of research on anionic pollutant removal by CMC-hybrid materials to treat the contaminated water in comparison to cationic pollutants in the literature.

As a result, we recommend concentrating on the development of hybrid materials that are CMC-based, more efficient, and less expensive, in particular nano-hybrid super-absorbent materials. To remove different cationic contaminants from wastewater, including cationic dyes, metal ions, various cationic and radioactive elements, more study will be needed in the future. Additionally, CMC-based adsorbents' surfaces may be improved in the future through hybridization with various kinds of organic-inorganic positively charged species, making them more effective for the simultaneous treatment of cationic and anionic pollutants.

Conclusion

Although the sources of CMCs were restricted at the start of its development, in the current scenario, CMC is preferred over other derivatives because of its versatility and quantity of precursor ingredients. Numerous of their substitutes have been proven scientifically over the course of the last two decades. Maize husks was the most promising discovered material among them, which offered the highest product yield with appropriate purity. Essentially, based on their diverse uses and applications, CMCs are now used in biomedical engineering, textile, pharmaceutical, and food industries. One of the most prevalent contaminants in wastewater is dyes and heavy metals, which are discharged by a variety of businesses and have a negative impact on the ecosystem, human health, and aquatic life. The removal of contaminants from wastewater is therefore essential for a safer environment. Cellulose-based hydrogels (CBHs) are excellent choices since they satisfy the criterion while also offering further advantages such high removal effectiveness, cost-effectiveness, and simplicity. The synthesis of CBHs, the adsorption process, and parameters to maximize adsorption capacities are some of the significant components of wastewater treatment utilizing CBHs that have hardly been discussed in the literature. The effective use of CMCs in the water treatment process to remove additional contaminants is now a growing area of research. Despite the fact that several hybrid materials, particularly a variety of super-absorbents based on CMC, have been reported in this context, there is still a great possibility that many more can be created in the future.

Statements

Author's Contribution: Concept, design, and overall supervision: SY; Acquisition and Analysis or interpretation of information and data: SY and SK; Drafting of the manuscript: SY, SK and PR; Editing of the manuscript: SY, SK and PR; All authors provided comments on the manuscript and evaluated critically. All authors gave their consent for publication.

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References:

1. A. M. Bochek, I. L. Shevchuk, L. M. Kalyuzhnaya, Properties of blends of methyl cellulose and carboxymethyl cellulose with different degrees of ionization in solutions and solids, Russ. J. Appl. Chem. 81 (2008) 691–695.
2. V. Pushpamalar, S. J. Langford, M. Ahmad, Y. Y. Lim, Optimization of reaction conditions for preparing carboxymethyl-cellulose from sago waste, Carbohyd. Polym. 64 (2006) 312– 318.
3. P. Methacanon, O. Chaikumpollert, P. Thavorniti, K. Suchiva, Hemicellulosic polymer from vetiver grass and its physicochemical properties, Carbohyd. Polym. 54 (2003) 335–342.
4. D. Fengel, The ultrastructure of cellulose from wood. Wood Sci. Technol. 3 (1969) 203–217.
5. M. P. Adinugraha, D. W. Marseno, Synthesis and characterization of sodium carboxy-methylcellulose from cavendish banana pseudo stem (Musa cavendishii LAMBERT). Carbohydr. Polym. 62 (2005) 164–169.
6. V. Pushpamalar, S. J. Langford, M. Ahmad, Y. Y. Lim, Optimization of reaction conditions for preparing carboxymethyl cellulose from sago waste. Carbohydr. Polym. 64 (2006) 64, 312–318.
7. M. I. H. Mondal, M. S. Yeasmin, M. S. Rahman, Preparation of food grade carboxymethyl cellulose from corn husk agrowaste. Int. J. Biol. Macromol. 79 (2015) 144–150.
8. T. Shui, S. Feng, G. Chen, A. Li, Z. Yuan, H. Shui, T. Kuboki, C. Xu, Synthesis of sodium carboxymethyl cellulose using bleached crude cellulose fractionated from cornstalk. Biomass Bioenergy 105 (2017) 51–58.
9. R. K. Singh, A. K. Singh, Optimization of reaction conditions for preparing carboxymethyl cellulose from corn cobic agricultural waste. Waste Biomass Valor. 4 (2013) 129–137.
10. K. Gutawa, A. Willy, G. Nikita, Synthesis and characterization of sodium carboxymethylcellulose from pod husk of Cacao (Theobroma cacao L.). Int. J. Food Sci. Microbiol. 3 (2015) 99–103.
11. P. Rachtanapun, S. Luangkamin, K. Tanprasert, R. Suriyatem, Carboxymethyl cellulose film from durian rind. LWT Food Sci. Technol. 48 (2012) 52–58.
12. M. I. H. Mondal, M. S. Yeasmin, M. S. Rahman, M. A. Sayeed, Synthesis and characterization of high-purity food grade carboxymethyl celluloses from different parts of maize waste. In Cellulose and Cellulose Derivatives; Ed.; Nova Science, NY, USA, 2015; p. 227.
13. S. Dapía, C. A. Tovar, V. Santos, J. C. Parajó, Rheological behaviour of carboxymethylcell-ulose manufactured from TCF-bleached milox pulps. Food Hydrocoll. 19 (2005) 313–320.
14. L. Golbaghi, M. Khamforoush, T. Hatami, Carboxymethyl cellulose production from sugarcane bagasse with steam explosion pulping: Experimental, modeling, and optimization. Carbohydr. Polym. 174 (2017) 780–788.
15. W. Klunklin, K. Jantanasakulwong, Y. Phimolsiripol, N. Leksawasdi, P. Seesuriyachan, T. Chaiyaso, C. Insomphun, S. Phongthai, P. Jantrawut, S. R. Sommano, Synthesis, Characterization, and Application of Carboxymethyl Cellulose from Asparagus Stalk End. Polymers 13 (2020) 81.

16. H. Dai, H. Huang, Enhanced swelling and responsive properties of pineapple peel carboxymethyl cellulose-g-poly (acrylic acid-co-acrylamide) superabsorbent hydrogel by the introduction of carclazyte. J. Agric. Food Chem. 65 (2017) 565–574.
17. F. Yasar, H. Togrul, N. Arslan, Flow properties of cellulose and carboxymethyl cellulose from orange peel. J. Food Eng. 81 (2007) 187–199.
18. N. Haleem, M. Arshad, M. Shahid, M. A. Tahir, Synthesis of carboxymethyl cellulose from waste of cotton ginning industry. Carbohydr. Polym. 113 (2014) 249–255.
19. G. Joshi, S. Naithani, V. Varshney, S. S Bisht, V. Rana, P. Gupta, Synthesis and characterization of carboxymethyl cellulose from office waste paper: A greener approach towards waste management. Waste Manag. 38 (2015) 33–40.
20. X. He, S. Wu, D. Fu, J. Ni, Preparation of sodium carboxymethyl cellulose from paper sludge. J. Chem. Technol. Biotechnol. 84 (2009) 427–434.
21. H. Bidgoli, A. Zamani, A. Jeihanipour, M. Taherzadeh, Preparation of carboxymethyl cellulose superabsorbents from waste textiles. Fibers Polym. 15 (2014) 431–436.
22. A. F. Alam, M. I. H. Mondal, Utilization of cellulosic wastes in textile and garment industries. I. Synthesis and grafting characterization of carboxymethyl cellulose from knitted rag. J. Appl. Polym. Sci. 128 (2013) 1206–1212.
23. I. A. Jahan, F. Sultana, M. N. Islam, M. A. Hossain, J. Abedin, Studies on Indigenous Cotton linters for Preparation of Carboxymethyl Cellulose. Bangladesh Journal of Scientific and Industrial Research, 42(2007) 29–36.
24. L. Z. Wang, L. Liu, J. Holmes, J. Huang, J. F. Kerry, J. P. Kerry, Effect of pH and addition of corn oil on the properties of whey protein isolate-based films using response surface methodology. Int. J. Food Sci. 43 (2008) 787–796.
25. F. Langmaler, P. Mokrejs, K. Kolomamik, M. Mladek, Biodegradable packing materials from hydrolysates of collagen waste proteins. Waste Management, 28 (2008) 549–556.
26. P. J. Shand, H. Ya, Z. Pietrasik, P. Wanasundara, Physicochemical and textural properties of heat-induced pea protein isolate gels. Food Chem. 102 (2007) 1119–1130.
27. S. Roy, J. W. Rhim, Carboxymethyl cellulose-based antioxidant and antimicrobial active packaging film incorporated with curcumin and zinc oxide. Int. J. Biol. Macromol. 148 (2020) 666–676.
28. M. T. Ghannam, M. N. Esmail, Rheological properties of carboxymethyl cellulose. J. Appl. Polym. Sci. 64 (1997) 289–301.
29. A. A. Oun, J. W. Rhim, Preparation and characterization of sodium carboxymethyl cellulose/cotton linter cellulose nanofibril composite films. Carbohydr. Polym. 127 (2015) 101–109.
30. C. Sarkar, K. Anuvrat, S. Garai, S. K. Sahu, J. Chakraborty, One pot method to synthesize three-dimensional porous hydroxyapatite nanocomposite for bone tissue engineering. J. Porous Mater. 27 (2020) 225–235.
31. A. Koneru, K. Dharmalingam, R. Anandalakshmi, Cellulose based nanocomposite hydrogel films consisting of sodium carboxymethylcellulose–grapefruit seed extract nanoparticles for potential wound healing applications, Int. J. Biol. Macromol. 148 (2020) 833–842.
32. D. Li, H. Sun, L. Jiang, K. Zhang, W. Liu, Y. Zhu, J. Fangteng, C. Shi, L. Zhao, H. Sun, Enhanced biocompatibility of PLGA nanofibers with gelatin/nano-hydroxyapatite bone biomimetics incorporation. ACS applied materials & interfaces 6 (2014) 9402-9410.
33. A. A. Mansur, F. G. de Carvalho, R. L. Mansur, S. M. Carvalho, L. C. de Oliveira, H. S. Mansur, Carboxymethylcellulose/ZnCdS fluorescent quantum dot nanoconjugates for cancer cell bioimaging. Int. J. Biol. Macromol. 96 (2017) 675–686.
34. T. T. H. Thi, Y. Lee, S. B. Ryu, H. J. Sung, K. D. Park, Oxidized cyclodextrin-functiona-lized injectable gelatin hydrogels as a new plat formfor tissue-adhesive hydrophobic drug delivery, RSC Adv. 7 (2017) 34053–34062.
35. J. Li, D. J. Mooney, Designing hydrogels for controlled drug delivery, Nat. Rev. Mater.
36. 1 (2016), 16071.
37. M. C. Adeyeye, A. C. Jain, M. K. Ghorab, W. J. Reilly, Viscoelastic evaluation of topical creams containing microcrystalline cellulose/ sodium carboxymethyl cellulose as stabilizer. AAPS Pharm Sci Tech 3 (2002) 16–25.
38. B. S. Gupta, J. V. Edwards, in Advanced Textiles for Wound Care (Second Edition), 2019
39. D. Kumar, V. Jain, B. Rai, Can carboxymethyl cellulose be used as a selective flocculant for beneficiating alumina-rich iron ore slimes? A density functional theory and experimental study, Miner. Eng. 121 (2018) 47-54.

40. Y. Qiu, K. Park, Environment-sensitive hydrogels for drug delivery Adv. Drug Deliv. Rev. 53 (2001) 321–39.
41. M. S. Rahman, M. S. Hasan, A. S. Nitai, S. Nam, A. K. Karmakar, M. S. Ahsan, M. J. A. Shiddiky, M. B. Ahmed, Recent Developments of Carboxymethyl Cellulose, Polymers 13 (2021) 1345.
42. L. B. Peppas, N. A. Peppas, Equilibrium swelling behavior of pH-sensitive hydrogels Chem. Eng. Sci. 46 (1991) 715–22.
43. M. Muddasar, A. Beaucamp, M. Culebras, M. N. Collins, Cellulose: Characteristics and applications for rechargeable batteries, Int. J. Biol. Macromol. 219 (2022) 788-803.
44. M. Akhlaq, U. Mushtaq, S. Naz, M. Uroos, Carboxymethyl cellulose-based materials as an alternative source for sustainable electrochemical devices: a review, RSC Adv. 13 (2023) 5723-5743.
45. A. Vanamudan, K. Bandwala, P. Pamidimukkala, Adsorption property of Rhodamine 6G onto chitosan-g-(N-vinyl pyrrolidone)/ montmorillonite composite. Int. J. Biol. Macromol. 69 (2014), 506–513.
46. M. H. Karimi, G. R. Mandavinia, B. Massoumi, A. Baghban, M. Saraei, Ionically crosslinked magnetic chitosan/ kappacarrageenan bio adsorbents for removal of anionic eriochrome black-T. Int. J. Biol. Macromol. 113 (2018) 361–375.
47. E. M. Ahmed, Hydrogel: Preparation, characterization, and applications: A review. J. Adv. Res. 6 (2015) 105–121.
48. P. Fatehi, L. Qian, R. Kititerakun, T. Rirksomboon, H. Xiao, Complex formation of modified chitosan and carboxymethyl cellulose and its effect on paper properties. Tappi J. 8 (2009) 29–35.
49. E. N. Gencoglu, O. Ozden, O. Simseker, Effects of carboxymethyl cellulose as a surface sizing agent on the printable properties of newspaper. Asian J. Chem. 22 (2010) 5561.
50. X. Zhang. X. Liu, S. Yang, K. L. Y. Wu, Effect of carboxyl methyl cellulose on the adhesion properties of sodium silicate wood adhesive, International Conference on Biobase Material Science and Engineering (BMSE) (2012) 230-233
51. R. You, X. Han, Z. Zhang, L. Li, C. Li, W. Huang, J. Wang, J. Xu, S. Chen, An environmental friendly cross-linked polysaccharide binder for silicon anode in lithium-ion batteries, Ionics 25 (2019) 4109-4118.
52. D. W. Davidson, M. S Verma, F. X. Gu, Controlled root targeted delivery of fertilizer using an ionically crosslinked carboxymethyl cellulose hydrogel matrix, Springer Plus 318 (2013) 1-9.
53. E. Dickinson, Hydrocolloids as emulsifiers and emulsion stabilizers. Food Hydrocoll. 23 (2009) 1473–1482.
54. S. Meyers, D. Butler, W. Hastings, Alginates as binders for crustacean rations. Progress. Fish Cult. 34 (1972) 9–12.
55. C. Arancibia, R. N. Lisboa, R. N. Zuniga, S. Matiacevich, Application of CMC as thickener on nanoemulsions based on olive oil: Physical properties and stability. Int. J. Polym. Sci. 2016 (2016) 1-10.
56. M Sikora D.Sc., L. Juszczak, M. Sady, Hydrocolloids in Forming Properties of Cocoa Syrups, International Journal of Food Properties 6 (2003) 215–228.
57. M. S. Islam, M. N. Alam, T. G. van de Ven, Sustainable cellulose-based hydrogel for dewatering of orange juice. Cellulose 27 (**2020)** 7637–7648.
58. A M Manurung, D F Ayu, V S Johan, Addition of Carboxymethyl Cellulose Concentration on Lemongrass Extract Ice Cream, International Conference on Sustainable Agriculture and Biosystem 2020 IOP Conf. Series: Earth and Environmental Science 757 (2021) 012063.
59. A. Dafe, H. Etemadi, H. Zarredar, G. R. Mahdavinia, Development of novel carboxymethyl cellulose/k-carrageenan blends as an enteric delivery vehicle for probiotic bacteria. Int. J. Biol. Macromol. 97 (2017) 299–307.
60. A. H. mohammadi, M. K. Pirouzifard, M. Shahedi, M. Alizadeh, Enrichment of a fruit-based beverage in dietary fiber using basil seed: Effect of Carboxymethyl cellulose and Gum Tragacanth on stability, LWT - Food Sci.Technol. 74 (2016) 84-91.
61. N. Ngamekaue, P. Chitprasert, Effects of beeswax-carboxymethyl cellulose composite coating on shelf-life stability and intestinal delivery of holy basil essential oil-loaded gelatin microcapsules. Int. J. Biol. Macromol. 135 (2019) 1088–1097.
62. R. Priyadarshi, S. M. Kim, J. W. Rhim, Carboxymethyl cellulose-based multifunctional film combined with zinc oxide nanoparticles and grape seed extract for the preservation of high-fat meat products, Sustainable Materials and Technologies 29 (2021) 00325.

63. M. Gibis, V. Schuh, J. Weiss, Effects of carboxymethyl cellulose (CMC) and microcrystalline cellulose (MCC) as fat replacers on the microstructure and sensory characteristics of fried beef patties. Food Hydrocoll. 45 (2015) 236–246.
64. M. Han, H. C. Bertram, Designing healthier comminuted meat products: Effect of dietary fibers on water distribution and texture of a fat-reduced meat model system. Meat Sci. 133 (2017) 159–165.
65. A. Khezrian, Y. Shahbazi, Application of nanocompostie chitosan and carboxymethyl cellulose films containing natural preservative compounds in minced camel's meat. Int. J. Biol. Macromol. 106 (2018) 1146–1158.
66. N. Roy, N. Saha, T. Kitano, P. Saha, Biodegradation of PVP–CMC hydrogel film: A useful Food Packag material. Carbohydr. Polym. 89 (2012) 346–353.
67. T. Guo, L. Gu, Y. Zhang, H. Chen, B. Jiang, H. Zhao, Y. Jin, H. Xiao, Bioinspired self-assembled films of carboxymethyl cellulose–dopamine/montmorillonite. J. Mater. Chem. A 7 (2019) 14033–14041.
68. T. U. Rashid, S. M. F. Kabir, M. C. Biswas, M. A. R. Bhuiyan, Sustainable Wastewater Treatment via Dye-Surfactant Interaction: A Critical Review. Ind. Eng. Chem. Res. 59 (2020) 9719–9745.
69. A. G. Varghese, S. A. Paul, M. S. Latha, Remediation of heavy metals and dyes from wastewater using cellulose-based adsorbents. Environ. Chem Lett 17 (2019) 17 867–877.
70. E. I. Ugwu, J. C. Agunwamba, A review on the applicability of activated carbon derived from plant biomass in adsorption of chromium, copper, and zinc from industrial wastewater. Environ. Monit Assess 192 (2020) 240.
71. S. Wong, N. A. Ghafar, N. Ngadi, F. A. Razmi, I. M. Inuwa, R. Mat, N. A. S. Amin, Effective removal of anionic textile dyes using adsorbent synthesized from coffee waste. Sci. Rep. 10 (2020) 2928.
72. F. S. A. Khan, N. M. Mubarak, Y. H. Tan, R. R. Karri, M. Khalid, R. Walvekar, E. C. Abdullah, S. A. Mazari, S. Nizamuddin, Magnetic nanoparticles incorporation into different substrates for dyes and heavy metals removal-A Review. Environ. Sci Pollut. R 27 (2020) 43526–43541.
73. M. H. Karimi, G. R. Mandavinia, B. Massoumi, A. Baghban, M. Saraei, Ionically crosslinked magnetic chitosan/ kappa-carrageenan bioadsorbents for removal of anionic eriochrome black-T. Int. J. Biol. Macromol. 113 (2018) 361–375.
74. L. H. Liu, Y. Lin, Y. Y. Liu, H. Zhu, Q. He, Removal of Methylene Blue from Aqueous Solutions by Sewage Sludge Based Granular Activated Carbon: Adsorption Equilibrium, Kinetics, and Thermodynamics. J. Chem. Eng. Data 58 (2013) 2248–2253.
75. D. S. Malik, C. K. Jain, A. K. Yadav, Removal of heavy metals from emerging cellulosic low-cost adsorbents: A review. Appl. Water Sci. 7 (2017) 2113–2136.
76. M. Akter, M. Bhattacharjee, A. K. Dhar, F. B. A. Rahman, S. Haque, T. U. Rashid, S. M. F. Kabir, Cellulose-Based Hydrogels for Wastewater Treatment: A Concise Review Gels 7 (2021) 30.
77. P. Thivya, S. Akalya, V. R. Sinija, A comprehensive review on cellulose-based hydrogel and its potential application in the food industry, Applied Food Research 2 (2022) 161.
78. Y. M. Zhou, S. Y. Fu, L. L. Zhang, H. Y. Zhan, M. V. Levit, Use of carboxylated cellulose nanofibrils-filled magnetic chitosan hydrogel beads as adsorbents for Pb(II). Carbohyd. Polym. 101 (2014) 75–82.
79. H. Tang, C. Y. Chang, L. N. Zhang, Efficient adsorption of Hg^{2+} ions on chitin/cellulose composite membranes prepared via environmentally friendly pathway. Chem. Eng. J. 173 (2011) 689–697.
80. H. Tu, Y. Yu, J. J. Chen, X. W. Shi, J. L. Zhou, H. B. Deng, Y. M. Du, Highly cost-effective and high-strength hydrogels as dye adsorbents from natural polymers: Chitosan and cellulose. Polym. Chem-Uk 8 (2017) 2913–2921.
81. V. Sinha, S. Chakma, Advances in the preparation of hydrogel for wastewater treatment: A concise review. J. Environ. Chem. Eng. 7 (2019) 103295.
82. Z. Mohammadi, S. Shangbin, C. Berkland, J. T. Liang, Chelator-mimetic multi-functionalized hydrogel: Highly efficient and reusable sorbent for Cd, Pb, and As removal from waste water. Chem. Eng. J. 307 (2017) 496–502.
83. S. Yang, S. Fu, H. Liu, Y. Zhou, X. Li, Hydrogel beads based on carboxymethyl cellulose for removal heavy metal ions. J. Appl. Polym. Sci. 119 (2011) 1204–1210.