CHEMISTRY & CHEMICAL TECHNOLOGY

*Chem. Chem. Technol., 2024,*
*Vol. 18, No. 2, pp. 200–210*

**Chemical Technology**

# CARBOXYMETHYL CELLULOSE-BLENDED FILMS FROM RICE STUBBLE AS A NEW POTENTIAL BIOPOLYMER SOURCE TO REDUCE AGRICULTURAL WASTE: A MINI REVIEW

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https://doi.org/10.23939/chcht18.02.200

**Abstract.** The vegetative part of the rice plant, *Oryza sativa* L., that remains after paddy fields have been cleared during harvest or afterward is known as rice stubble. Carboxymethyl Cellulose from Rice Stubble (CMCr) is a promising biopolymer source that can be made from rice stubble waste. Carboxymethyl cellulose was synthesized from rice stubble by a solvent-casting method. Various types of plasticizers (glycerol and olive oil) and the components they contain provide flexibility for use as a material for food packaging. The films' moisture barrier was enhanced by the olive oil content while their extensibility was enhanced by the glycerol content. Indonesia is known as a country with the majority of the population working as farmers. Along with the increase in rice harvested area each year, agricultural waste in the form of rice stubble is also increasing. In the future, the application of CMCr in food packaging has the potential to revolutionize sustainable practices in Indonesia's agricultural sector. By leveraging CMCr's unique properties, such as enhanced moisture barrier and increased extensibility, there is an opportunity to develop eco-friendly packaging solutions. This innovation not only addresses the challenge of rising rice stubble waste but also contributes to the reduction of environmental pollution, offering a greener and more sustainable approach to packaging in the country.

**Keywords:** carboxymethyl cellulose; rice stubble; biopolymer film; glycerol; olive oil.

## 1. Introduction

Indonesia is not only known as a maritime country but also as an agricultural country where the majority of the Indonesian people make their living as farmers. In addition to providing a means of subsistence, the agricultural sector contributes significantly to the growth of its economy and meets the population's food requirements. Table 1 shows the rice harvested area in Indonesia from 2018–2023. Harvested area (BPS) referred to here is the area of plants that are harvested after the plants are old enough, with a minimum yield of 11 % of normal conditions. This measure is described in hectares (ha) and covers monthly, quarterly, sub-round, or annual periods. Starting in 2018, the calculation of rice harvest area data shifted to the Area Sample Frame (*Kerangka Sampel Area* or KSA) method, replacing the previous method which used eye estimates collected through Agricultural Statistics (*Statistik Pertanian* or SP) reporting by the Head of District Service Branch (*Kepala Cabang Dinas* or KCD)[1].

Based on Table 1, the abundance of rice harvested areas also influences agricultural waste in the form of rice stubble. Rice stubble that is not reused will usually be burned just like that. Rice stubble burning is a common issue in Indonesia that could contribute to multiple levels of pollution. Burning also raises the temperature of the soil and makes it dry out, which means that irrigation needs more water.

Rice stubble has the main component, namely polysaccharides. However, when the stubble is burned, the nutrients it contains are lost. Therefore, the synthesis of CMC from rice stubble (CMCr) is expected to be an alternative to commercial CMC (CMCc) which is used in the food trade and must be imported from other countries. Numerous steps must be taken to recycle a large amount of agricultural waste. The process of extracting cellulose from these waste materials is one of the most innovative and valuable among them. Due to their exceptional

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physical and mechanical properties, biodegradability, and unique characteristics, cellulose and its derivatives are attracting an increasing amount of interest from the food packaging industry.

**Table 1.** Rice Harvested Area in Indonesia According to BPS Data for 2018–2023[1]

| Year | Harvested Area, ha |
|---|---|
| 2018 | 11,377,934.44 |
| 2019 | 10,677,887.15 |
| 2020 | 10,657,274.96 |
| 2021 | 10,411,801.22 |
| 2022 | 10,452,672.00 |
| 2023 | 10,196,886.77 |

Biopolymers that come from natural sources like plants, food waste (like banana and orange peel), microorganisms, and so on are examples of natural polymers. Natural or green polymers can be used to reduce the harmful and non-biodegradable substances produced daily by various industries. Among many different kinds of polymers, cellulose is one of the most common and easiest to obtain from the cell walls of plants[2,3]. When mixed with a variety of antibacterial polymers, cellulose materials, and their derivatives produce various composite films. Additionally, cellulose can protect against ultraviolet rays and has a high thermal resistance. Antioxidant and antibacterial agents can be carried by it. Because they are non-toxic, burnable, and decomposable, they can be utilized in the manufacturing of various polymer composites. In addition, it is easily accessible and available in large quantities worldwide. However, cellulose and its derivatives have several drawbacks, including inadequate interfacial adhesion and a high capacity for water absorption. Because of these restrictions, cellulose has been the subject of research for a considerable amount of time[4].

The biodegradability of biopolymer films and their potential use as eco-friendly packaging materials are currently the focus of research. Biopolymers come primarily from polysaccharides, particularly cellulose (CMC)[5,6]. The synthesis of Carboxymethyl Cellulose from Rice Stubble (CMCr) started by reacting fresh cellulose with sodium hydroxide (NaOH). Then followed by reacting cellulose with monochloroacetic acid or sodium monochloro-acetate in an alcohol support medium, CMC becomes a significant cellulose ether. After this, the obtained alkaline cellulose is extracted.[7] CMC is a polysaccharide derivative that dissolves in water and can be used alone or in combination with other materials to make an edible film; for instance, films made with CMC and corn starch[8], modified starch[9], *etc.*

Due to its hydrophilic nature, CMC-based film has poor moisture resistance and span mechanical properties (fragility)[5,10]. To overcome film brittleness caused by forces between molecules, plasticizers are required[5]. Glycerol is frequently used to increase the extensibility and flexibility of films because it allows polymer chains to move more freely[5,6,11]. However, glycerol also increased the film's hydrophilicity, increasing its porosity[9]. To improve the water barrier's effectiveness, vegetable oils, lipids, and fatty acids are incorporated into an emulsion film[12]. Olive oil is one of the most abundant sources of monounsaturated fatty acids among vegetable oils. Besides being able to increase the water barrier of the film, these fatty acids also have positive effects on health, including natural antioxidants[13]. As a result, it would be prudent to investigate the effects of oil on CMC-based films given that there is currently no information available on the subject. When the edible film is applied to food, this will not only enhance the film's properties but also provide nutrients.

## 2. Methods for Food Packaging Fabrication Made from Cellulose and Its Derivatives

There are lots of methods for fabricating cellulose-based packaging films. Cellulose and its derivatives in combination with other materials, as well as the methodology and results of the study are presented in Table 2.

### 2.1. Solution Casting

Solution casting is the simplest and low-economic method used to make thin films from solutions using a centrifugal force. The main components in this solution-casting method are polymers and solvents, but this does not rule out the use of other additives. However, what needs to be emphasized is that the polymer used must be soluble in the selected solvent at a strictly appropriate concentration. Usually, if the polymer concentration is low, it will produce a film with a porous structure, while the polymer with a higher concentration will produce a denser film structure.

### 2.2. Electrospinning

Electrospinning is a versatile and innovative method used in the fabrication of polymers by utilizing an electrical potential. This method is chosen because it is simple, flexible, cost-effective, and feasible for large-scale fabrication. This method is very helpful in the process of making biopolymers (synthetic or natural) and the manufacture of fibers from melts (metal oxides, ceramics, etc.). In a study conducted by (Ohkawa, 2015)[14], a two-step process was adopted in which Cellulose Acetate (CA) was used for the first electrospinning process to regenerate cellulose thin fibers.

## 2.3. Microencapsulation

Encapsulation is the process of including a compound in a capsule to protect it from the environment and also to control its release. Microencapsulation is gaining more attraction. This method is quite efficient in increasing the utilization of bioactive compounds because most of the bioactive agents are unstable in normal environments or deteriorate in contact with the environment (water, air, *etc.*), so the microencapsulation method is considered suitable in helping to maintain or controlling the release of bioactive compounds and also in optimizing their properties[15]. The other methods have been presented in Table 2.

**Table 2.** Methods of Manufacturing Food Packaging from Cellulose and its Derivatives with Other Materials, together with the Results

| Polymers | Other Material | Methods | Results | References |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Ethyl Cellulose (EC) | Gliadin (GN)-Nanofibers (NFs) | Electrospinning | The potent and time-dependent antioxidant and antimicrobial activity | 16 |
| Cellulose Acetate (CA) | Alginate and Carrageenan | Solution casting | Biodegradable; polysaccharides inhibit the growth of certain type of microorganisms | 17 |
| Microcrystalline Cellulose (MCC) | Naringin | Solution casting | High transparency; UV blocking; antioxidant capacity; antibacterial properties; improved barrier properties; biodegradability | 18 |
| Microcrystalline Cellulose (MCC) | C-6 Fluorinated Carboxylic Acid | Solution casting | Tuning of mechanical properties; hydrophobicity and oleophobicity; improved barrier properties; biodegradable in seawater | 19 |
| Ethyl Cellulose (EC) | Polyvinylpyrrolidone (PVP) | Microfluidic spinning | PVP ameliorates the thermal properties; the tensile properties were improved; fine tensile and hydrophilic performance; exhibiting good properties | 20 |
| Cellulose Nanofibers (CNF) | Citrus pectin | Nano emulsions | Emulsion gel showed a slightly larger droplet diameter, better viscoelasticity and emulsification; composite aerogel has a larger pore size and thinner pore wall; its tensile and compressive properties have been significantly improved; moisture absorption was close to 100 % of its weight; aerogel has better resistance to *Staphylococcus aureus* compared to *Escherichia coli*; when applied to *Agaricus bisporus* showed the relative humidity in a package and can be stabilized at about 97 %; hardness, color, total phenol content, cell membrane integrity, and total anti-oxidant capacity of *Agaricus bisporus* were maintained and fresh-keeping period was extended to 5 days | 21 |
| Cellulose Nanofibers (CNF) | Coconut shell, Polyvinyl alcohol (PVA), Essential oil (linseed oil and lemon oil) | Combination of Mechanical (ball milling), Chemical (acid hydrolisis), and Physical (ultra-sonication) | The essential oil improved the antioxidant and antimicrobial properties of PVA-CNF film; PVA-CNF-oil-based composite film showed good antimicrobial | |

Continuation of **Table 2**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| | | | activity against food-borne pathogens; excellent biodegradability; the film enhanced mechanical, thermal, optical, and antioxidant properties | 22 |
| Cellulose Nano Particles (CNP) | Polyvinyl alcohol and Essential oil | Alkaline treatment, bleaching, acid hydrolisis | Enhanced physicochemical and antimicrobial activity | 23 |
| Bacterial Cellulose (BC) | Pullulan and Ferulic Acid (FA) | Solution casting | Pullulan-based composite films showed better barrier, UV-Vis shielding, hydrophobicity, mechanical, and thermal stability properties; formed a dense structure between pullulan, BC, and FA through a hydrogen bond interaction; obtained superior antioxidant and anti-fogging properties | 24 |
| Cellulose Nanocrystals (CNCs) | Faba Beans Protein (FBP) | Solution casting | Improved the strength properties of the Faba beans protein films; showed improved barrier properties; decreased the water susceptibility of the Faba beans protein film | 25 |
| Cellulose Acetate (CA) | Rice Straw Cellulose Nanofibers (RS-CNFs) | Solution casting | Improved the tensile strength of CA films; enhanced the thermal and optical properties of the film | 26 |
| Carboxymethyl Cellulose (CMC) | Gelatin, Chitosan, and Curcumin (GEL/CUR/CS) | Microencapsulation | Improved the thermal stability, barrier, and tensile strength of the film; exhibited distinct color changes in different pH ranges | 27 |
| Ethyl Cellulose-Cinnamaldehyhde (CA) | Pullulan | Electrospinning | Exhibited hydrophobic surface; improved flexibility; strong antimicrobial activity | 28 |
| Cellulose Nanofibers (CNF) | Shikonin extracted from dried roots of gromwell (*Lithospermum erythrorhizon*) | Solution casting | Showed distinctive color changes depending on pH in the range of 2–12; dispersed in the CNF matrix to form a compatible red-colored film; improved the mechanical properties of the CNF film without significantly affecting the crystal structure, water vapor barrier, and thermal stability properties of the film; showed remarkable ultraviolet blocking properties without much-sacrificing transparency; showed potential antimicrobial and antioxidant activities | 29 |
| Hydroxyethylcellulose (HEC) | Citric Acid (CA) and ZnO | Solution casting | HEC/CA/ZnO inhibits the growth of *Staphylococcus aureus* (91.4 %) and *Eschericia coli* (61.7 %) bacteria | 30 |

Continuation of **Table 2**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Carboxymethyl Cellulose (CMC) | Agar and Natural colorants (anthocyanin and shikonin) | Solution casting | Film properties (WVP, WCA, and strength) were improved by adding the colorants; showed a considerable UV-light barrier property with high transparency; showed excellent pH-responsive color-changing and gas sensing properties; the color indicator showed potent antioxidant and antibacterial activities | 31 |
| Bamboo Shoot Cellulose (BSC) | Sodium Alginate (SA) | Freeze drying | Interpenetrating network structure was reinforced by $Ca^{2+}$-induced crosslinking; crosslinked aerogels showed enhanced thermal stability and mechanical properties; encapsulated curcumin showed a sustained release behavior and antioxidant activity | 32 |
| Tempo Cellulose Nanofibrils (TOCNs) | Pullulan (PULL) and Montmorillonite (MMT) clay | Solution casting | Improved the mechanical and thermal properties; improved water barrier properties; reduced moisture susceptibility; transparent and biodegradable | 33 |
| Carboxymethyl Cellulose (CMC) | Alginate and Medicinal plants (*Spinacia oleracea* and *Cissus quadrangularis*) | Lyophilization | Alg/CMC/SO scaffold expressed higher cell viability than Alg/CMC/SO-CQ scaffold, which possesses better cellular biocompatibilty | 34 |
| Carboxymethyl Cellulose (CMC) | Zinc Oxide Nanoparticles (ZnO NPs) | Low energy and Organic solvent-free, without calcination or grinding | Resulting in a physical barrier to prevent aggregation | 35 |
| Carboxymethyl Xylan (CMX) | Chitosan (CS) and Graphene Oxide (GO) | Solution casting | Exhibited a good oxygen barrier and antibacterial properties | 36 |
| Carboxymethyl Cellulose (CMC) | Grape Seed Extract (GSE) and Zinc Oxide Nanoparticles (ZnONPs) | Solution casting | The addition of GSE provided excellent antioxidant activity to the films and also gave the film 100 % UV-protection; the addition of ZnONPs increased the mechanical and water vapor barrier properties with potent antibacterial activity against food-borne pathogens | 37 |

## 3. Application of Cellulose and Its Derivatives in Food Preservation

Several factors can cause fruit and vegetable spoilage, such as climate and weather factors. Other factors include microorganisms, poor handling, and poor packaging. Cellulose and its derivatives can be used to overcome most of the problems caused by these factors. Most of the fruit spoilage is caused by the activity of spoilage microbes. Fruit that has been cut also has a fairly short shelf-life, and loses its texture and color (brown color due to oxidation), so a solution is needed to overcome this problem. Cellulose and its derivatives are actively used to combine various antimicrobial agents to overcome this but need to be readjusted depending on the fruit to be coated with the cellulose film. For example, the chemical structure of the fruit decides whether the packaging must be soft or must be hard and fibrous[38]. Scientists have proven that packaging with edible coatings can prevent the softening of vegetables because softening vegetables is a big deal in the context of fresh cut vegetables[39]. If this is not handled, it can cause texture loss that cannot be accepted by the customer. Cellulose can be utilized in this case as a stabilizer which also contains various preservatives. Cellulose-based packaging is not only used to prevent spoilage of fruits and vegetables but can also be applied to other foods. Table 3 presents a mixture of cellulose and its derivatives with other polymers in their use as food preservatives.

**Table 3.** Blend of Cellulose and Its Derivatives with Other Polymers for Various Foods Preservatio

| Foods | Blended Polymers | Activity of Film | References |
|---|---|---|---|
| Fish and meat | Cellulose Nanofibers/Cellulose Acetate (CNF/CA) | Anthocyanin converts the film into a sensor for ammonia vapor detection | 40 |
| Pomegranate (*Punica granatum*) | Polypropylene/Nanocomposite Multi-layered Film (PP/NMF) | Showed high barrier properties; extending its shelf-life in the refrigerator to over 15 days | 41 |
| Tilapia fillets | Bacterial Cellulose/Cyanidin-3-Glucoside (BC/C3G) | The mechanical properties of the film were significantly changed due to higher crystallinity induced by C3G; increased crystallinity and transmittance intensity of the film; exhibited distinctive color changes from red to green when exposed to buffers with a pH from 3 to 10 | 42 |
| Minced beef | Cellulose-Chitosan-Alizarin | The film can track the freshness of minced beef during storage through perceptible color changes | 43 |
| Black grape fruits | Chitosan/Cellulose Acetate Pthalate/incorporated with ZnO nanoparticles (CS/CAP/ZnO) | Enhanced tensile, UV resistance, and barrier properties; exhibited excellent antimicrobial activity against *S. aureus* and *E. coli* than the pure CS film; increased the shelf-life of fresh black grape fruits to 9 days | 44 |
| Shrimp | *Echium amoenum* extract (EAE) | Exhibited distinguishable color changes from violet to yellow through pH 2−12; visually identified shrimp spoilage by color changes | 45 |
| Fish | Bacterial Nanocellulose/Black Carrot Anthocyanins | Demonstrated a significant correspondence of fish shelf-life and color changes of a nanocellulose-based-pH-sensing indicator | 46 |
| Fresh-cut green bell peppers | Xanthan gum, hydroxypropyl methyl cellulose, tea polyphenol | Enhanced antioxidant activity and antibacterial properties | 47 |
| Strawberry | Cellulose Nanocrystals (CNCs) and Gum Arabic (GA) | Enhanced mechanical strength and thermal stability of the film; strongly decreased the water vapor and oxygen permeability of films; endowed the composite films with smooth and compact microstructure; could delay the spoilage during storage | 48 |

CMCr was successfully synthesized from rice straw cellulose with 7 g of chloroacetic acid per 5 g of cellulose at 50 °C for 180 min. The result is a water-soluble yellow powder with a yield of 150.08 %, a water content of 6.99 %, a pH of 8.21, a DS of 0.64, a viscosity of 33.03 cP, and a purity of 90.18 %. Although suitable for commercial use, it is necessary to develop synthesis conditions to improve quality. CMCr from rice straw has potential as a new biopolymer for food and pharmaceutical packaging films, adding value to agricultural waste[49]. This research discusses the production and characteristics of carboxymethyl cellulose (CMC) film and a mixture of CMC film with polyvinyl alcohol (CMC/PVA) using husk as a raw material. CMC is produced through two stages, namely cellulose extraction from husks and an etherification process with NaOH and monochloroacetic acid (MCA). CMC and CMC/PVA films with a PVA content of 12.5–50 % show an increased clarity and tensile strength, with CMC/PVA (12.5) films having a maximum tensile strength of 20 MPa. In addition, both types of films can be degraded more than 50 % in 10 days, while CMC/PVA (12.5) films have potential as biodegradable planting materials[50].

The research conducted by Miroshnichenko *et al.*[52] explored improving the operational properties of biodegradable polymer hydrogel materials based on hydroxypropyl methylcellulose through modification with humic acid from lignite. As a result, an environmentally friendly hybrid hydrogel film with antibacterial properties was obtained. Through physicochemical analysis, it was identified that hydroxypropyl methylcellulose modified with humic acid followed the matrix synthesis mechanism. The optimal humic acid content for hydroxypropyl methylcellulose-based biodegradable hydrogel films was revealed to be 15 wt. %. This hybrid modification allows the film to remain biodegradable while gaining antibacterial properties, outperforming similar films based on already known natural biopolymers[51]. The research carried out by Lebedev *et al.*[3] explored the potential of a biodegradable hybrid film based on hydroxypropyl methylcellulose and humic acid which has not only high strength but also environmentally friendly antibacterial properties. Through physicochemical and IR spectroscopy studies, confirmation of the formation of the hybrid structure was achieved. Variations in water absorption, tensile strength, relative elongation, and mold formation time were identified depending on the humic acid content. The modified hybrid maintains biodegradability while providing antibacterial properties. As a result, this biodegradable film shows superior operational characteristics compared to similar films based on natural biopolymers[52].

Environmental welfare, environmentally friendly materials and waste recycling are becoming major concerns in the food industry. To support sustainability, biodegradable packaging is considered better than plastic. Carboxymethyl cellulose (CMC), found in vegetable and fruit waste, plays an important role in the manufacture of biodegradable packaging. By combining CMC with biopolymers or nanomaterials, films with desired mechanical and technofunctional properties can be produced. Although biodegradable packaging is growing in popularity due to environmental concerns, economic challenges remain, and large trials are needed to gauge its applicability on a broader industrial scale[3].

## 4. Effect of Plasticizer on the Properties of CMC-based Films

### 4.1. Glycerol

Compared to the control film, the moisture content (MC) of the glycerol-added film increased significantly with the glycerol concentration, this is because the glycerol interacts with water. And then, the addition of glycerol to the film also increases the solubility of the film, due to the hydrophilic nature of the glycerol itself. But on the other hand, the amount of glycerol does not affect the solubility of the film. All of the glycerol-plasticized films shared a similar transparent, uniform, and smooth surface structure, as shown in Fig. This demonstrates that the amount of glycerol in the CMCc-based film does not affect its opacity. As it was expected, the WVP of CMCc-based films increased significantly with the glycerol concentration. Glycerol's high hydrophilicity is to blame for this. The hydrophilicity of glycerol brings water closer to the polymer matrix and increases the free volume of the polymer, resulting in increased film elongation and decreased film mechanical strength. The concentration of glycerol also has a significant impact on the film's mechanical properties, decreasing tensile strength (TS) and elastic modulus (EM) but increasing elongation (E)[53].

### 4.2. Olive Oil

When compared to the control film, the film added with olive oil had lower MC and solubility than the film added with glycerol. Nevertheless, MC did not decrease significantly when olive oil concentration increased. It is possible that the hydrophobic nature of olive oil reduces its capacity to absorb moisture and also decreases its solubility in films[54,55]. In gelatin/olive oil films[12] and chitosan/olive oil films[56] it also showed similar results. At the same time, olive oil also causes a significant increase in film opacity. According to Pereda *et al.*[56], olive oil can prevent light from passing through the film, as shown by most emulsion films. Olive oil globule particle size increases with oil concentration. However, the smooth surface of the CMCc-based films (OL 10 and OL 20) showed uniform dispersion of the oil in the film-forming solution without the addition of emulsifiers. Pereda *et al.*[56], found comparable results with incorporating olive oil into gelatin or chitosan films. Olive oil here increases the TS and EM values of the film. This is because the inclusion of oil into the polymer matrix causes a cross-linking effect which can reduce the free volume and mobility of the polymer[56]. Elongation of film plasticized with olive oil also increased (from OL 10 to OL 20), but decreased with increasing oil phase (OL 30 and OL 40). This could be due to the large lipid globules in the polymer network (Figure), reflecting the film stiffness as a result of the heterogeneous emulsion phase of the film-forming solution. Likewise, the chitosan film ‘E,[56] fell below 20 % OL.

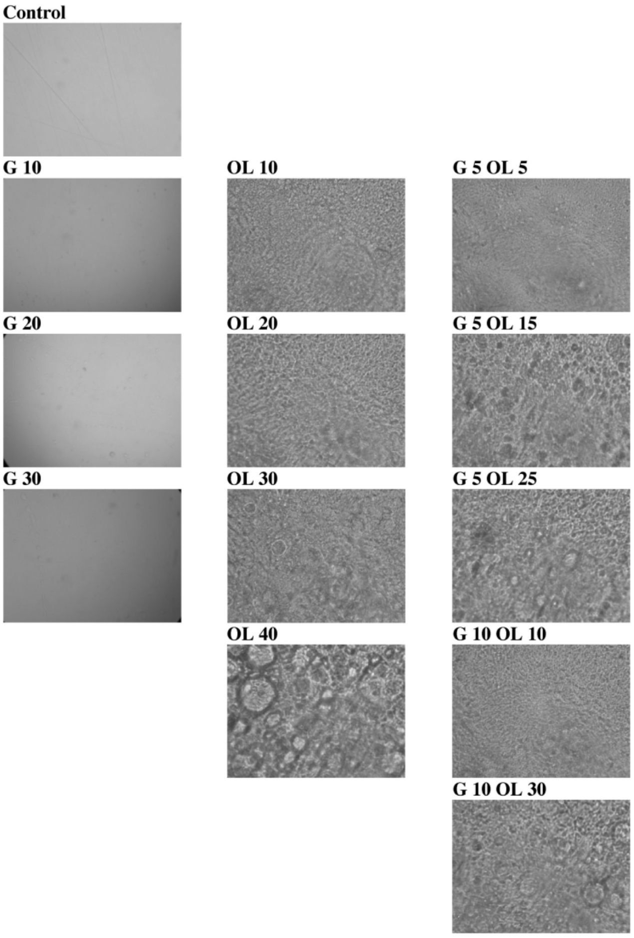

**Fig.** Optical images of the surface of films made of carboxymethyl cellulose that are readily available in the market with a variety of plasticizers and concentrations (400×)[57]

## 4.3. Olive Oil and Glycerol Mixture

Unexpectedly, the MC and solubility of the CMCc-based films were not affected by the G:OL ratio, which was different from the control film. Glycerol generally increases film MC and solubility due to its high hygroscopicity, but lipids help to reduce the porosity and hydrophilicity of the film, resulting in mediocre MC and solubility in CMCc-based films. Meanwhile, the effect of adding olive oil to the plasticizer mixture resulted in a film with a larger opacity. At the highest OL concentrations (G 5 : OL 25 and G 10 : OL 30), the film contained large grains of olive oil. Uniform oil distribution in the range of less than 20 % OL was evident on the smooth surface of the G 5 : OL 5 and G 10 : OL 10 films. This implies that the system may use glycerol as an emulsifier. WVP was significantly lower in G:OL films based on OL concentrations. This may be possible because the capacity of the CMC molecules to absorb moisture is reduced by the hydrophobic nature of olive oil. In addition, the lower WVP of the G 10 : OL 10 and G 10 : OL 30 films may be due to the association of lipid and glycerol network formation in the film matrix[58]. These results are in line with films containing pectin[59] and whey protein concentrates[60]. Here, the mixture of glycerol and olive oil in the plasticizer significantly improved the mechanical properties of all films (TS, EM, and E). E film was increased by glycerol, while TS and EM were increased by OL. For example, the TS and EM film values were higher at 25 % Olive oil (G 5 : OL 25) than those at 5 % Olive oil (G 5 : OL 5). In addition, the film extensibility was superior to 10 % Glycerol (G 10 : OL 10 and G 10 : OL 30) compared to 5 % Glycerol (G 5 : OL 5, G 5 : OL 15, and G 5 : OL 25). The high strength of oils and lipids naturally gives strength to brittle films, but the elasticity of glycerol gives the films flexibility. When olive oil and glycerol are used together, the mechanical properties of the film can be improved more effectively than when glycerol is used alone, as in whey protein concentrate films[60].

## 5. Conclusions

The development of the first edible biopolymer film using glycerol and olive oil as plasticizers represents a significant milestone. Comparative analysis of moisture content, solubility, water vapor permeability, and tensile properties revealed that films based on CMCr remained consistent while employing olive oil or glycerol (20 %), or a combination of both (10 % each). However, when substituting 50 % CMCr for CMC commercial in a blended film with 10 % glycerol and 10 % olive oil, the resulting characteristics closely matched those of the smooth and uniform CMC commercial-based film. These blended films, owing to their transparency, flexibility, acceptable water barrier, and mechanical properties, exhibit substantial potential for application in the food packaging industry. The integration of CMC commercial and CMCr not only offers a viable solution to reduce agricultural waste but also holds promise in enhancing product quality and extending the shelf-life, thus contributing to sustainable practices in the food packaging sector.

## Disclosure statement:

*Conflict of Interest:* The authors declare that there are no conflicts of interest.

*Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

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*Received: December 11, 2023 / Revised: February 04, 2024 / Accepted: March 25, 2024*

# ПЛІВКИ НА ОСНОВІ КАРБОКСИМЕТИЛЦЕЛЮЛОЗИ З РИСОВОЇ СТЕРНІ ЯК НОВЕ ПОТЕНЦІЙНЕ ДЖЕРЕЛО БІОПОЛІМЕРІВ ДЛЯ ЗМЕНШЕННЯ ВІДХОДІВ СІЛЬСЬКОГО ГОСПОДАРСТВА: МІНІОГЛЯД

***Анотація.*** *Вегетативна частина рослини рису, Oryza sativa L., яка залишається після очищення рисових полів під час збору врожаю або після нього, відома як рисова стерня. Карбоксиметилцелюлоза з рисової стерні (CMCr) є перспективним джерелом біополімерів, що можуть бути виготовлені з відходів рисової стерні. Карбоксиметилцелюлоза була синтезована з рисової стерні методом лиття в розчиннику. Різні типи пластифікаторів (гліцерин та оливкова олія) і компоненти, які вони містять, забезпечують гнучкість використання як матеріалу для пакування харчових продуктів. Вміст оливкової олії підвищив вологонепроникність плівок, а вміст гліцерину – їхню розтяжність. Індонезія відома як країна, де більшість населення займається сільським господарством. Разом зі збільшенням посівних площ рису з кожним роком збільшується і кількість сільськогосподарських відходів у вигляді рисової стерні. У майбутньому застосування CMCr у пакуванні харчових продуктів може привести до революційних змін у практиці сталого розвитку сільськогосподарського сектору Індонезії. Використовуючи унікальні властивості CMCr, такі як посилений вологозахисний бар'єр і підвищену розтяжність, є можливість розробити екологічно чисті пакувальні рішення. Ця інновація не тільки вирішує проблему збільшення відходів рисової стерні, але й сприяє зменшенню забруднення навколишнього середовища, пропонуючи більш екологічний і сталий підхід до пакування в цій країні.*

***Ключові слова:*** *карбоксиметилцелюлоза, рисова стерня, біополімерна плівка, гліцерин, оливкова олія.*