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Research article

APPLICATION OF MICROCRYSTALLINE CELLULOSE EXTRACTED FROM OIL PALM EMPTY FRUIT BUNCHES (EFB) AS A THICKENING AGENT IN ARTIFICIAL MEAT

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ABSTRACT
Empty fruit bunches (EFB), a byproduct of palm oil processing, contain approximately 40% cellulose, presenting a valuable resource for sustainable applications. This study explores the extraction of microcrystalline cellulose (MCC) from EFB and evaluates its effects on the characteristics of artificial meat. MCC was incorporated at varying concentrations (1%, 2%, and 3%) into artificial meat formulations using different red bean-to-soybean flour ratios (1:3, 3:1, and 1:1). Fourier-transform infrared (FTIR) spectroscopy confirmed the successful extraction of MCC, as evidenced by the presence of OH, CH, C=C, C-O, and C-O-C functional groups. The addition of soybean flour increased moisture content (50.26%–53.55%), ash (1.63%–1.66%), and protein (1.55%–1.63%), while red bean flour contributed to higher fat (1.59%–2.22%) and carbohydrate levels (44.01%–46.3%). The 1:1 flour ratio significantly enhanced crude fiber content (2.19%–3.8%). Although MCC addition had minimal impact on the overall chemical composition, it notably improved the fiber content of artificial meat, suggesting its potential as a functional ingredient for texture enhancement and dietary fiber enrichment.

1. Introduction

Agriculture in Indonesia produces a variety of commodities, one of which is oil palm, a key agricultural product. Palm oil is a major source of Crude Palm Oil (CPO) and Palm Kernel Oil (PKO) (Arifandy et al., 2021). Crude palm oil was obtained by diverse steps, one of the most important steps was the grazing process that during this process temperature has a major impact in generating high crude (Swastawati et al., 2019; Wibawanti et al., 2021). During the processing of oil palm, empty fruit bunches

(EFB) are generated as a byproduct. This waste material is renewable, abundant, and has the potential to be used as a source of cellulose. It is commonly repurposed as fertilizer or utilized as a substrate for growing fungi and plants. For every ton of fresh oil palm fruit bunches processed, approximately 230 kg of empty palm fruit bunches are produced (Kamal, 2018).

The palm oil processing process produces not only solid waste in the form of EFB but also palm kernel shells and fibers. The cellulose content in the solid waste is relatively high, at approximately 40%, while other components include hemicellulose (24%), lignin (21%), and ash (15%) (Ngatirah, 2017). Cellulose is characterized by its fibrous structure, white color, and insolubility in water and organic solvents. Cellulose molecules are straight chains consisting of about 5,000 glucose units, forming fibrils bonded by hydrogen interactions between hydroxyl groups (Nosya, 2016). Glucose molecules with a chain length of 250 units form microcrystalline cellulose (MCC) molecules (Al-Baarri et al., 2018; Nawar et al., 2010). Microcrystalline cellulose is commonly used in drug manufacturing as a binder. Beyond the pharmaceutical industry, MCC is also widely utilized in the food industry as a food additive. Its applications include use as an anti-caking agent, thickener, bulking agent, emulsifier, filler, and texturizer to improve food texture (Sundarraj & Ranganathan, 2018)

To date, studies on the utilization of microcrystalline cellulose from oil palm empty fruit bunches (EFB) have been limited to compost production and capsule shells. No research has explored the use of MCC in artificial meat products. This research seeks to utilize palm oil waste as a raw material for producing MCC to enhance the characteristics of artificial meat. The study aims to identify MCC derived from EFB and determine the effects of different MCC concentrations on the characteristics of artificial meat.

2. Materials and methods

2.1. Materials

EFB were processed using general laboratory equipment such as a sieve, scales, and glassware for sorting, weighing, and grinding. Specialized equipment, including a furnace for heating, a Soxhlet apparatus for extraction, and a Kjeldahl apparatus for protein analysis, were used during the cellulose extraction process. The structural properties of the resulting microcrystalline cellulose were analyzed using an FT-IR spectrophotometer, and the texture of the artificial meat was assessed with a texture analyzer Brookfield Ametek. Chemical treatments employed NaOH for delignification, H_2O_2 for bleaching, and HCl for neutralization, with standard filtration using filter paper.

2.2. Methods

The initial stages of the research included sorting the empty fruit bunches, followed by washing and drying. This was followed by the preparation of oil palm empty fruit bunch flour, cellulose extraction, and MCC extraction.

Cellulose extraction began with the delignification process of oil palm empty fruit bunch flour using a 12% (w/v) NaOH solution for 3 hours at 90°C. Afterward, the solution was cooled and filtered to separate the cellulose from the NaOH and other components of the flour. The next step involved bleaching with a 3% H2O2 solution (6 mL) and 2 mL of buffer solution. The mixture was then heated on a hot plate for 1 hour at 80°C. The cellulose was subsequently washed with distilled water until the pH was neutral, resulting in high-purity α-cellulose (Dewanti, 2018).

The MCC preparation process involved hydrolyzing 10 g of cellulose flour using 2 N HCl in a glass beaker, which was then heated on a hot plate for 1 hour. The precipitate was washed with distilled water until the pH of the solution was neutral. Next, the precipitate was dried in a cabinet dryer for 24 hours at 60°C, after which it was ground (Ohwoavworhua et al., 2009). Additionally, red bean and soybean flour were prepared. The final stage of this research involved the preparation of artificial meat by adding microcrystalline cellulose (MCC) from EFB and analyzing its chemical characteristics.

The research factors included the ratio of red bean and soybean flour, which were as follows:

F1 (1:3), F2 (3:1), and F3 (1:1). The MCC concentration levels were 1%, 2%, and 3%, along with the respective ratios of red bean and soybean flour: FT1 (1:3), FT2 (3:1), and FT3 (1:1).

3. Results and discussions

3.1. Identification of MCC using FTIR

Fourier transform infrared (FTIR) spectroscopy is a technique that identifies chemical bonds in a molecule by creating a spectrum of the molecule's infrared absorption. Figure 1 presents absorption bands characteristic of microcrystalline cellulose prepared from sugarcane bagasse and EFB as analyzed by means of FTIR.

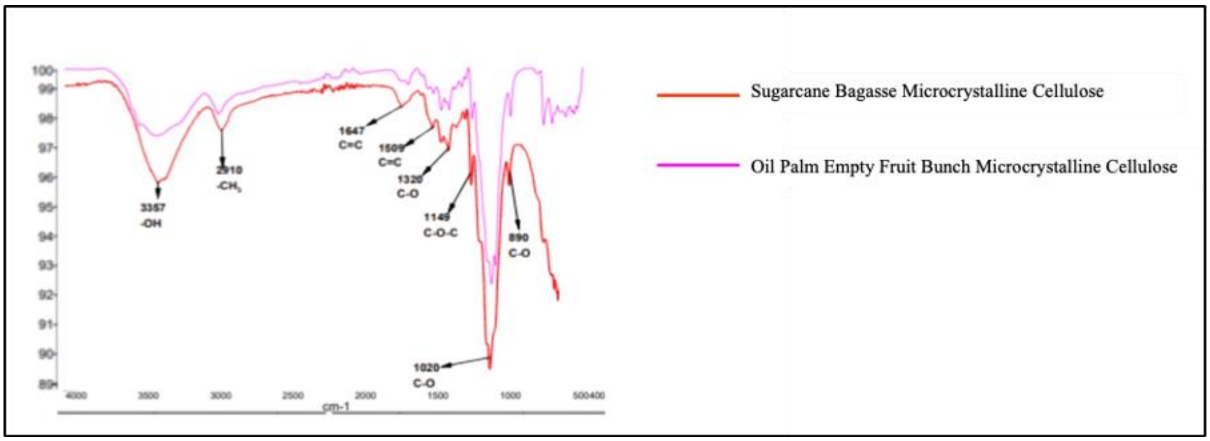

Figure 1. FTIR Analysis of Microcrystalline Cellulose Prepared from Sugarcane Bagasse and Oil Palm Empty Fruit Bunch (EFB)

At the frequency region of 3400–3200 cm⁻¹, the presence of O-H bonds from α-cellulose was observed, with the intensity of the wave showing variations and broadening. The absorption band at 2900–2901 cm⁻¹ indicated the presence of C-H bonds, further confirming α-cellulose. The C=C stretching vibration group, characteristic of the lignin skeleton, appeared in the range of 1500–2000 cm⁻¹.

Additionally, the absorption at 1320 cm⁻¹ indicated the presence of C=O groups, while the wavelength range of 1000–1150 cm⁻¹ represented the C-O ester group. The C-H alkene group was identified at a wavelength of 700–850 cm⁻¹, signifying an increase in crystalline regions within the MCC. These results confirm the structural integrity and purity of the MCC.

3.2. Moisture content

The damage occurring in a product is a key parameter in determining its quality and shelf life. Such damage is generally caused by a high moisture content in the product, which results from internal metabolism, biological activity, or the presence of microbes that can degrade the product (Daud et al., 2019). The moisture content of the artificial meat samples in Figure 2 shows a value of 50.26%-67.34%. According to the Indonesian National Standard (SNI) (National Standardization Agency of Indonesia, 2014), the maximum moisture content in meatballs is 70%. The highest water content analysis results were produced in the chicken control, which amounted to 67.34%. As for the lowest result, artificial meat is 50.26% with the treatment ratio of red bean flour and soybean flour is 3:1 and the addition of microcrystalline cellulose as much as 1%. Thus, the water content of artificial meat results has met the SNI requirements.

Figure 2 shows that the formulation of red bean flour: soybean (1:1) produces the highest moisture content value compared to other formulations. The addition of 2% microcrystalline cellulose produced the highest moisture content compared to 1% and 3% concentrations. Cellulose, with its hydrophilic properties, can bind water molecules to its hydroxyl (OH) groups, a key component in cell wall formation. The polymer structure of cellulose, with its weak hydrogen bonds, allows water to easily penetrate (Fatriasari et al., 2019). It is reported that the moisture content of MCC from bagasse is 4.96%, while corn cob MCC exhibited a moisture content of 6.9%(Kunusa, 2017; Nawangsari, 2019).

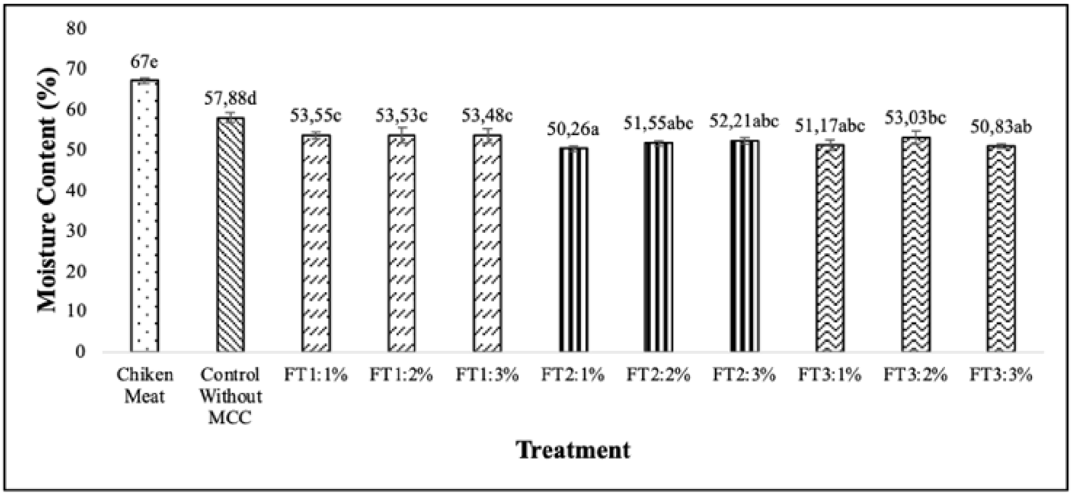

Figure 2. Moisture content of artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

The addition of red bean flour reduced water content in chicken sausage as the proportion of flour increased (Yuliatun et al., 2023), a decrease in moisture content was observed in crackers with increased peanut flour (Asfi et al., 2017), and higher red bean flour content in cork fish nugget products resulted in lower moisture content(Almayda et al., 2024). Conversely, adding soybean tempeh flour to artificial jerky increased its moisture content (Sidup et al., 2022), while higher soybean pulp flour content in cookies led to greater water retention (Wijaya et al., 2023). The ability of food ingredients to bind water is influenced by their protein content, as proteins contain hydrophilic groups that help retain water. As heat treatment causes protein molecules to form a network, this matrix can act as a water binder, preventing water molecules from escaping (Astawan et al., 2016).

3.3. Ash content

Ash content refers to the material remaining after a product has been completely burned. It refers to the proportion of inorganic mineral residue remaining after the complete combustion of organic material (Qadaryati et al., 2023). Food products typically consist of 96% organic substances and water, with the remaining portion comprising inorganic substances, or ash content (Hutomo et al., 2015). Determining ash content in food ingredients is essential for assessing product quality. Higher ash content often indicates a decline in food quality (Tahar et al., 2017). Calcium, phosphorus, and iron are mineral components that remain after ignition. These minerals are essential inorganic compounds that the human body requires for various physiological functions (Khuluqiah et al., 2109).

Figure 3 shows that the ash content values ranged from 0.67% to 6.43%. The highest value, 6.43%, was observed in the chicken control, while the lowest ash content, 0.67%, was found in the formulation with a 1:1 red bean to soybean flour ratio and 1% microcrystalline cellulose. According to the Indonesian National Standard (SNI) (National Standardization Agency of Indonesia, 2014), the maximum allowable ash content in meatballs is 3%. Therefore, the ash content of all samples, except the chicken control, meets the SNI quality requirements.

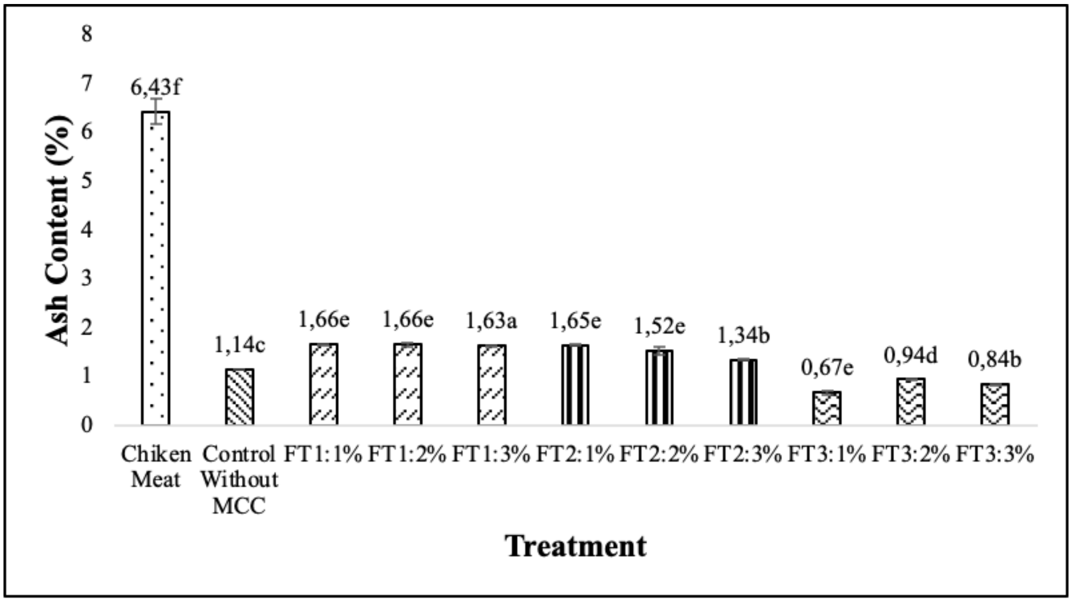

Figure 3. Ash content analysis of artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

The ability of food ingredients to bind water is influenced by their protein content, as proteins contain hydrophilic groups that help retain water. As heat treatment causes protein molecules to form a network, this matrix can act as a water binder, preventing water molecules from escaping (Astawan et al., 2016). The mineral content in soybeans includes calcium (300.36 mg/100 g), magnesium (258.24 mg/100 g), iron (16.4 mg/100 g), sodium (3.0 mg/100 g), zinc (2.7 mg/100 g), and phosphorus (695.20 mg/100 g) (Etiosa et al., 2018). The ash content in soybean flour has been reported as 2.89% (Astuti et al., 2014) and 3.88% (Fanzurna & Taufik, 2020). Increasing the amount of soybean flour in nugget products leads to a higher ash content (Parinduri & Rusmarilin, 2016) and adding soybean flour also increases the ash content (Swamilaksita et al., 2021).

Red bean flour has been reported to contain 2.75% ash (Astuti et al., 2014), though some studies have indicated values as low as 0.67% (Awalin et al., 2023). In the context of meatball production, the ash content of red bean flour was found to be 2.74% (Khuluqiah et al., 2109). Furthermore, the inclusion of higher amounts of red bean flour in porridge has been shown to decrease its ash content (Munte et al., 2019), Also observed in cookie formulations, where the addition of red bean flour resulted in a reduction of ash content (Binalopa et al., 2023).

3.4. Protein content

Protein plays a crucial role in replacing damaged tissue and maintaining existing tissue (Virgiansyah, 2018). Soybean flour contains higher protein levels compared to other beans, with 40-50% protein content, approximately 34.9 grams per 100 grams (Harleni & Nidia, 2017). In contrast, red bean flour contains 1.95 grams of protein per 100 grams (Wiranata et al., 2017). Figure 4 presents the results of the protein analysis in artificial meat. Figure 4 shows that the protein content of artificial meat with the addition of MCC from oil palm empty fruit bunches ranged from 0.83% to 3.32%. According to the quality standards set by SNI 3818:2014 (National Standardization Agency of Indonesia, 2014), the minimum protein content for meatballs is 8.0%, meaning that this artificial meat does not meet the SNI requirements.

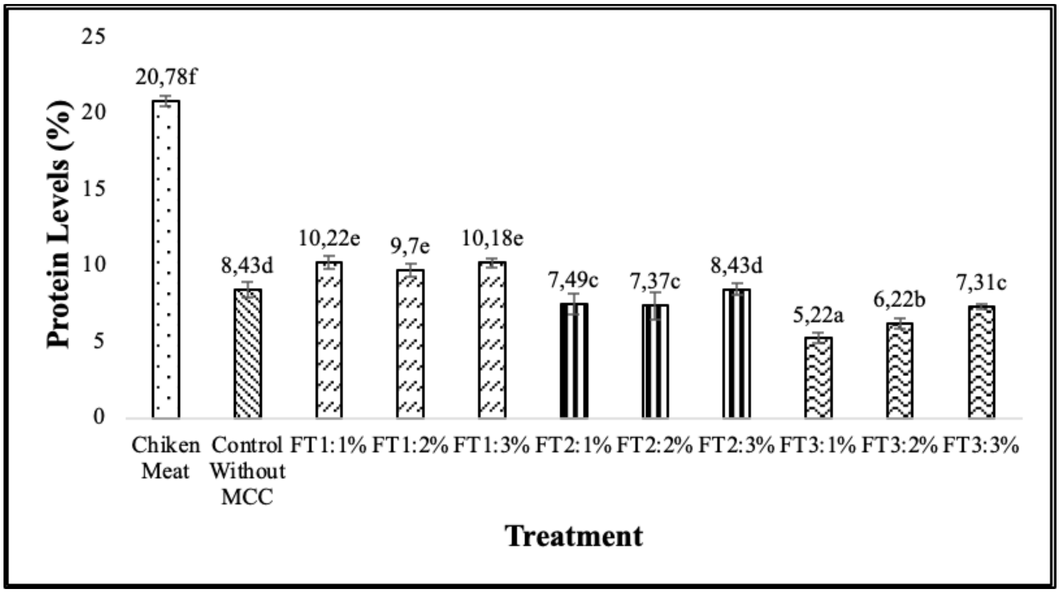

Figure 4. Protein content analysis of artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

Research has shown that the protein content in beef meatballs increases with the addition of soybean flour (Hermana et al., 2023). This is consistent with previous studies that reported an increase in protein levels in tapioca dumplings with higher soybean flour content (Aninditia et al., 2023). Similarly, it was found that adding soybean flour to buffalo meat nuggets increased their protein content (Suryaningsih et al., 2015). Conversely, other research observed a decrease in protein content in chicken sausage products as the amount of red bean flour increased (Pinardi et al., 2020). The protein content in red bean flour has been reported as follows: 21.61% (Siahaan et al., 2021), 15.3% (Audu & Aremu, 2011), 41.64% (Fanzurna & Taufik, 2020), 35.9% (Taufik, 2018), and 28.25% (Jariyah et al., 2017).

3.5. Fat content

Fats are a class of lipids, which are organic compounds insoluble in water but soluble in nonpolar solvents such as diethyl ether, benzene, chloroform, and hexane. Fats, specifically triglycerides, are solid at room temperature (Mulyani & Sujarwanta, 2018). Figure 5 shows that the fat content in artificial meat with the addition of microcrystalline cellulose from oil palm empty fruit bunches ranged from 1.01% to 5.29%. According to the quality standards outlined in SNI 3818:2014 (National Standardization Agency of Indonesia, 2014), the maximum allowable fat content in artificial meat is 10%. Therefore, the fat content of the samples meets the SNI requirements.

The fat content in soybean flour is reported to be 28.44% [25], while another study indicates it as 26.22% (Indrawan et al., 2018). This is consistent with research that found increasing the amount of soybean flour results in higher fat content (Hariadi et al., 2017). In contrast, red bean flour contributes to lower fat content in artificial meat. Red bean flour has a fat content of 9.83% (Pangastuti et al., 2013), while another study reports it as 0.48% (Tamrin & Pujilestari, 2016). Similarly, red bean flour contains 0.47% fat (Chrestella, 2020). Therefore, higher amounts of soybean flour can increase fat content in the product.

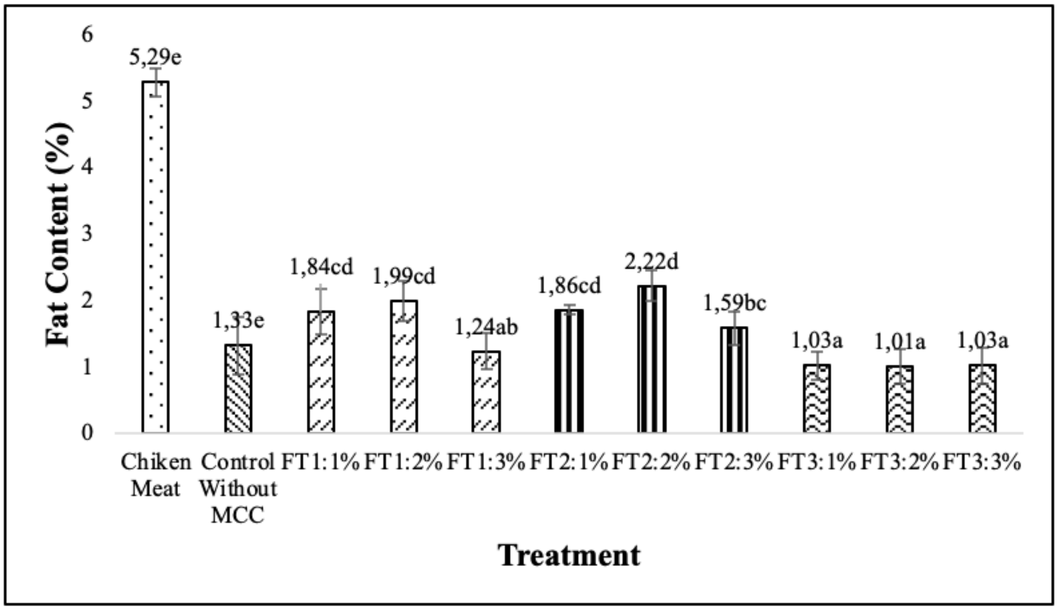

Figure 5. Fat content analysis of artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

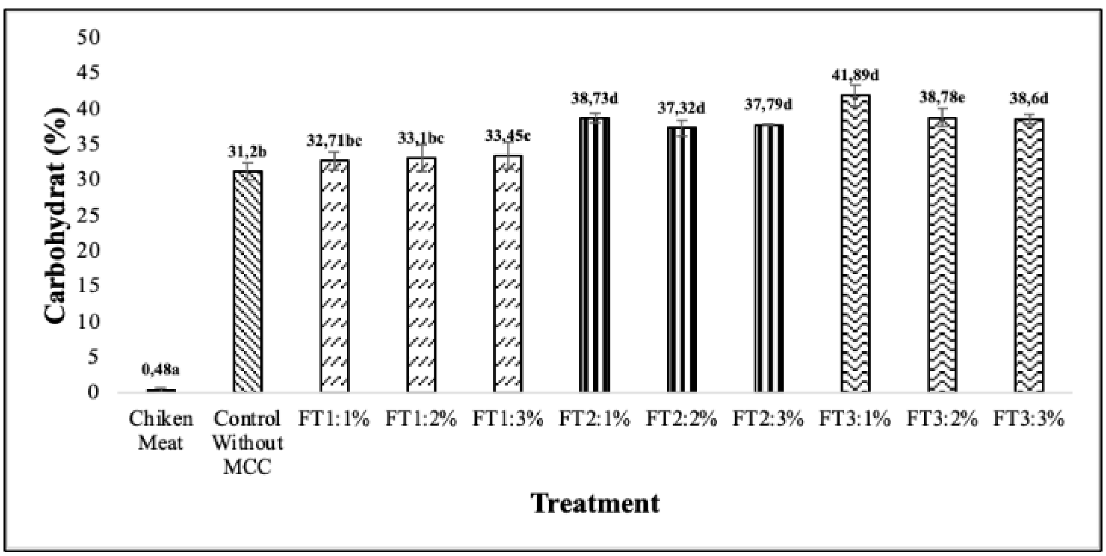

Figure 6. Carbohydrate content analysis of artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

The addition of soybean flour to gourami fish meatballs was found to increase the fat content (Tina et al., 2018). Similarly, an increase in fat content was observed in nugget products with higher amounts of soybean flour (Simanjuntak & Pato, 2021). In brownies, replacing wheat flour with soybean flour also results in higher fat content (Kunusa, 2017). In contrast, artificial meat with added soybean flour had lower fat content compared to that with red bean flour. This is because soaking soybeans reduces fat content. The soaking process activates lipase enzymes, which break down fats, resulting in free fatty acids that are easily dissolved in water during soaking (Pangastuti et al., 2013).

3.6. Carbohydrate content

Carbohydrates are essential nutrients for the body, primarily serving as energy sources. They are a group of organic compounds with diverse molecular structures (Siregar, 2014). Figure 6 shows that the carbohydrate content of artificial meat with the addition of microcrystalline cellulose from oil palm empty fruit bunches ranged from 17.61% to 46.30%. The lowest carbohydrate content, 17.61%, was found in the chicken meat control, while the highest value, 46.30%, was observed in the formulation with a 1:1 red bean to soybean flour ratio and 1% microcrystalline cellulose. Mentari et al. (Mentari et al., 2016) reported that artificial meatballs produced a carbohydrate content of 21.63%.

Increasing the substitution of soybean flour has been shown to decrease the carbohydrate content in snack bar products (Qoriah et al., 2021). Similarly, Suriany et al. (2020) found that adding more soybean flour to noodles led to a reduction in carbohydrate content. Conversely, the addition of red bean flour in food bars increased the carbohydrate content as the level of substitution rose (Utama & Anjani, 2016). Carbohydrates in food ingredients are often reduced due to the higher levels of water, ash, protein, and fat present (Ratnawati et al., 2019). The carbohydrate content in red bean flour is reported to be 12.83% (Prasetyo et al., 2014). In contrast, the carbohydrate content of soybean flour has been reported as 32.24% (Ekafitri & Isworo, 2014) and 34% (Sukaryono et al., 2017). The reduction in carbohydrate content in soybeans is attributed to the degradation of carbohydrate molecules into simpler sugars. Additionally, soaking and boiling soybeans can further decrease the carbohydrate content due to the loss of oligosaccharides (Kusuma Putri et al., 2021).

3.7. Crude fiber content

Crude fiber is a component of food that cannot be hydrolyzed by chemicals. It is determined using sulfuric acid (H_2SO_4 1.25%) and sodium hydroxide (NaOH 1.25%) (Hardiyanti & Nisah, 2021). The crude fiber content in a food ingredient depends on the fiber content of the ingredients used in the formulation (Widnyani et al., 2021). Crude fiber is a carbohydrate component that is separated from nitrogen-free extracts, primarily starch, through a simple chemical analysis. It consists of cellulose, hemicellulose, and lignin (Londok & Pandelaki, 2023).

Figure 7 presents the crude fiber content in artificial meat formulations. The analysis revealed that the crude fiber values varied across different formulations of red bean and soybean flour. Notably, when red bean and soybean flour were used in equal proportions, a higher crude fiber content was observed compared to other formulations. Furthermore, increasing the concentration of microcrystalline cellulose (MCC) in the formulations resulted in a significant increase in the crude fiber content.

It was reported that increasing the substitution of red bean flour raises the crude fiber content (Rahmawati, 2018). However, in snack bar products, the addition of red bean flour led to a decrease in fiber content as the proportion of red bean flour was reduced (Siregar et al., 2017).

Red bean flour is a rich source of fiber and increasing its amount in artificial rice made from ganyong tubers also increased crude fiber content (Salsabila et al., 2020). It was reported that red beans contain 5.77% crude fiber (Li et al., 2002), while adding red bean flour to arrowroot flour cookies increases crude fiber content. Approximately one-fifth of food fiber consists of crude fiber (Istiqomah & Rustanti, 2015) The insoluble fiber content in soybean seeds ranges from 3.08% to 5.49%(Ratnaningsih et al., 2018; Wibawanti et al., 2021). It was stated that adding soybean flour to chicken nuggets increased crude fiber values (Mawati et al., 2017). In tempeh products, a higher proportion of soybeans results in greater crude fiber content compared to tempeh made with a smaller number of soybeans (Nasrulloh et al., 2021).

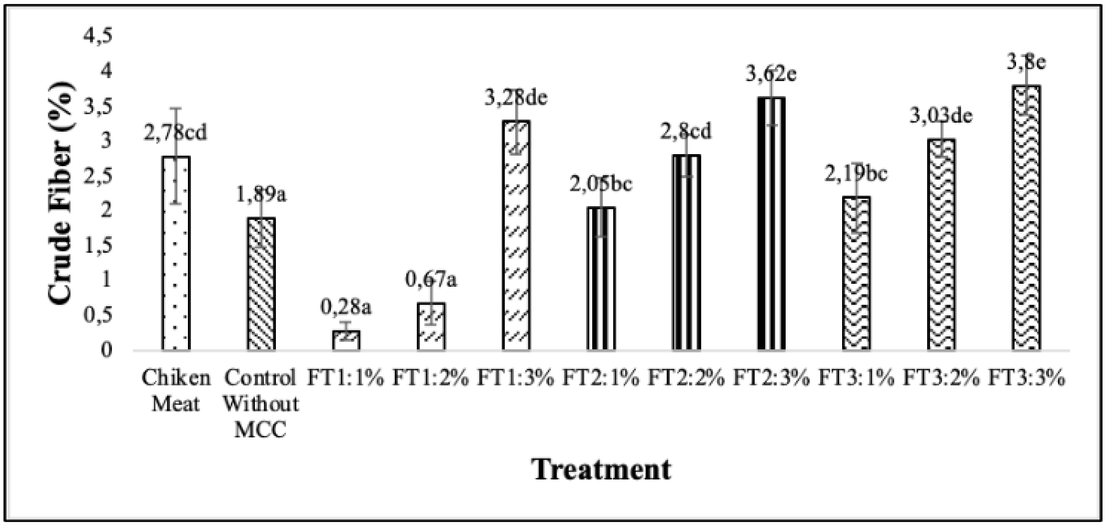

Figure 7. Crude fiber content in artificial meat with varying ratios of red bean and soybean flours and MCC concentrations. Data labels are shown as means, whereas standard deviations are shown as error bars. Different superscript letters within the same category parameter indicate statistically significant differences ($p < 0.05$).

4. Conclusions

The addition of microcrystalline cellulose to artificial meat increases crude fiber content but does not significantly affect chemical characteristics such as moisture content, ash content, protein content, fat content, or carbohydrate content. In contrast, the incorporation of soybean flour and red bean flour does impact the chemical characteristics of artificial meat.

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