Heliyon 9 (2023) e17176

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Physicochemical and structural impact of CMC-hydrocolloids on the development of gluten-free foxtail millet biscuits

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ARTICLE INFO

Keywords:
Cereal
Foxtail millet
Hydrocolloids
Physicochemical characteristics

ABSTRACT

Patients with celiac disease and those who are gluten intolerant have a need for gluten-free bakery items but developing them is a challenge for technologists and dietitians. Foxtail millets are naturally gluten-free and nutrient-dense grains. Herein, CMC-modified foxtail millet biscuits (CFMBs) were prepared using 0.01%, 0.05%, and 0.1% of CMC hydrocolloids with foxtail millet flour. The effects of CFMBs on the physicochemical properties, sensory, and morphology were investigated and compared with wheat (WB-100) and foxtail millet (FMB-100) products. CFMBs were thicker, had a larger specific volume, and had a lower diameter and spread ratio than FMB-100. CFMB-0.1 exhibited higher moisture content, higher water activity, and lower fat content than FMB-100 and WB-100. The hardness of CFMB-0.1 (35.08 ± 0.26 N) was close to WB-100 (37.75 ± 0.104 N) but higher than FM-100 (21.61 ± 0.064 N). The scanning electron microscope (SEM) study indicated that incorporating CMC influenced the morphology and microstructure of CFMBs. Skilled panelists gave WB-100 and CFMB-0.1 the highest sensory ratings and FMB-100 the lowest due to their color, appearance, flavor, and overall acceptability. Finally, CMC may be easily included in FMB manufacturing and supported like gluten in the food sector to suit the nutritional demands of customers.

1. Introduction

Human diets primarily depend on cereal grains and flour-based foods. Additionally, cereals provide the primary protein source for many people living in still-developing countries [1]. Rice and wheat are the most widely utilized crops as cereals and flour-based food products. Among the wheat-based bakery products biscuits are one of the most popular, enjoyed by children, teens, adults, and seniors [2,3]. These snacks are ready-to-eat, economical, and come in a variety of flavors. To fulfill the demand of global nutritional requirements, biscuit consumption is rising in parallel [4–6]. The biscuit global market was worth $76.385 billion at the end of 2017 and is predicted to expand to USD 164 billion by 2024, with compound annual growth rates (CAGRs) of 3.7% and 5.08%, respectively [5].

Most commercially available biscuits are made with gluten-based wheat flour which is capable of triggering immune-mediated disorders, like celiac disease [7,8]. Celiac disease (CD) is an inflammatory illness of the small intestine caused by barley, rye, and wheat gluten proteins [7–9]. Gluten intolerance and hypersensitivity cause serious public health problems, so the demand for products designed to meet particular dietary needs increases. Due to the rising number of persons with celiac disease and gluten-related diseases

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https://doi.org/10.1016/j.heliyon.2023.e17176
Received 16 February 2023; Received in revised form 21 March 2023; Accepted 9 June 2023

and those who follow a gluten-free diet without medical necessity, the global market for gluten-free items (including baked goods, snacks, ready-to-eat meals, pasta, sauces, and dressings) is expected to grow from $4.18 billion in 2017 to $6.47 billion in 2023 [10]. The size of the worldwide market for gluten-free goods is anticipated to reach 13.7 billion USD by the year 2030. It is anticipated that the market would grow at a compound annual growth rate of 9.8% between the years 2022 and 2030 in North America, Europe, Asia Pacific, South America, the Middle East, and Africa countries [11]. The most often eaten gluten-free cereal products are bread and cookies [12].

However, the increase in consumption of gluten-free products also concerning in sense of individual's nutritional intake. According to research by Alvarez-Jubete et al., a gluten-free diet leads to an unbalanced protein, fat, and carbohydrate intake. In addition to this, another problem with commercial gluten-free foods is that they contain insufficient amounts of vitamin B, fiber, and iron [13]. Consequently, people who consume excessive gluten-free food typically experience malnutrition [14,15]. Additionally, consumers emphasize sensory characteristics e.g., texture and palatability of consumable food items like biscuits [16]. Gluten-free biscuits often have worse sensory characteristics when compared to normal biscuits [16,17]. The texture of the biscuit depends on the starch gelatinization and the super-cooled sugar [18]. Despite this, most commercially available gluten-free biscuits consist mainly of starch and have poor organoleptic quality [14,15]. Many gluten-free biscuits are made with starch or processed flour, which is low in fiber and resistant starch, resulting in various health issues caused by inadequate fiber intake [19]. Although gluten only plays a minor role in regulating the processability and quality of biscuits, there is a considerable need for new investigations of an alternative pathway to improve the nutritional value of gluten-free products because the only effective treatment for celiac disease is a gluten-free diet [8,20]. By identifying several strategies for growing the gluten-free bakery industry, it may be possible to improve the nutritional quality of gluten-free biscuits products by adding nutrients-enriched gluten-free flour that operates and perform similarly to conventional wheat flour. Many studies have been done to improve the nutritional quality of gluten-free biscuit products by adding nutrient-enriched gluten-free flour. For instance, rice [21], maize [22], pseudo cereals like quinoa and amaranth [23], buckwheat [1], millet [9,15], pulses like beans [8] and others like chestnut shells [2], has been used as a replacement of wheat flour. This research has also updated knowledge, goods, and consumption habits among individuals who desire and require new dietary alternatives. To make diets more sustainable, i.e., diets with minimal environmental impact, diversity, affordability, and nutritional adequacy, it is very desired that they are diversified, inexpensive, and nutritionally sufficient. Cereal grains are a mainstay in the human diet because they offer an inexpensive, readily accessible, and renewable supply of nutrients [24]. Millet species that are endemic to the area and are both unusual and nutritious might provide a nutritional alternative.

Recently, foxtail millet *(Setaria italica (L.) P. Beauvois*), a pseudo-cereal grown in Africa, Europe, and South Asia, has been drawing a lot of attention as an important food grain, particularly because of its various vitamins, nutraceuticals, and minerals [25–27]. Foxtail millet has an excellent nutritional profile and contains the same amount of protein, fiber, minerals, and vitamins as other basic grains, like wheat and rice [25]. It contains protein (11.65%), dietary fiber (14%), fat (3.48%), minerals (3%), phytochemicals (phenolic acids, flavonoids), and β-carotene (126 to 191 μg/100 g) [27]. However, due to the absence of gluten in these grains, only a limited variety of baked products can be produced using them. Additionally, technical challenges arise when replacing gluten in baked products because of structural characteristics. The elimination of gluten makes the dough's structure more fragile, making it more challenging to prepare dough and biscuits [15]. Consequently, foods made with foxtail millet that is baked in an oven often have weak binding and stretching abilities, poor color, and other problems with their quality [28]. Thus, there are several possibilities for developing gluten-free products that replace traditional composite flour as well as the issue of structural and sensory properties. Many studies have been established to enhance the quality of gluten-free biscuits concerning human health and sensorial properties. For instance, Giuffre et al. found enhanced shelf-life, and sensory and physicochemical properties of Italian Cantuccini biscuits via the replacement of margarine and the partial replacement of butter with extra virgin olive oil [6]. Lagana et al. prepared biscuits fortified with bergamot Pastazzo flour with improved water activity, hardness, and antioxidant properties [29]. Additionally, Saeed et al. developed gluten-free biscuits with enhanced nutritional profiles by incorporating Assyrian plum and date pit flour in rice flour without altering technological and sensorial properties [7].

Along with the replacement of gluten-containing flour, to ensure the structural integrity of finished products, it is common practice to incorporate a variety of additives that can mimic the viscoelastic behavior of gluten. In gluten-free formulations, hydrocolloids are an essential component since they are utilized in the food industry to enhance the consistency and appearance of finished goods. In addition to the apparent benefits of mouth feel, taste, moisture management, water mobility, and texture, they enhance overall product quality and stability by overcoming the obstacles of manufacturing, distribution, and final production [30]. Kaur et al. evaluated the influence of several hydrocolloids on the quality of buckwheat flour-based gluten-free biscuits [31]. They discovered that adding hydrocolloids to buckwheat flour improved the sensory properties and acceptability of the formulated biscuits significantly. The combination of carboxymethylcellulose (CMC) and buckwheat flour improved the overall acceptability of rice flour-based biscuits but reduced their hardness and fracture ability [32].

Hydrocolloids are often used to improve the rheological characteristics of gluten-free goods. For instance, the addition of the hydrocolloid hydroxypropyl methylcellulose (HPMC) to gluten-free biscuits is an excellent approach to increase both the specific volume and their texture [19]. Additionally, CMC and HPMC made baked goods better at keeping in moisture or absorbing less oil by forming a thermal gel barrier on the surface of the product at high temperatures [33]. However, the quality of foxtail millet-based gluten-free biscuits made using CMC without adding common wheat hasn't been demonstrated in the published literature.

The goal of this study is to make foxtail millet-based biscuits (FMB) without adding wheat flour (WF) by using carboxymethylcellulose (CMC) hydrocolloids. The study also examined the effects of the incorporation of CMC on the physicochemical properties like texture, color, moisture content, fat content, and morphological properties of CMC-modified foxtail millet biscuits (CFMBs).

2. Materials and methods

2.1. Raw materials

Fresh foxtail millet (Bari Kaon-2) was collected from the Panchagarh district (Panchagarh is located at 26° 20′ 7.3572″ North and 88° 33′ 6.1092″ East) of Bangladesh. The all-purpose wheat flour was collected from the local market and sieved through 60 mesh (250 μm). Food-grade carboxymethylcellulose (CMC) (Merck, Germany), sugar, baking powder, baking soda, soya bean oil (mainly imported from Argentina, Canada, and Brazil, etc.; store in a cold, and well-ventilated room at 30 °C; PET container; 1 L; 2022), and salt were also purchased from a local market and used without further processing.

2.2. Preparation of foxtail millet flour

Initially, the foxtail millet grain is cleaned and washed. The washed grain was then dried for 8 h at 60 °C and crushed into foxtail millet flour (FMF) in a grinding machine. Finally, the flour was sieved using 60 mesh (250 μm) of sieves to avoid the granulometry effect that arises due to particle sizes in wheat flour.

2.3. Preparation of biscuits

(i) The CMC-modified foxtail millet biscuits (CFMBs) were made in 2022 using AACC 2000 (method 10–52) [34]. The dough was prepared by mixing foxtail millet flour (100 g), butter (16 g; source: cow; pasteurized; unsalted; stored at −18 °C; pack size: 100 g), powdered sugar (40 g), oil (18 ml), baking soda (0.8 g), baking powder (1.2 g), water (50 ml), and CMC (0.01%, 0.05%, and 0.1% of the weight percentage of FMF). The dough was kept for 10 min before being rolled out with a rolling pin to a thickness of 5–6 mm and then cut with a biscuit cutter into circles of 50 mm in diameter. After cutting the biscuit, it was put in a pan, baked in a hot air oven (Memmert UNB 100, Germany) at 180 °C for 18 min, and then allowed to cool at room temperature on a cooling rack for 1 h. The prepared biscuits were labeled CFMB-0.01, CFMB-0.05, and CFMB-0.1 for 0.01%, 0.05%, and 0.1% CMC, respectively. Biscuits were covered with plastic wrap, placed in a sealed jar, and stored at ambient temperature on an open shelf. All physical and chemical analyses were performed within 7 days of the biscuit baking.

(ii) The wheat biscuits were prepared using wheat flour (WF) instead of FMF with all ingredients except CMC, designated as WB-100.

(iii)The pure FMB was prepared using FMF without CMC with all ingredients except CMC and nominated as FMB-100.

2.4. Physico-chemical characteristics

2.4.1. Spread ratio measurement

The thickness and diameter were measured using a Vanier caliper (WA-VC115 Wiika, China) at two distinct locations, and the average was determined. The spread ratio was then calculated by dividing the average biscuit diameter by the average biscuit thickness. For each variation, three replicate measurements were taken from the same batch, and the results are shown as the mean ± standard deviation [31].

$$\text{Spread Ratio} = \frac{Average\ Diameter(cm)}{Average\ Thickness\ (cm)} \tag{1}$$

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2.4.2. Specific volume measurement

The weight was taken using a 4-digit electronic balance (ViBRA HT224RCEN, Japan). The specific volumes were measured using equation (1) and represented as cm^{-3} g^{-1} [35].

$$\text{Specific Volume } \left(cm^3 g^{-1}\right) = \frac{Thickness(cm) \times Width(cm) \times Length(cm)}{Wight(g)} \tag{2}$$

The results of this study are presented as the mean ± standard deviation. Each variation included triple replicate measurements collected from the same batch.

2.4.3. Water activity (a_w) and moisture content measurement

Water activity (aw) was measured using a water activity meter (Model: Novasina RS 200, Axair Ltd., Pfaffikon, Switzerland) in a sealed measuring chamber using the chilled-mirror dew point method at 25 °C with three milled biscuit replicates of each formulation. The moisture content of the biscuits was determined using the official AOAC 2005 (method 925.10) [36], utilizing a hot-air oven (Memmert UNB 100, Germany).

2.4.4. Fat content measurement

The biscuits' fat content was determined using the official AOAC 2005 (method 922.06) [36], utilizing the Soxhlet apparatus and

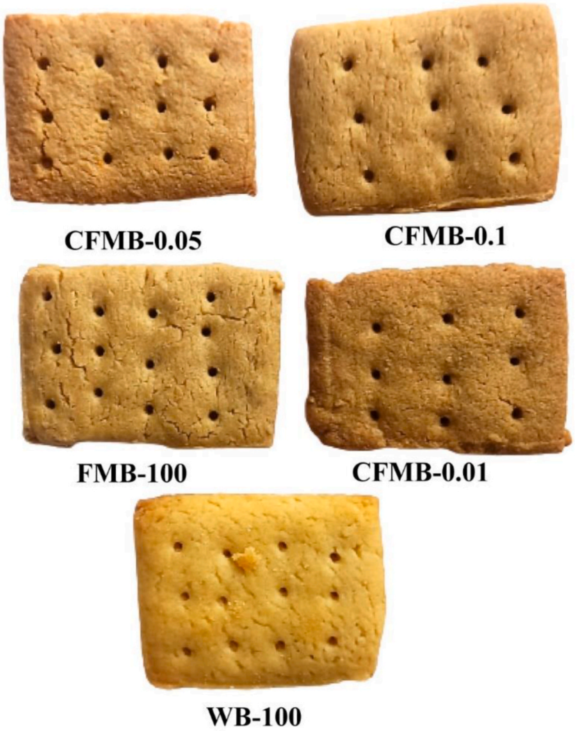


Fig. 1. Illustration of prepared gluten-free foxtail millet biscuits. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

petroleum ether (40–60 °C, Sigma Aldrich). In a typical experiment, a 15 g sample was taken in 90 ml of petroleum ether and extracted for 6 h over two days with an interval of 12 h at the boiling range of petroleum ether.

2.4.5. *Texture properties*

With a texture analyzer (Model: TMS-Pro, Food Technology Corporation, USA) and the three-point bend fixture test method, the texture profiles were analyzed in ten repetitions. The three-point bend fixture test method was used. The biscuit sample, with measurements of 6 ± 1 mm in thickness and 35 ± 1 mm in width on average, was placed on the two beams at a distance of 20 mm apart and tested for compression at a speed of 1 mm s^{-1}. The hardness is the height of the force peak on the first compression cycle of the force-time diagram [first bite], which was measured as the fracture force (N) and expressed as the hardness of the biscuits to evaluate the textural characteristics. Each sample was analyzed in three replicates.

2.4.6. *Color measurement*

The biscuits' color quality was measured with a colorimeter (Model: Minolta CR-410, Konica Minolta Inc., Japan). According to the CIE, L represents brightness/darkness and ranges from 0 (black) to 100 (white). The remaining two color coordinates are a* (redness/greenness) and b* (yellowness/blueness). The following equation (3) was used to calculate each sample's chroma value, which may be regarded as the color's saturation or intensity [29,35]:

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \tag{3}$$

where a^* and b^* are the color parameter values of the sample at different points.

2.5. *Scanning electron microscope*

The microstructure of the biscuit was investigated using a scanning electron microscope (SEM; Model ZEISS EVO 18, Carl Zeiss Microscopy GmbH, Germany). Before the SEM study, dried biscuit samples were kept in a desiccator. Double-sided scotch tape was used to mount biscuit samples on a slide and arrange them individually on sample holders. A 20 kV accelerating voltage was used to snap photographs of the prepared sample.

Table 1
Physical properties of biscuits[e].

Sample	Weight (g)	Thickness (mm)	Diameter (mm)	Specific Volume (V$_{sp.}$; cm^3 g^{-1})	Spread Ratio
WB-100	10.79 ± 0.356	8.26 ± 0.033	63.98 ± 0.541	1458.57 ± 0.065^{a}	7.74 ± 0.039^{a}
FMB-100	10.17 ± 0.015	7.41 ± 0.013	63.53 ± 0.322	1368.29 ± 0.008^{a}	8.57 ± 0.058^{b}
CFMB-0.01	10.52 ± 0.003	8.05 ± 0.045	62.32 ± 0.176	1383.34 ± 0.009^{a}	7.74 ± 0.054^{a}
CFMB-0.05	10.51 ± 0.015	8.10 ± 0.051	62.21 ± 0.827	1389.55 ± 0.022^{a}	7.68 ± 0.142^{a}
CFMB-0.1	10.43 ± 0.020	8.43 ± 0.25	61.07 ± 0.739	1396.61 ± 0.008^{a}	7.24 ± 0.159^{c}

WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

[a-c] different superscripts within the same column are significantly different by Duncan's multiple range test ($p < 0.05$).

[e] Values are mean ± SD of three replicates.

2.6. Sensory evaluation

The sensory evaluation of prepared biscuits was conducted by eleven trained panelists (five male and six female) among twenty assigned panelists of the Institute of Food Science and Technology (IFST), Bangladesh Council of Scientific and Industrial Research (BCSIR) in Dhaka, Bangladesh. All the selected panelists were non-smokers. The evaluation was conducted in a facility that was equipped with white-lit sensory booths for each participant. The samples were labeled with codes assigned by the head of the panelists and were provided arbitrarily to the panelists 24 h after baking. The participants were asked to comment on quality factors like color and appearance, texture, flavor, taste, and mouthfeel and filled out a form, which is attached herewith as supplementary material (Supplementary Material: Form-1). Furthermore, the panelists were questioned about their overall acceptability. On the 9-point Hedonic Scale, the quality attributes of each sample were scored as follows: 9- like extremely; 8- like very much; 7- like moderately; 6- like slightly; 5- neither like nor dislike; 4- dislike slightly; 3- dislike moderately; 2- dislike very much; 1- dislike extremely [1]. During the evaluation, we made sure to get each participant's signed informed consent on the same form. The overall report was generated by the head of the panelists following a specific report format (Supplementary Material: Form-2).

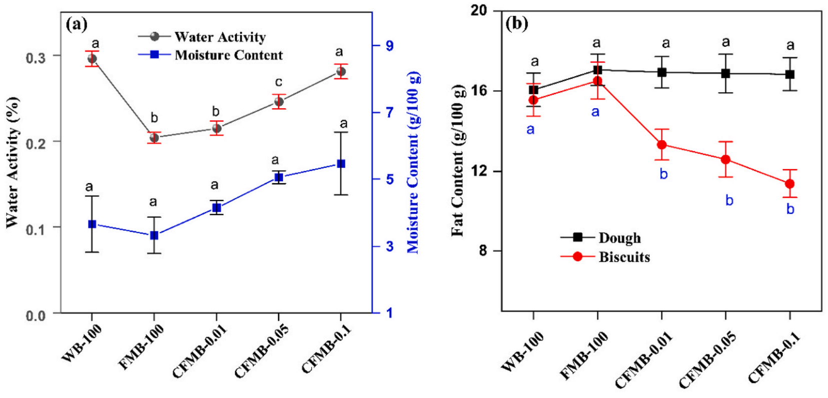
2.7. Statistical analysis

The results were presented as means ± SD (standard deviations) for replicates, and a one-way analysis of variance (ANOVA) was run in Statistical Package for the Social Sciences (SPSS 20.0, IBM, Chicago, IL, USA). If the value of $p < 0.05$, then the findings were regarded to have a statistically significant impact. The graphs were generated using Origin (Version 2018).

3. Results and discussion

3.1. Physical properties of biscuits

Physical properties are vital in developing novel food items and are believed to be necessary for sensory acceptability. This assessment may be linked to sensory characteristics that facilitate processing-based evaluation. The pictures of all biscuits confirmed that biscuits maintained their shape during cooking and had a pleasant appearance, as shown in Fig. 1. The physical properties of the baked biscuits are summarized in Table 1. The diameter of the CFMBs decreased rather than the FMB-100 and WB-100. The diameter of CFMB-0.10 was significantly ($p < 0.05$) to a lesser extent than that of WB-100 because WF contains gluten, which forms a strong gluten network upon baking, and FMF has no gluten. The thickness of the CFMBs was increased compared to FMB-100 upon the addition of CMC. The spread ratio of WFB-100 and FMB-100 was found to be highest at 7.75 ± 0.039 and 8.57 ± 0.058, respectively, and the incorporation of CMC to FM reduced this ratio to 7.24 ± 0.158. The spread ratio of the CFMB-0.1 was significantly ($p < 0.05$) decreased compared to FMB-100 and WB-100. Lowering these dimensions is linked with the elastic recoil capacity offered by hydrocolloids containing carbohydrates. Also, due to a diluting impact on the wheat protein, the spread ratio falls linearly with the level of gluten [14]. The CMC hydrocolloids act as an alternative to gluten in biscuit formation; hence, the spread ratio decreased with the addition of CMC compared to WB-100. This study reported a spread ratio that was in the same range as Mudgil et al. [37], which was 4.37 to 9.14; however, Radhika et al. [38] also described having a more excellent spread ratio, which was 8.84 to 10.22. These findings were consistent with those of Lourencetti et al. [39], who made biscuits using carbohydrate-based hydrocolloids like maltodextrin and inulin. Devisetti et al. observed that the spread ratio decreased when hydrocolloids were introduced to proso millet flour and buckwheat flour due to variations in the water-binding capacity of hydrocolloids [15]. The specific volumes of CFMBs with various amounts of CMC addition were increased. Also, FMB-100 showed a lower specific volume (1368.59 ± 0.008 mm^3 g^{-1}) compared to the WB-100 (1458.20 ± 0.065 mm^3 g^{-1}). The highest specific volume was found at 1396.66 ± 0.008 mm^3 g^{-1} for the CFMB-0.1, which was lower than WB-100 but higher than FMB-100. The higher specific volume of CFMBs could be because bubbles stay in the dough longer while it's baking. This is because the dough's viscosity goes up and there are more H-bonding sites, which allow the hydroxyl group of hydrocolloids to hold more water. This makes the dough stay stable for longer while it's baking and gives the biscuits a better texture [35,40].



The values are presented as mean ± SD (n = 3). The statistical analysis was conducted using a one-way ANOVA. Different lowercase letters within the graph denote differences that are statistically significant ($p < 0.05$).

Fig. 2. Effect of concentration of CMC on the (a) water activity and moisture content of biscuits (b) fat content of dough and biscuits. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

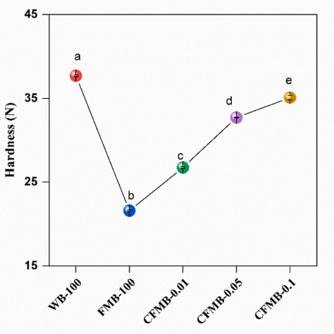
3.2. Water activity (a_w) and moisture content of biscuits

The water activity and moisture content of food items are essential for forecasting shelf life and understanding their texture, notably crispiness [40]. The water activity and moisture content of the biscuits of WB-100, FMB-100, and CFMBs are shown in Fig. 2 (a). The water activity and moisture content of CFMBs were higher than those of FMB-100. The moisture contents of the FMB-100 and CFMBs doughs (14.76 ± 0.92 to 16.22 ± 0.84 g/100 g) had no significant ($p < 0.05$) difference from the WB-100 (14.54 ± 0.86 g/100 g) dough (Fig. S1 (Supplementary Material)). After baking, the moisture content of CFMBs varied from 4.15 ± 0.20 to 5.47 ± 0.94 g/100 g to that of FMB-100 (3.32 ± 0.54 g/100 g) and WB-100 (3.66 ± 0.84 g/100 g). The moisture content of CFMB-0.10 (5.47 ± 0.94 g/100 g) was significantly ($p < 0.05$) higher than that of FMB-100 (3.32 ± 0.54 g/100 g) biscuits after baking. The dough made of wheat as well as FM without CMC reduces a higher amount of moisture after baking than the dough of CMC incorporated FM. But compared to other CMC-incorporated biscuits, CFMB-0.1 dough retained more moisture than FMB-100. The incorporation of hydrocolloids enhanced the water-holding capacity of baking products which enhanced the texture and acceptance of finished products.

The water activity of CFMBs gradually increased with the amount of CMC added. CFMB-0.1 showed significantly ($p < 0.05$) higher water activity than FMB-100. The water activity and moisture content values of CFMB-0.1 are similar to WB-100. Adding 0.01%, 0.05%, and 0.1% CMC increased the water activity from 0.212 to 0.280 of the finished baked product compared to the hydrocolloid-free control (FMB-100). All of the formulated biscuits had a water activity (a_w) that was less than 0.6, and as a result, they fall into the classification of foods that are microbiologically stable [3]. Food products with an a_w between 0.40 and 0.70 do not require refrigeration but must be kept in moisture-resistant packets to protect them from microorganism growth [3]. Hydrocolloids like carboxymethylcellulose (CMC) are essential for producing barrier films due to their outstanding ability to retain water and their propensity to form a gel when subjected to increased temperatures. The surface coating can prevent any remaining water from evaporating during the baking process at high temperatures [35]. The films formed over the flour particles at temperatures above their initial gelatinization temperature of CMC retained their inherent barrier and gluten-like characteristics of conventional gluten protein [35]. The results regarding moisture content were the same as what Pourmohammadi et al. [41] and Chugh et al. [42] found in their studies. They said that removing the fat could reduce the moisture content by 1 to 5%. It is likely that heat denaturation of the surface CMC, which forms a barrier and slows water loss, causes lower fat penetration during baking. Moreover, similar moisture content and water activity of CMFB-0.1 with WFB is advantageous not only for improving shelf life but also for the crispiness of prepared biscuits without exceeding the threshold value for microorganism growth.

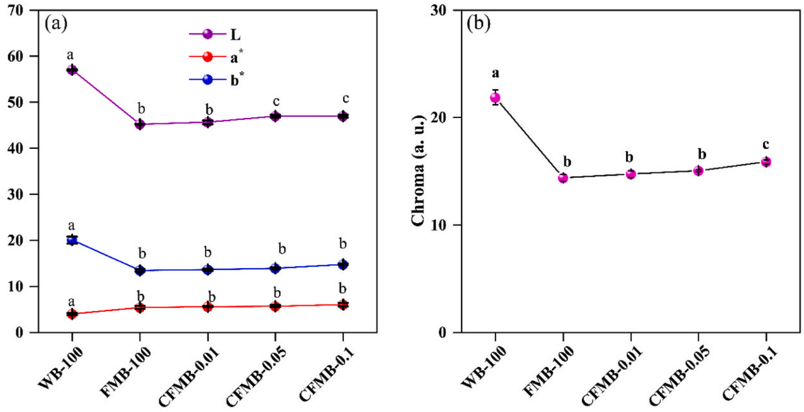
3.3. Fat content of dough and biscuits

The fat contents of the dough and biscuits of WB-100, FMB-100, and CFMBs are shown in Fig. 2(b). The fat contents of FMB-100 and CFMB doughs were almost the same. The fat content of FMB-100 and all CFMBs dough (17.06 ± 0.79 g/100 g to 16.84 ± 0.83 g/100 g) was higher than the wheat flour dough (16.06 ± 0.84 g/100 g). During the baking process, WF-100 had a significantly ($p < 0.05$) higher fat content (15.56 ± 0.80 g/100 g) than CFMB-0.05 and CFMB-0.10, which indicates that more oil absorbed the microparticles of wheat flour during the baking process compared to CFMBs. The CMC-modified FM biscuits had fat content values ranging from 11.38 ± 0.70 g/100 g to 16.51 ± 0.91 g/100 g. The CFMB-0.1 had a 26% and 31% lower fat content than the WB-100 and FMB-100, respectively. These results indicate that CMC helped release more oil from the internal structure of the dough. Due to their water-holding capacity and gel-forming characteristics at elevated temperatures, hydrocolloids are essential for creating barrier films. The formation of a thin surface film over the granules of starch may prevent absorbed water from evaporating during the baking



The values are presented as mean ± SD (n = 3). The statistical analysis was conducted using a one-way ANOVA. Different lowercase letters within the graph denote differences that are statistically significant ($p < 0.05$).

Fig. 3. Effect of concentration of CMC on the hardness of biscuits. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.



The values are presented as mean ± SD (n = 3). The statistical analysis was conducted using a one-way ANOVA. Different lowercase letters within the graph denote differences that are statistically significant ($p < 0.05$).

Fig. 4. Effect of concentration of CMC on the (a) L, a*, b* value, and (b) chroma of biscuits. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

process, consequently lowering the amount of fat contained in the baked products. In other words, when compared to the WB-100 and FMB-100, the CMFB absorbed less oil. The CFMB-0.1 fat content was significantly ($p < 0.05$) lower than the WB-100 and FMB-100. This happened because hydrocolloids based on carbohydrates, like carboxymethylcellulose (CMC), can hold more moisture in the food matrix. With the help of CMC, starch particles may be able to keep their natural barrier properties by forming films at temperatures above their initial gelatinization temperature. The amount of oil or fat absorbed into the baked products is reduced by physically preventing oil migration into the crust using gum or cellulose derivatives in the formulation [35].

3.4. Texture analysis of biscuits

Evaluation of texture is a crucial stage in developing new food products and is thought to be essential for the palatability acceptance of foods by the consumer. Although there are other textural qualities, consumers prioritize hardness because it affects how they perceive products and their quality. The variations of hydrocolloids and their amounts affect the texture of the biscuits, as shown in Fig. 3. The hardness was 37.75 N for WB-100 and 21.61 N for FMB-100. The CFMBs were significantly ($p < 0.05$) harder than FMB-100. The hardness of CFMBs was significantly impacted by the addition of CMC, as shown in Fig. 3. The hardness values were 26.76, 32.73, and 35.09 N for CFMB-0.01, CFMB-0.05, and CFMB-0.1, respectively. The increased hardness of CFMBs compared to FMB-100 may be explained by decreased water loss and low-fat content after baking. A lesser amount of fat allows flour and fiber for greater accessibility to water since a smaller amount of fat plays a significant lubricant role by coating the matrix, which could be related to a decrease in both water loss and low-fat content compared to FM-100, which is supported by the literature. The dough becomes harder when the

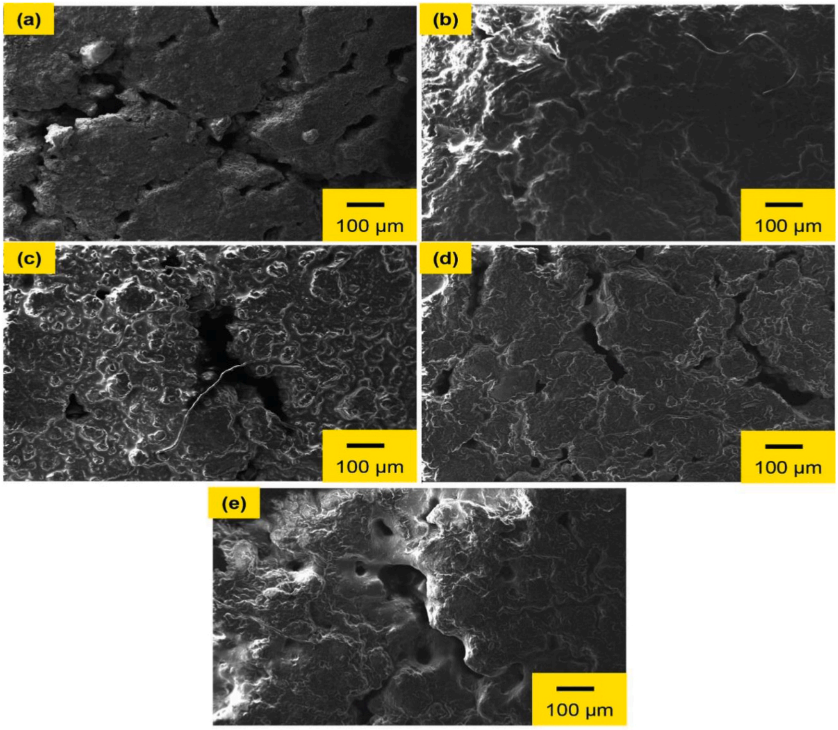


Fig. 5. Scanning electron micrographs of biscuits: (a) WB-100, (b) FMB-100, (c) CFMB-0.01, (d) CFMB-0.05, and (e) CFMB-0.1. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

hydration level rises, resulting in harder biscuits [43].

According to Goswami et al. [44] using carbohydrate-based hydrocolloids helps to reduce fat that could be made CFMB take up extra water to build a robust gluten-like network between the starch particles, thus raising the biscuit's hardness value. The results were the same as those of other studies examining how fat substitutes affect the hardness of baked goods. For example, Zambrano et al. [45] found that adding guar gum and xanthan can make baked goods harder. Additionally, the structure and composition of the baking flours affect the biscuit sample's hardness. Compared to prior studies on millet, buckwheat, and other gluten-free products with wheat flour, the relatively high hardness of CMC-incorporated FM biscuits was obtained without including wheat flour [31,40].

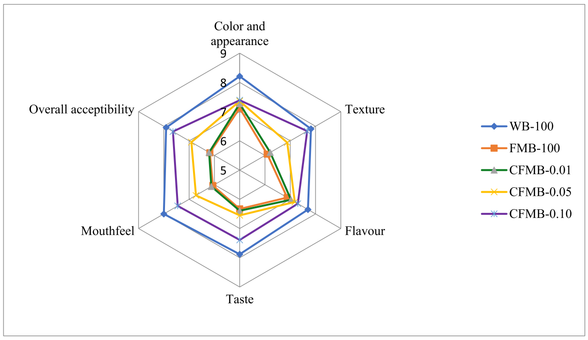
3.5. *Colorimetric measurements of biscuits*

When the dough is baked into biscuits, the lightness (L), redness (a), and yellowness (b) characteristics deviate to varying degrees from their respective doughs. In general, color offers a valuable assessment for identifying processing changes and their potential customer acceptability. Also, colorimetric analysis is a baked product's most crucial quality characteristic.

Fig. 4 shows the color quality of CFMBs with the concentration of CMC. The chromatic appearance of prepared biscuits ranged from 47.01 to 57.02, 3.918 to 5.735, and 13.48 to 20.39 of L, a*, and b* values, respectively. The varying percentages of CMC can significantly ($p < 0.05$) change the color value (L, a*, b*) of CFMBs. Compared to FMB-100 and CFMBs, WB-100 had the highest L value, and a* and b* had the lowest values. These could be attributed to the comparatively high protein content and phenolic compounds of FM, which may have contributed to decreasing the lightness values of the FMB-100 and CFMBs than WB-100, due to the Millard reaction with sugar, with a consequent increase in melanoidin formation, resulting in darkening. Furthermore, the oxidation of the high phenolic content of FMF and the subsequent generation of dark pigments may have interfered [8]. Different amounts of CMC may be impacted the color quality of the CFMBs substantially via the hydrocolloids thin coating of microparticles of FMF as well as the presence of high phenolic compound content in FMF [46].

3.6. *Scanning electron microscopy of biscuits*

Variations in the microstructure's porosity impact the product's quality, volume, stiffness, and texture profile [47]. The varying microstructure of the biscuits closely relates to water migration and activity, the amount of fat, and the gelatinization of starch granules. Water movement during the baking process leads to ruptured cells with significant porosity. The microstructure of prepared biscuits WB-100, FMB-100, and CFMBs is shown in Fig. 5(a–e) using a scanning electron microscope (SEM). The surface structure of



Values are means of eleven panelists'± standard deviations

Fig. 6. Sensory evaluations of biscuits. WB-100: 100% wheat flour (WF) instead of FMF with all ingredients except CMC; FMB-100: 100% FMF without CMC with all ingredients except CMC; CFMB-0.01, CFMB-0.05, and CFMB-0.1: 100% Foxtail millet flour with 0.01%, 0.05% and 0.1% of CMC, respectively.

WB-100 consists of a less condensed, disoriented, and ruptured granular microstructure, as shown in the micrographs (Fig. 5(a)). The micrograph of a WB-100 also demonstrates the burst cells brought on by rapid water migration during the baking process, increasing the dough's porosity. This occurs due to the quick evaporation of water, which minimizes the amount of water necessary for the gelatinization process. However, gluten-free flour-based products have the major issue of high porosity and low structural strength levels, affecting acceptable quality. Compared to the WB-100, the microstructures of CFMBs products were characterized by regions with fewer void spaces and a densely packed arrangement of starch granules that were partially covered with a homogeneous matrix, including fat, implying that the starch particles were protected from hydration. This indicates that melting the CMC matrix, including fat, during baking generates a smooth surface over starch granules. The results of the CFMB's water activity, fat content, and moisture content agreed with those of the SEM.

In addition, the increase in the hardness of CFMBs compared to FMB-100 can be mainly explained by film-like screens, as shown in the SEM of CFMBs, which are thought to have been generated by CMC hydrocolloids. Dehydration of these films during baking results in the formation of a hard crust on the outside of the biscuit, which can increase their resistance against breakdown. The inner matrix can be more strongly linked in the presence of hydrocolloids based on carbohydrates, which leads to less uniform cavitation. Bonet et al. [48], found that soy donuts made with HPMC were less porous and had a denser structure inside. However, the continuous microstructure of the FMB-100 surface suggested a constant network with embedded nongelatinized starch.

3.7. Sensory evaluation

The prepared biscuits were evaluated for their color and appearance, taste, flavor, texture, and overall acceptability using a 9-point hedonic scale (Fig. 6). The control sample (WB-100) had the best sensory features, and the quality of CFMB-0.10 was comparable to that of WB-100. The color and appearance of the goods create the initial impression in the mind of the customer. Color and appearance mean scores for WB-100, FMB-100, and CFMBs varied from 8.21 to 7.12. The control biscuit (WB-100) scored the highest; the lowest score was found in FMB-100. The texture is another important aspect of a biscuit that lets you know how soft or hard it is. The mean scores for WB-100, FMB-100, CFMB-0.01, CFMB-0.05, and CFMB-0.10 were 7.82, 6.09, 6.21, 6.88, and 7.67, respectively. In the study, the texture of CFMBs got better as the amount of CMC increased. The market success and popularity of a biscuit depend on how it tastes and is flavored. The WB-100, FMB-100, and CFMBs all had mean scores for flavor and taste that ranged from 7.70 to 6.88 and 7.88 to 6.33, respectively. CFMB-0.10 had a flavor and taste that were comparable to WB-100. The mouthfeel and overall acceptability of WB-100, FMB-100, and CFMBs were 8.0 to 6.06 and 7.91 to 6.18, respectively. Additionally, the sensory characteristics support the texture profile and micrograph of FMB and its attributes that consumers felt a crumbly and sandy mouthfeel which results unpleasant to the consumer. Mouthfeel and taste are directly dependent on the flours employed, their composition, granulometry, and their interaction with other ingredients [49]. When CMC was added to a certain level the mouthfeel of CMFB improved due to the enhanced texture and interaction between FMF. Therefore, biscuits manufactured with 0.10% CMC show acceptance among consumers.

4. Conclusion

The incorporation of CMC into FMF considerably facilitates the development and quality enhancement of biscuits made from nutrient-dense foxtail millet. Biscuits with good nutritional and acceptable sensory characteristics were made by adding up to 0.1% CMC hydrocolloid to foxtail millet flour. These biscuits are considerably better than those available commercially due to the lower fat level. Due to the nutritional value of foxtail millets and other phytochemical components, these biscuits are suitable for people who have celiac disease and gluten intolerance, and they may also be an excellent option for many others who suffer from lifestyle disorders.

Author contribution statement

Akter Hossain Reaz, Md. Jaynal Abedin, Abu Tareq Mohammad Abdullah, Tasnim Farzana: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Mohammed Abdus Satter: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The study was conducted in the Research and Development (R&D) work under the Bangladesh Council of Scientific and Industrial Research (BCSIR), Ministry of Science and Technology, Bangladesh.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17176.

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