



Rice Straw Based Thickening Agent for Dysphagia Supplements

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Abstract

The increasing prevalence of dysphagia among elderly and neurologically impaired populations highlights the urgent need for safe and stable texture-modified diets. Starch, the conventional thickening agent, is prone to rapid enzymatic breakdown by salivary amylase, resulting in compromised viscosity and safety risks during swallowing. Carboxymethyl cellulose (CMC), a cellulose derivative, offers superior viscosity stability and resistance to enzymatic degradation. This study aimed to synthesize CMC from underutilized agricultural waste, namely rice straw, and evaluate its potential as a sustainable thickening agent for dysphagia supplements in comparison with commercial pharmaceutical-grade CMC. Cellulose was extracted from rice straw, carboxymethylated, and incorporated into supplement formulations. The products were characterized using Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and rheological analysis with rotational and shear rheometry. Rice straw-derived CMC achieved a degree of substitution (DS) of 0.79, while commercial CMC displayed a higher DS of 1.3. Both types of CMC resisted amylase-induced degradation, in contrast to starch solutions, which exhibited a loss of more than 97% in viscosity. Rheological results confirmed pseudoplastic behavior; commercial CMC showed higher viscosity (1460 cP, honey-like), whereas rice straw CMC demonstrated lower but more stable viscosity (268 cP, nectar-like). The novelty of this research lies in valorizing rice straw, an abundant agricultural residue, into a functional biopolymer for dysphagia-oriented nutrition. Practically, this approach provides a safer alternative to starch-based thickeners while promoting sustainable resource utilization, thereby addressing both clinical nutrition challenges and environmental concerns.

Keywords *carboxymethyl cellulose, dysphagia, viscosity, enzymatic stability, medical supplement.*

INTRODUCTION

Over the past decades, global health trends have shown a steady increase in life expectancy, resulting in a growing proportion of elderly individuals worldwide. This demographic transition has brought age-related physiological changes to the forefront, particularly those that impair organ function and reduce adaptive capacity to physical and environmental stressors (Ekayamti, 2021). One of the most critical health conditions associated with aging is dysphagia. This swallowing disorder interferes with the safe and efficient passage of food and liquids from the mouth to the stomach (Giura et al., 2021). Dysphagia affects approximately 15-30% of the elderly and may exceed 50% among hospitalized or institutionalized patients, contributing to complications such as aspiration pneumonia, malnutrition, and dehydration (Armas-Navarro et al., 2023).

The formulation of texture-modified diets for dysphagia management has increasingly relied on enhancing viscosity. These functional ingredients help prevent the rapid dispersion of liquids in the oral cavity, enabling better control during swallowing. Among various types of polysaccharides, cellulose and its derivatives have gained attention for their superior stability and resistance to enzymatic degradation, offering more consistent rheological properties compared to starch-based thickeners (Wang et al., 2024).

One notable derivative is Carboxymethyl Cellulose (CMC), obtained through the carboxymethylation of cellulose chains. CMC is widely used in the food industry as a thickener, stabilizer, and emulsifier, known for its ability to maintain texture and consistency in aqueous solutions over time (Goh et al., 2022). In the context of dysphagia, CMC serves as a promising candidate to be incorporated into specialized dietary supplements or thickened drinks. Application

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of CMC has so far relied on refined cellulose sources, raising concerns regarding sustainability and cost. Agricultural waste, such as rice straw, presents an abundant and underutilized source of cellulose (Lavoine et al., 2012). Every year, nearly 700 million tons of rice straw are produced globally, yet these residues remain vastly underutilized (Suryaningrum, 2022).

Therefore, this study aims specifically to characterize CMC synthesized from rice straw and to compare its properties with those of commercial pharmaceutical-grade CMC as a reference standard. The investigation aims not only to evaluate the structural and functional quality of the synthesized CMC but also to assess its feasibility as a thickening agent in dietary supplements for the management of dysphagia. By addressing the research gap between fundamental characterization of biomass-derived CMC and its practical application in functional foods, this work contributes to sustainable health innovation.

LITERATURE REVIEW

Dysphagia and Rheological Requirements in Texture Modified Diets

Dysphagia is a common swallowing disorder that disproportionately affects elderly populations and patients with neurological diseases such as stroke, Parkinson's, and dementia (Giura et al., 2021). To manage this condition, Texture-Modified Diets (TMDs) are widely implemented as a clinical strategy to improve swallowing safety. Beyond viscosity, rheological parameters such as cohesiveness, adhesiveness, and particle size play critical roles in swallowing performance and patient acceptability. Cohesiveness determines the ability of the bolus to remain intact during oropharyngeal transport, while adhesiveness influences oral and pharyngeal residue, and particle size distribution affects bolus clearance and aspiration risk (S. Liu et al., 2023; Seifelnasr et al., 2024). Recent studies emphasize that assessing these parameters alongside shear-thinning behavior provides a more accurate prediction of swallowing safety than viscosity alone (Bolivar-Prados et al., 2023; Ismael-Mohammed et al., 2025).

One of the most widely adopted frameworks for dysphagia diets is the National Dysphagia Diet (NDD), which categorizes liquid viscosity based on a shear rate of $50\text{--}55\text{ s}^{-1}$. The categories are summarized in Table 2.1.

Table 1. Classification of Liquid Viscosity in The National Dysphagia Diet (NDD)

Category	Viscosity (centipoise/cP)
Thin	0-50
Nectar-like	51- 350
Honey-like	351 – 1750
Pudding-like	>1750

Polysaccharides, Cellulose, and Carboxymethyl Cellulose (CMC)

Polysaccharides are biopolymers with diverse functions, ranging from energy storage to structural reinforcement, and are widely used to modify food texture (Wang et al., 2024). Their ability to form gels and increase viscosity without altering taste makes them suitable as thickeners in dysphagia diets (Li et al., 2024). Among these, cellulose derivatives, particularly Carboxymethyl Cellulose (CMC), have attracted growing interest due to their structural stability and consistent rheological performance, which provide advantages over starch-based systems (Chakhtouna et al., 2024). CMC is produced through carboxymethylation of cellulose, a modification that enhances water solubility, confers pseudoplastic flow behavior, and improves resistance to enzymatic degradation (Goh et al., 2022). Recent food and nutrition studies demonstrate the practical application of this concept in dysphagia diets, including its ability to maintain viscosity in thickened beverages despite exposure to salivary α -amylase, where starch thickeners typically fail (Y. Li et al.,

2024). Furthermore, CMC has been shown to improve the texture and cohesiveness of minced or pureed foods, reducing chewing effort and enhancing swallowing safety in elderly patients (T. Liu et al., 2024). CMC with a higher degree of substitution also provides better stability in nutritional drinks and purees, ensuring consistent nectar-like or honey-like viscosity classifications over storage time (Ren et al., 2024).

RESEARCH METHOD

Materials and Chemicals

Agricultural residues used in this study were rice straw, while commercial pharmaceutical-grade *carboxymethyl cellulose* (CMC) was included as a reference. The primary reagents included *sodium hydroxide* (NaOH, 25%, 30%, and 8%), *sodium monochloroacetate*, *hydrogen peroxide*, *glacial acetic acid*, *sulfuric acid*, *formic acid*, and *phenolphthalein* indicator. A confidentiality agreement covers the materials used in the supplement and are therefore coded as *polysaccharide 1*, *polysaccharide 2*, *polysaccharide 3*, *oil 1*, *oil 2*, *oil three*, and food-grade emulsifiers (*emulsifier 1*, *emulsifier 2*, *emulsifier 3*). Distilled water (aquadest) was used as the solvent.

Extraction of Cellulose from Agricultural Waste

Rice straw was subjected to alkaline delignification followed by hydrogen peroxide bleaching, adapted from previously reported protocols for lignocellulose isolation (Prajapati & Kango, 2022). The process involved treatment with 25% NaOH at 100 °C for 120 min to remove lignin/hemicellulose, followed by bleaching with 2% H₂O₂ at 60 °C for 120 min. Purified cellulose was obtained after repeated washing and oven-drying.

Synthesis of Carboxymethyl Cellulose (CMC)

Carboxymethylation was carried out using the methods described by Han et al. (2025) and Klunklin et al. (2020), with modifications. Cellulose (20 g) was suspended in 400 mL of distilled water and alkalinized with 10 mL of 30% NaOH under magnetic stirring for one hour. *Sodium monochloroacetate* (30 g) was added, and the mixture was heated at 60 °C for three hours. The product was filtered, soaked in 800 mL of distilled water for 24 hours, and neutralized with glacial acetic acid until the pH reached 7. The solid was re-filtered and oven-dried at 100 °C until it reached a constant weight, yielding the synthesized CMC.

Formulation of Dysphagia-Oriented Supplement

CMC (1.24%) was dispersed in distilled water (60.51%) by mechanical stirring for 30 min to form a viscoelastic matrix. Polysaccharide 1 (2.90%), Polysaccharide 2 (13.68%), and Polysaccharide 13 (12.00%) were gradually incorporated, followed by Oil 1 (2.25%). The oil phase, consisting of Oil 2 (4.80%) and Oil 3 (2.44%), with emulsifiers (Emulsifier 1, 0.05%; Emulsifier 2, 0.10%; Emulsifier 3, 0.03%), was homogenized separately and then slowly added to the aqueous phase until a stable emulsion was formed.

Characterization of CMC

Degree of Substitution (DS): Determined following the method of (Rachtanapun et al., 2021). Titration of 0.7 g dried CMC using H₂SO₄ and NaOH with phenolphthalein indicator, calculated according to Eq. (1–2)

$$A = V_{H2SO4} \times N_{H2SO4} - (V_{NaOH} \times N_{NaOH}) \text{CMC sample weight (s)} \quad (1)$$

$$DS = 162 \times A / 10000 + 80 \times A \quad (2)$$

- Scanning Electron Microscopy (SEM): Morphology was observed at 1,000× and 15,000× magnification under 10 kV to assess fibril structure, porosity, and surface homogeneity. Were examined following standard imaging protocols (Torres-Vargas et al., 2025).
- Fourier Transform Infrared Spectroscopy (FTIR): Functional groups and structural features were identified in the range 4000-400 cm^{-1} range using the method described by (Prajapati & Kango, 2022).

Degradation Test of 1% CMC Solutions

Resistance to salivary α -amylase was evaluated according to [Ali et al. \(2021\)](#), where CMC solutions were incubated with amylase (2.4 U/mL) at 37 °C for 30 min, and viscosity changes were monitored.

Characterization of 1% CMC Solutions and Supplements

Viscosity and rheological behavior were determined using a Brookfield DV2T rotational viscometer following the IDDSI and NDD framework for thickened liquids (Marín-Sánchez, 2025; Omari et al., 2025). Shear-rate dependency, thermal stability, time stability, and enzymatic degradation were recorded.

Data Analysis

All experiments were performed in triplicate ($n = 3$), and results are presented as the mean $\pm$ standard deviation (SD). DS values were calculated from titration data, while FTIR and SEM were analyzed qualitatively to identify functional groups and morphology. Viscosity changes during enzymatic degradation were expressed as percentage loss relative to initial viscosity and compared with NDD classification standards. Data processing and visualization were performed using OriginPro 2022 (OriginLab Corporation, USA).

FINDINGS AND DISCUSSION

Degree of Substitution (DS)

The degree of substitution (DS) is a key parameter that represents the number of hydroxyl groups (-OH) in cellulose replaced by carboxymethyl groups (-CH₂COOH). This value strongly determines the solubility, viscosity, and functional stability of CMC ([Rahman et al., 2021](#)). In the present study, CMC derived from rice straw exhibited a DS of 0.79, which is lower than that of commercial CMC 1.3, but still falls within the internationally accepted food-grade range (0.6–1.4) (FAO, 2019). The lower DS of rice straw-based CMC may be attributed to residual lignin and hemicellulose, the relatively high crystallinity of rice straw cellulose, and variations in the efficiency of the carboxymethylation reaction. This finding aligns with previous reports, which have documented DS values for rice straw-based CMC within the range of 0.31–1.48 ([Golbaghi et al., 2017](#); [Nur et al., 2019](#)). The novelty of this study lies in showing that rice straw, an abundant agricultural residue, can be transformed into functional CMC with food-grade DS values directly applicable to dysphagia-oriented supplements, thereby linking sustainable resource utilization with clinical nutrition needs.

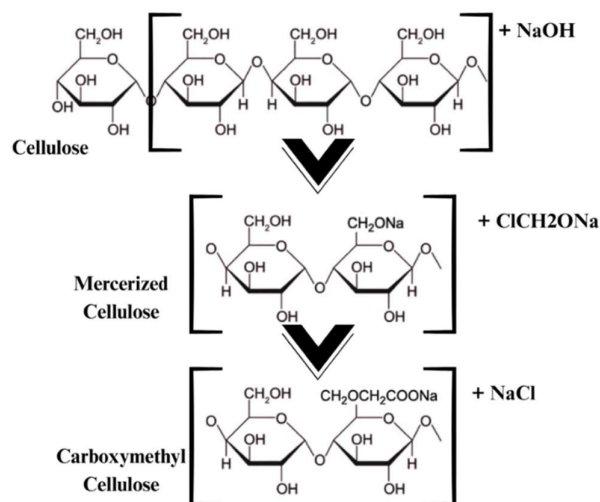


Figure 1. Chemical Chain Structure of CMC Produced From Cellulose

FTIR Spectral Analysis of CMC

The FTIR spectra of rice straw-derived CMC showed characteristic absorption bands at 3420 cm^{-1} (-OH stretching), 2920 cm^{-1} (C-H stretching), and 1600 cm^{-1} (carboxylate stretching), confirming successful carboxymethylation. These results are comparable to those of previous studies on CMC synthesized from agricultural residues, which reported similar functional group patterns (Capanema et al., 2018). The reduced intensity of lignin-associated peaks further indicated effective purification, consistent with findings by Yousefi et al. (2024). The novelty of this study lies in verifying, through FTIR, that rice straw, a widely available agricultural by-product, can be converted into food-grade CMC suitable for dysphagia-oriented supplements, a practical application rarely addressed in earlier research.

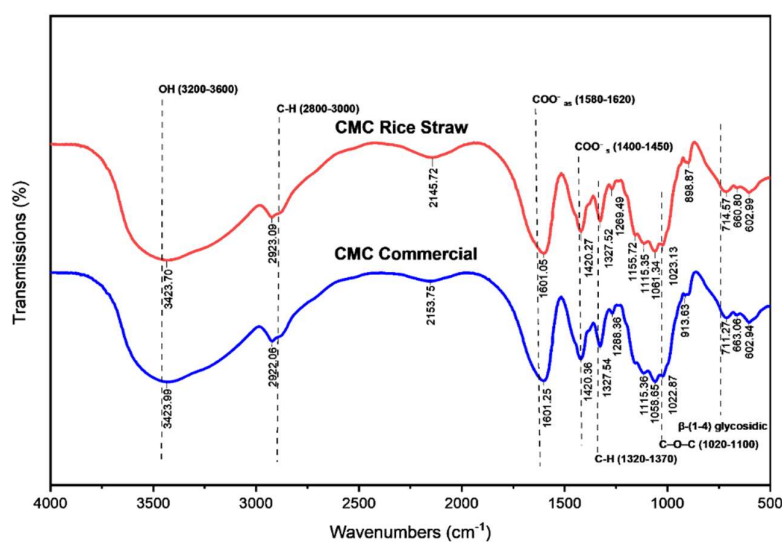


Figure 2. Spectra FTIR Commercial and Rice Straw CMC

Surface Morphology of CMC

SEM analysis revealed distinct morphological differences between commercial and rice straw-derived CMC. At 1,000 $\times$ magnification, commercial CMC showed a smooth, compact, and homogeneous surface, consistent with reports that highly purified cellulose yields dense polymer matrices with efficient carboxymethylation (Wang et al., 2025). In contrast, rice straw CMC exhibited heterogeneous fibrillar networks with voids and cracks, similar to previous observations of CMC from agricultural residues where incomplete delignification limited uniform substitution (Golbaghi et al., 2017; Nur et al., 2019). At higher magnification (15,000 $\times$), localized smooth regions indicated partial structural rearrangement, supporting the lower DS observed in this study. The novelty of these findings lies in demonstrating that, despite its less compact morphology, rice straw-derived CMC retains functional characteristics suitable for dysphagia supplement applications, highlighting the potential of agricultural waste valorisation in clinical nutrition.

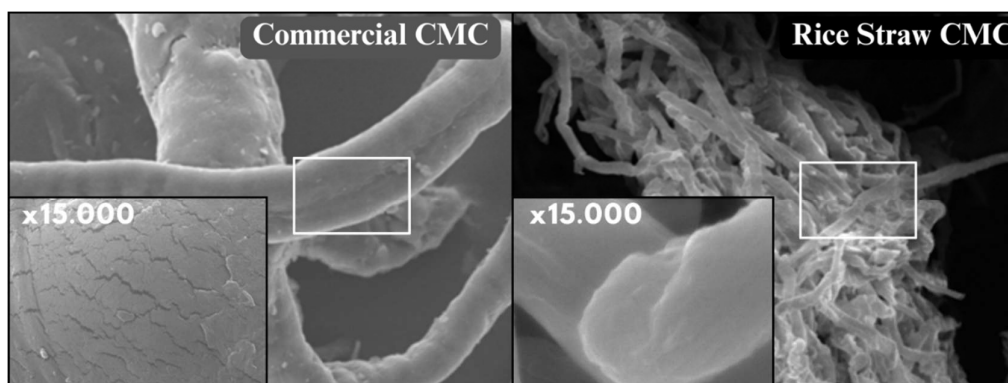


Figure 3. Comparison of CMC Surface Morphology from Rice Straw Sources

Degradation Test of CMC-Thickened Solution by The Use of Amylase

Viscosity stability during gastrointestinal transit is essential for the safety and effectiveness of dysphagia diets (Azizan et al., 2023). In this study, both commercial and rice straw-derived CMC were resistant to salivary amylase due to their β -1,4-glycosidic linkages, as also reported in previous studies on cellulose-based thickeners (Visvanathan et al., 2024; Zhang et al., 2024). Although rice straw CMC exhibited a lower initial viscosity than commercial CMC, it maintained higher stability under enzymatic exposure. In contrast, starch solutions showed a viscosity loss of more than 97%, confirming their susceptibility to hydrolysis (Farazi et al., 2024). These results highlight the novelty of rice straw CMC as a sustainable thickener that combines enzymatic resistance with clinically relevant viscosity stability, supporting its practical use in dysphagia-oriented supplements.

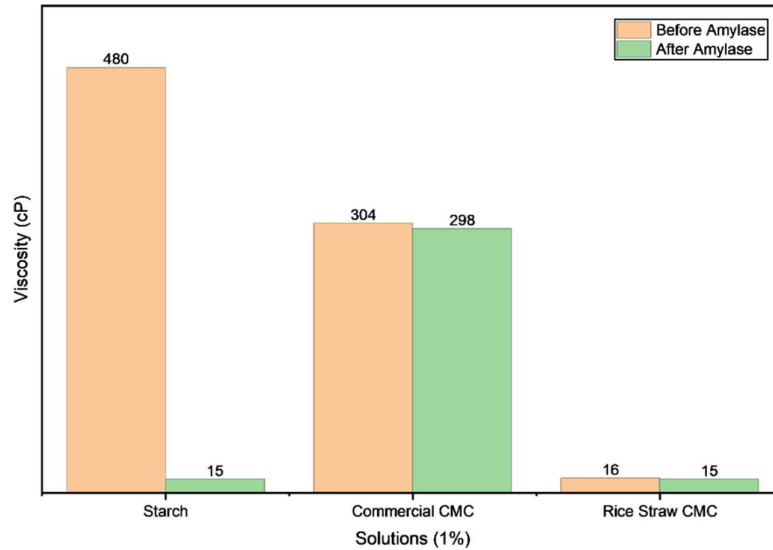


Figure 4. Effect of Amylase on the Viscosity of Starch and CMC Solutions (1%)

Nutritional Content Evaluation and Supplement Suitability Based on Dysphagia Standards

Commercial CMC-based supplements exhibited the highest viscosity (1460 cP), categorizing them as honey-like. Similar values have been reported in previous studies, where high-DS CMC formed dense polymer networks that enhanced water binding and provided strong pseudoplastic behavior, making them effective for patients with severe dysphagia (Zeng et al., 2021). In contrast, rice straw-derived CMC exhibited a lower viscosity of 268 cP, classified as Nectar-like, comparable to findings from other studies on low-DS CMC formulations used for mild to moderate dysphagia management (Cuomo et al., 2021). While viscosities below 300 cP may approach the safety threshold, the ability of rice straw CMC to consistently meet NDD classification criteria highlights its novelty as a sustainable thickener source. This research explicitly demonstrates, for the first time, that CMC derived from rice straw can be positioned within standardized dysphagia diet frameworks, linking agricultural waste valorisation with clinical nutrition applications.

Table 2. Supplements Categories Based on NDD

No.	Source	Viscosity (cP)	Category
1.	Commercial CMC	1460	Honey-Like
2.	Rice Straw CMC	268	Nectar-Like

CONCLUSIONS

CMC synthesized from rice straw demonstrates significant potential as a thickening agent for dysphagia-oriented dietary supplements. Rice straw-derived CMC exhibited a DS of 0.79, retained β -1,4-glycosidic backbone integrity, and showed superior mechanical stability under shear, despite lower initial viscosity compared to commercial CMC. Both synthesized and commercial CMC resisted amylase-induced viscosity degradation, highlighting their suitability over starch-based thickeners for gastrointestinal transit. SEM and FTIR analyses confirmed structural differences, including the presence of residual lignin in rice straw CMC, which contributed to heterogeneous morphology and reduced crystallinity. Overall, the study demonstrates that agricultural residues can be valorized into functional, safe, and sustainable CMC for dysphagia management, aligning with global goals for health, food security, and circular bioeconomy.

LIMITATIONS & FURTHER RESEARCH

This research is limited by its laboratory-scale synthesis, confidentiality of certain formulation components, and the absence of in vivo or clinical swallowing assessments. Future studies should therefore focus on optimizing carboxymethylation to enhance DS, evaluating long-term stability in complex food systems, and conducting patient-centered trials to validate the safety, acceptability, and clinical efficacy of rice straw-derived CMC-based supplements

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