

# Exploring the Potential of Palm-Based Carboxymethyl Cellulose

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## CELLULOSE AND ITS DERIVATIVES

Cellulose is a natural polymer found abundantly in the cell walls of plants, providing structural support. Due to its rigidity and high tensile strength, cellulose is a crucial component in various industrial applications. Its derivatives, such as cellulose acetate, cellulose nitrate, and carboxymethyl cellulose (CMC), are chemically modified forms that exhibit unique properties. These derivatives enhance solubility, flexibility, and reactivity, making them valuable in producing textiles, films, coatings, and pharmaceuticals. The versatility and biodegradability of cellulose and its derivatives make them essential in sustainable material development (Habibi *et al.*, 2010). One of the most in-demand and widely used in various applications is CMC (Klemm *et al.*, 2005).

CMC is a highly versatile cellulose derivative that is widely used across various industries due to its excellent water solubility, thickening, and stabilising properties. Its ability to dissolve in water allows CMC to enhance the texture and consistency of products, making it valuable particularly in food, pharmaceuticals, and cosmetics industries. Additionally, the biodegradability and non-toxic nature of CMC make it a preferred choice for environmentally conscious applications, reducing concerns about environmental impact. As industries increasingly seek sustainable alternatives, CMC's renewable origin and functional benefits position it as a leading ingredient in the development of eco-friendly products (Söderqvist-Lindblad *et al.*, 2005).

## OIL PALM BIOMASS

Biomass refers to organic materials derived from the cultivation and processing of crops, providing a sustainable source for bioenergy and bioproducts (McKendry, 2002).

The oil palm industry generates a substantial amount of biomass during various stages of production, particularly during replanting, where large quantities of trunks and fronds are left behind. Additionally, the oil extraction process produces significant byproducts, such as empty fruit bunches and palm kernel shells, which contribute to the overall biomass available. Regular maintenance activities like pruning, also add to this biomass, as excess leaves and branches are collected, further enhancing the potential for utilising these materials in sustainable applications. Palm oil biomass is abundant in lignocellulosic materials, which are composed of cellulose, hemicellulose, and lignin, making it a valuable resource for various applications (Abdullah and Sulaiman, 2013).

## PRODUCTION OF CARBOXYMETHYL CELLULOSE (CMC) FROM BIOMASS

The production of CMC from cellulose involves a chemical modification process known as etherification. In this process, cellulose reacts with sodium hydroxide (NaOH) to form alkali cellulose, which then reacts with monochloroacetic acid (MCA) to produce CMC (Isogai and Atalla, 1998). This method, known as the Williamson ether synthesis, results in the substitution of hydroxyl groups (OH) in the cellulose backbone with carboxymethyl groups, enhancing solubility and functionality (Pushpamalar *et al.*, 2006).

Different methods of etherification vary mainly in the reagents and conditions used. The classical method employs sodium hydroxide and monochloroacetic acid under controlled temperature and pressure, yielding high-quality CMC with desirable degrees of substitution (Kamide and Saito, 1981). Alternatively, methods using solvents such as isopropanol or ethanol can improve reaction efficiency and product purity (Hebeish *et al.*,

2010). Another approach involves the use of microwave irradiation to accelerate the reaction, reducing energy consumption and reaction time (Singh *et al.*, 2009).

Comparatively, the NaOH and MCA method is the most widely used due to its simplicity, cost-effectiveness, and scalability. However, solvent-based methods can offer better control over product properties and purity, while microwave-assisted synthesis provides a faster and more environmentally friendly alternative (Chang *et al.*, 2011). Each method has its advantages, and the choice depends on factors such as desired product specifications, environmental considerations, and production scale (Li *et al.*, 2019). Numerous sources of lignocellulosic material can be utilised to produce CMC, as outlined in *Table 1*.

### CHARACTERISATION OF PALM-BASED CARBOXYMETHYL CELLULOSE (CMC)

The characterisation of CMC is essential for understanding its properties and ensuring its effectiveness in various applications. Characterising agricultural biomass-derived CMC involves analysing its structural, physicochemical, and rheological properties to ensure quality and functionality. These techniques offer a comprehensive understanding of the structural integrity, chemical composition, and performance characteristics of biomass-derived CMC, ensuring its suitability for use in many industrial sectors (Wang *et al.*, 2011).

Fourier Transform Infrared (FTIR) spectroscopy is employed to identify functional groups and confirm carboxymethyl substitutions by detecting specific absorption bands (Pushpamalar *et al.*, 2006).

1. X-ray Diffraction (XRD) analysis assesses the crystallinity of CMC, which significantly influences its solubility and mechanical properties (Klemm *et al.*, 2005).
2. Scanning Electron Microscopy (SEM) provides detailed images of CMC's surface morphology, revealing crucial information about particle size and shape (Das *et al.*, 2010).
3. Rheological studies are vital for evaluating the flow behaviour and viscosity of CMC solutions, which are essential for various industrial applications (Fischer *et al.*, 2006).

### APPLICATIONS OF PALM-BASED CARBOXYMETHYL CELLULOSE (CMC)

The production of CMC from oil palm has been successfully achieved for application as a food additive (*Figure 1*), utilising the abundant lignocellulosic materials derived from the oil palm industry (Othman *et al.*, 2021). This CMC variant offers excellent water solubility and thickening properties, making it ideal for improving the texture and stability of various food products, such as sauces, dressings, and desserts (*Figure 2*). Additionally,

**TABLE 1. SOURCES OF CARBOXYMETHYL CELLULOSE (CMC) FROM VARIOUS TYPE OF BIOMASS**

Biomass Source	Key Properties/Applications	Reference
<i>Musa paradisiaca</i> (Banana Plant)	Industrial-grade CMC for food additives, pharmaceuticals, and other industrial uses.	Alabi <i>et al.</i> , 2020
Corn Husk	Suitable for various industrial applications due to its high substitution level.	Yeasmin <i>et al.</i> , 2015
Oil Palm Empty Fruit Bunch (OPEFB)	Used in drug delivery systems, industrial effluents, food additives and heavy metal removal.	Mohamood <i>et al.</i> , 2021
Bacterial Cellulose	Food and beverage industries as a thickener, stabiliser and emulsifier.	Casaburi <i>et al.</i> , 2018
<i>Eleocharis dulcis</i> (Purun Tikus)	Used in food, pharmaceuticals, detergents and paper coatings	Sunardi <i>et al.</i> , 2017
Asparagus stalk	Drug delivery system, tissue engineering, coating and food packaging	Klunklin <i>et al.</i> , 2020



Figure 1. Carboxymethyl cellulose (CMC) from oil palm empty fruit bunch.

oil palm-based CMC is environmentally friendly, as it utilises byproducts from palm oil production, contributing to waste reduction and sustainability. Its bio-based nature and functional advantages position oil palm-derived CMC as a promising ingredient in the development of innovative and sustainable food formulations.



Figure 2. Carboxymethyl cellulose (CMC) from oil palm empty fruit bunch as thickening agent.

Beyond the food industry, CMC has a wide range of potential applications, including use in pharmaceuticals, cosmetics, the paper industry, and various other sectors (Figure 3). In pharmaceuticals, it is used as a binder in tablets, as a stabiliser in liquid formulations, and as a component in controlled-release drug delivery systems (Thimma *et al.*, 2004). The cosmetic industry benefits from CMC's ability to enhance the viscosity and stability of creams and lotions, improving their texture and consistency (Ghannam *et al.*, 2012). Additionally, CMC

plays a key role in the paper industry by enhancing the strength, printability, and quality of paper products. In oil drilling, it acts as a viscosifier and fluid-loss reducer, highlighting its importance in industrial applications. Its role in environmental applications includes being used as a biodegradable hydrogel for water purification and soil stabilisation (Sannino *et al.*, 2009). Figure 4 illustrates the diverse industrial applications of CMC based on its functional properties, which enable it to serve as a thickener, water binder, film former, and function as a dispersing agent and suspending aid. The utilisation of CMC derived from agricultural biomass not only supports sustainable practices by valorising agricultural waste but also offers eco-friendly alternatives to synthetic polymers in various sectors (Söderqvist-Lindblad *et al.*, 2005).

#### ADVANTAGES AND CHALLENGES OF CARBOXYMETHYL CELLULOSE (CMC) FROM AGRICULTURAL BIOMASS

Using CMC derived from agricultural biomass offers significant sustainability benefits over traditional sources. By utilising agricultural residues, this approach not only reduces waste but also minimises the environmental impact of agricultural practices and supports a circular economy by transforming waste into valuable products (Sannino *et al.*, 2009; Cherubini and Ulgiati, 2010). Biomass-derived CMC also reduces dependence on fossil-based raw materials, thereby lowering the carbon footprint of its production. With the abundant availability of agricultural biomass, the supply of raw materials is consistent and can often be sourced at a lower cost, making biomass-derived CMC an economically viable option for various industries. Additionally, turning agricultural residues into CMC can generate additional income for rural communities and enhance local economies (Bajpai, 2016). This transition aligns with global sustainability goals, offering a greener alternative to conventional CMC sources.

However, there are challenges to address. One major issue is the variability in biomass composition, which can affect the consistency and quality of the CMC produced. Biomass sources differ in cellulose content and impurities, requiring careful selection and preprocessing to ensure product uniformity (Zhu *et al.*, 2016). Scaling up production poses another challenge, as converting biomass into CMC on an industrial scale involves complex processes that must be optimised for efficiency and cost-effectiveness (Chen *et al.*, 2018). High

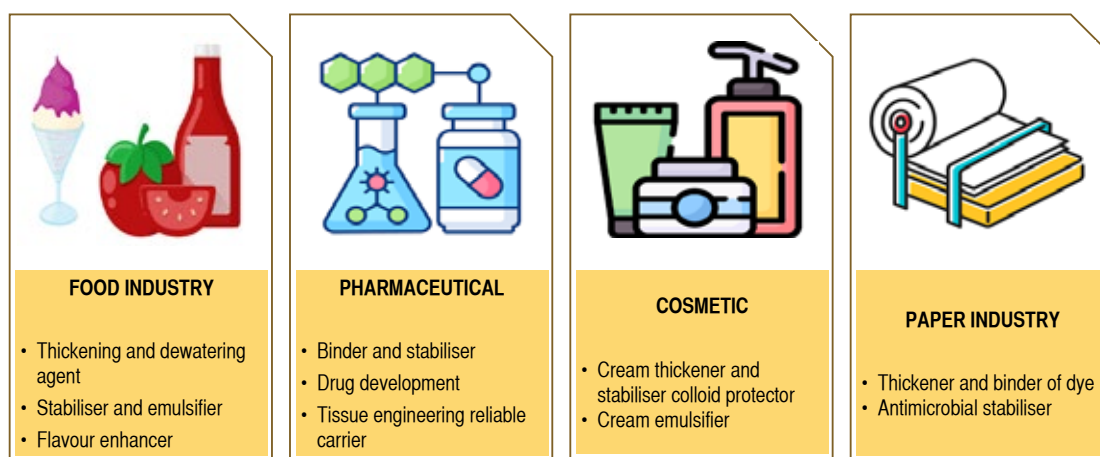


Figure 3. Main applications of Carboxymethyl cellulose (CMC).

Thickener	Water binder	Film former	Dispersed	Suspending aid
<ul style="list-style-type: none"> <li>• Toothpaste</li> <li>• Shampoo</li> <li>• Syrups</li> <li>• Detergent</li> </ul>	<ul style="list-style-type: none"> <li>• Ice cream</li> <li>• Ceramic</li> <li>• Ashesive</li> <li>• Bakery</li> <li>• Dairy product</li> </ul>	<ul style="list-style-type: none"> <li>• Textile size</li> <li>• Paper coating</li> <li>• Lithographic solution</li> <li>• Geo-textile</li> </ul>	<ul style="list-style-type: none"> <li>• Wet tack</li> <li>• Binder</li> <li>• Food packaging</li> </ul>	<ul style="list-style-type: none"> <li>• Beverages</li> <li>• Cosmetic</li> <li>• Sauces and dressing</li> <li>• Paint and coating</li> </ul>

Figure 4: Applications of Carboxymethyl cellulose (CMC) in various industries based on its functional properties.

initial investments in infrastructure and technology, along with the logistical challenges of collecting, transporting, and storing agricultural residues, can increase costs (Söderqvist-Lindblad *et al.*, 2005). Securing a stable raw material supply and maintaining quality are crucial for sustainable production. Addressing these challenges will require further research and collaboration across agricultural, industrial, and research sectors to standardise processes and develop scalable technologies (Li *et al.*, 2019).

## COMPARISON WITH CARBOXYMETHYL CELLULOSE (CMC) DERIVED FROM OTHER SOURCES

CMC derived from agricultural biomass differs significantly from CMC produced from traditional sources such as wood pulp or synthetic raw materials, in terms of sustainability, cost, and environmental impact. While agricultural biomass-derived CMC offers a more environmentally friendly and potentially lower-cost option, wood pulp-based CMC remains a well-established alternative, benefiting from mature supply chains, consistent quality, and reliable production methods.

Economically, CMC from agricultural biomass can be cost-effective due to the low cost of raw materials, but variability in biomass composition and logistical challenges may offset these savings (Zhu *et al.*, 2016). Wood pulp-based CMC benefits from established supply chains and consistent quality but may face increasing costs due to environmental regulations. Synthetic CMC, although highly controlled and pure, tends to be more expensive and has a larger environmental impact (Chen *et al.*, 2018). However, for agricultural biomass-derived CMC to effectively compete with both wood pulp-based and synthetic sources, challenges related to scalability, consistency and logistics must be addressed.

## POTENTIAL AREAS FOR FURTHER RESEARCH AND DEVELOPMENT

The future of CMC derived from agricultural biomass presents significant opportunities for innovation and growth, especially in enhancing production processes. A key focus for future research is improving the efficiency and scalability of CMC production by optimising reaction conditions, such as temperature, pH and reaction time to

increase yields and reduce production costs. Efforts to lower energy consumption and streamline the manufacturing process will be crucial for making CMC from biomass more commercially viable. Additionally, researchers are focusing on improving the consistency and quality of CMC produced from various types of agricultural biomass, including oil palm biomass, given the variability in the composition of different biomass sources (Li *et al.*, 2019). Developing standardised protocols for converting diverse biomass types into CMC will help ensure a reliable and uniform product that meets the needs of various industries.

Furthermore, research into novel catalysts and green chemistry approaches is essential for reducing the environmental impact of CMC production. Traditional methods often involve the use of harsh chemicals and generate significant waste, so the adoption of more sustainable techniques, such as using bio-based catalysts or eco-friendly solvents, could revolutionise the production process (Sannino *et al.*, 2009). In addition to refining production methods, advanced characterisation techniques will play a critical role in controlling the properties of biomass-derived CMC to suit specific industrial applications. For instance, industries such as food, pharmaceuticals, and textiles have varying requirements for CMC properties, such as viscosity, solubility, and binding strength, making it essential to develop more precise and customisable methods of production (Zhu *et al.*, 2016). Overall, ongoing innovations in both production and characterisation will be vital for maximising the potential of CMC derived from agricultural biomass.

## CONCLUSION

Agricultural biomass-derived CMC represents a significant development in sustainable materials science, offering numerous advantages over traditional and synthetic sources. Key findings highlight its potential to utilise renewable, often waste materials, thereby promoting a circular economy and reducing environmental impact. Agricultural biomass-derived CMC not only matches the functional properties of conventional CMC but also provides a more environmentally friendly and potentially cost-effective alternative. The importance of this green chemistry innovation lies in its ability to reduce reliance on non-renewable resources, lower carbon footprints, and support sustainable agricultural practices. As industries increasingly prioritise sustainability, the development and application of biomass-derived CMC are likely to expand,

driven by ongoing research, technological advancements, and the global shift towards eco-friendly solutions. This positions agricultural biomass-derived CMC as a crucial component in the future of sustainable industrial practices.

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