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Research Article

Physicochemical, Rheological, and Sensory Properties of Gluten-Free Cookie Produced by Flour of Chestnut, Date Seed, and Modified Starch

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A gluten-free rice flour-based cookie was produced using different mixtures of chestnut flour (0, 30, 40, and 50%), date seed flour (0, 10, and 20%), and modified starch (0.3, 0.5, 0.6, and 0.9%). Physicochemical, rheological, and sensory properties of the prepared treatments were investigated. The results showed that moisture, specific volume, and dough viscosity were the lowest in control and the highest in treatment T1 containing 20% date seed flour, 30% chestnut flour, and 0.9% modified starch ($P < 0.05$). The highest (22.15 N) and the lowest hardness (13.5 N) were obtained in the control and T1, respectively, both of which increased over the storage time ($P < 0.05$). Regarding the texture characteristics of different dough treatments, the control illustrated the lowest adhesiveness and the highest hardness and chewiness. Sensory evaluation revealed that gluten-free treatments were acceptable from the consumers' point of view. It was concluded that T1 as a gluten-free cookie had the highest quality.

1. Introduction

Coeliac or celiac disease (CD) is among the most common chronic diseases worldwide that emerge in individuals genetically susceptible to gluten resulting in enteritis and nutrient malabsorption. Consumption of prolamines found in cereals like wheat, barley, rye, some oat cultivars, and their derivatives has been reported as the leading cause of this disease [1]. Adherence to a gluten-free (GF) diet is proposed for CD treatment. According to Codex Alimentarius, "GF" label can be applied only for foods made of GF ingredients containing less than 20 ppm gluten [2].

Producing GF food products, especially those with acceptable functional and sensory properties, is a great challenge since gluten is responsible for the structure of these products, and the limited availability of GF products indicates this difficulty [3–5]. To prevail this issue, utilization of various GF flours (rice, maize, and sorghum), pseudocereals (quinoa, amaranth, and buckwheat), legumes (soybean, chickpea, and carob germ flour), starches (corn, potato, cassava, and modified starch (MS)), hydrocolloids, and proteins have been investigated to modify GF products' technological, sensory, and nutritional features [6, 7].

Cookies are extensively consumed throughout the world and are a good energy source for all age groups. They are available in different shapes and flavors with long shelf life and low cost. Moreover, they can be produced through GF formulations with excellent quality and sensory properties. There is no need for gluten network development, and the influential primary factor on the texture is the gelatinization of starch [8]. A large number of ingredients such as alfalfa seed [9], quinoa [10], and germinated pinto bean [11] flour as well as locust bean gum [12], xanthan gum [13], waxy rice starch [14], and pea protein [15] have so far been used as an alternative for wheat flour in the cookie recipe.

Rice flour is one of the most suitable cereals for developing gluten-free products due to its mild taste, colorlessness, hypoallergenic properties, low levels of sodium, and easily digestible carbohydrates [16]. However, one of the significant problems associated with GF bakery products is low nutritional quality as a result of the lower content of vitamins (folate and B_{12}), minerals (iron, zinc, magnesium, and calcium), and dietary fibers [17] that can be addressed by adding suitable ingredients in the formulation such as chestnut flour and date seed flour.

Chestnut is composed of water, carbohydrate, and a low quantity of fat. Chestnut flour (CF) is used for producing GF foods such as GF bread and biscuit [18–26]. Its composition is near to cereal flours regarding the amount of starch (40–50% w/w); however, its sucrose content is higher (20–32%) [27]. Besides, it is a good source of essential amino acids, dietary fibers, vitamin E, vitamin B group, potassium, phosphorous, and magnesium and contains low-fat content mainly composed of unsaturated ones and phenolic compounds and vitamins [28].

Modified starch (MS) could be used as a substitute for wheat starch as it influences water absorption and rheological properties of the dough, degree of starch gelatinization, texture, and bread staling [29–31]. Reports show that modified starch is used in GF bakery products like high amylose corn starch, acetylated distarch adipate, and hydroxypropyl distarch phosphate in GF bread [32]; pregelatinized tapioca starch in rice bread [33]; and maltodextrin [34]. In the heat-moisture treatment of starch, the granular shape is maintained at heating above 100°C in the presence of water. Heat-moisture treatment starch increases the stability to mechanical agitation, increases the hydrophobicity, and decreases the hydrophilicity of starch paste [35].

Date palm (*Phoenix dactylifera* L.) mainly grows in the Middle East and North Africa. The date is a nutritious and high-energy food. Date seeds contain significant dietary fiber and micronutrients such as selenium, iron, calcium, phenolic compounds, mainly flavonoids, sterols, tocopherols, metal ions, and essential amino acids. Date seed is considered a good source of bioactive ingredients in the formulation of functional foods. Date seed flour (DSF) has been used as an alternative for wheat flour in pita bread preparation because it increases the formulated product's phenolic compounds and dietary fiber [36].

The literature review shows no investigation of the influence of different CF, DSF, and MS combinations on the GF cookies. The reason could be that the date mainly grows in the Middle Eastern countries, including Iran. Hence, the present research attempts to develop a GF rice flour (RF)-based cookie using different CF, DSF, and MS levels and determine their effect on the cookie.

2. Materials and Methods

2.1. Materials. Rice, *Fajr* cultivar, purchased from a market in Rasht city, Iran, was soaked in water, ground, and then passed through an 80-mesh sieve. The obtained flour was heated in an oven at 45°C to reach the moisture content of 10%. Sugar, shortening, eggs, vanilla powder, and baking powder were obtained from the local supermarkets in the same city.

In order to prepare CF, European chestnut (*Castanea sativa*) fruits were purchased from a local market. Then, they were added to boiling water to facilitate peeling and reducing bitterness. After drying and peeling the fruits, they were ground, and the fine flour with 180–200 μm was obtained after sieving. In order to prepare DSF, seed powder of date, *Shahani* cultivars, was purchased from Minoo Co. (Shiraz, Iran). Then, it was ground, and the fine flour with 300–500 um was obtained after sieving. The heat-moisture method was applied to modify wheat starch [37].

2.2. Cookie Preparation. The ingredients used for the preparation and treatment of cookies are presented in Table 1. Initially, shortening and sugar were mixed for 3 min. Then, we added water, eggs, and MS and mixed them all for 5 min. Next, RF and other powdered ingredients were added and mixed to achieve a dough flattened into sheets of 0.6 cm thickness. Next, it was allowed to rest for 30 min at 4°C. Afterward, it was cut using a circular mold (4.5 cm diameter) and baked at 180°C for 14 min. Then, all cookies were cooled down and maintained in distinct sealed bags at room temperature. For each formulation, three batch replicates were produced. GF cookies were prepared based on the control method by adding CF and DSF.

2.3. Physicochemical Analysis. Moisture (Method 44–19) was measured using the AACC method. The specific volume of treatments was calculated by the method of rapeseed displacement 2 h after baking [38] as follows:

$$\text{specific volume}\left(\mathrm{cm}^3/g\right) = \frac{\text{volume displacement by each treatment}}{\text{weight of each treatment}}. \tag{1}$$

Table 1: Quantities of variable ingredients (g) used in the formulation of cookies doughs.

Treatments[A]	Rice flour	CF	DSF	MS
Control[B]	100	0	0	0.5
T1	50	30	20	0.9
T2	50	40	10	0.9
T3	50	50	0	0.9
T4	50	30	20	0.6
T5	50	40	10	0.6
T6	50	50	0	0.6
T7	50	30	20	0.3
T8	50	40	10	0.3
T9	50	50	0	0.3

[A]The other ingredients (g) in all treatments: sugar: 45, shortening: 30, water: 20, egg: 8, baking powder: 0.9, $NaHCO_3$: 0.75. [B]Control (cookie without CF and DSF).

Color analysis was performed using HunterLab ColorFlex EZ (USA) in three different zones of the crust, and the output was reported as three measurements' average using the values of CIE $L*$, $a*$, and $b*$. $L*$ is indicative of lightness varying from 0 (black) to 100 (perfect white), whereas $a*$ and $b*$, respectively, illustrate +redness/−greenness and +yellowness/−blueness [39].

2.4. Dough Viscosity Measurement. Apparent viscosity (mPa·s) of different dough treatments was measured using Brookfield viscometer (Model DVII, USA). Spindle No. 7 was set to 10 rpm. We used spindle No. 7 for all experiments, and viscosity measurement was conducted at room temperature (25 ± 1 °C).

2.5. Textural Analysis. Textural analysis of different treatments was determined for hardness, adhesiveness, and chewiness using a TA. XTplus texture analyzer (Stable Micro Systems, UK) [40]. Hardness was determined on the 1st and 4th days after baking. Texture properties were determined 6 times for each treatment. The peak force to snap the treatments was reported as fracture force in "N."

2.6. Sensory Evaluation. Sensory analysis of fresh treatments was done on a baking day by 10 male and 10 female trained assessors comprising technicians and laboratory members of the cookie producer company with ages ranging from 30 to 45 years in separate booths. Three-digit random codes were assigned to the treatments and were assessed for flavor, firmness, chewing ability, and overall acceptability based on a 5-score hedonic scale (like extremely = 5 and dislike significantly = 1). Bottled water at room temperature was also provided to clean the palate between the treatments [41].

2.7. Statistical Analysis. All statistical analyses were performed by the SPSS software (ver. 22) (IBM Corporation, Somers, NY). Data were presented as M ±SD and analyzed by the ANOVA. Duncan's multiple range test was used to determine significance between means. Differences at $p < 0.05$ were considered to be significant.

3. Results and Discussion

3.1. Physicochemical Characteristics. Moisture content substantially influences the cookies' mechanical strength (crumbliness) and crunchiness. As shown in Figure 1, the control has the lowest moisture content (35.5%) compared to other treatments ($p < 0.05$). Furthermore, T1 showed the highest moisture content (51%) among all treatments ($p < 0.05$). This can be attributed to the high protein and fiber content in DSF and CF and the presence of hydroxyl groups that enhanced the capability of interaction with water molecules and thus increased moisture content. The high MS (0.9%) level also contributed to maintaining the moisture within these treatments.

Reference [42] found an increase in the moisture amount of bread containing guar gum because of hydrocolloids' high water holding capacity. According to [43], CF exhibited higher water holding capacity than other GF flours for its higher fiber content. Moreover, it has been declared that CF contained a high level of damaged starch, which increased water absorption [44].

Bakery product volume is a crucial factor influencing consumer acceptability. Many GF products are formulated with RF; however, the lack of gluten in RF decreases CO_2 retention [45]. The influence of RF replacement by CF, DSF, and MS on a specific volume of treatments is demonstrated in Figure 2. The control and T1 showed the lowest (2.85 cm^3/g) and the highest (4.6 cm^3/g) values, respectively, compared to the other treatments ($p < 0.05$). Reference [46] mixed potato starch and CF to prepare GF cake. They reported that a specific volume of treatments decreased by increasing CF in the formulation. Likewise, as [47] mentioned, increasing the level of okara flour substitution in GF cookies decreased the specific volume because fibers interfered in the structure and gas retention, hindering the dough. It has also been expressed that increasing the protein content led to an increase in cake volume due to an increase in batters' viscoelasticity and the time the batters need to become semisolid. This can be attributed to protein-starch transition and interaction [48].

Protein and sugar interaction during baking ends with Maillard reaction and change of color values. Thus, a baked product's color, texture, and taste are important in consumers' acceptability. Figure 3 presents the $L*$, $a*$, and $b*$ values of prepared treatments with different flours. As shown, the control is brighter than other treatments, as indicated by higher L^* values, and T1 has the lowest value. Concerning $a*$, T7 possesses the highest $a*$ value compared to other treatments ($p < 0.05$), except T3 and T9, whereas T5 showed the lowest a^*. As shown in Figure 3, the highest b^* value is observed in T5 compared to other treatments ($p < 0.05$), and the lowest value belongs to T1. In terms of the recorded difference in total color (ΔE), the lowest and the highest values were T1 (47.48) and T5 (66.18), respectively ($p < 0.05$). It can be elucidated that incorporating different flours as gluten replacers reduced L^* value and elevated a^* value. A similar trend was observed by incorporating okara into the GF cookie, where a reddish color and an increased yellowness were achieved. In addition, a

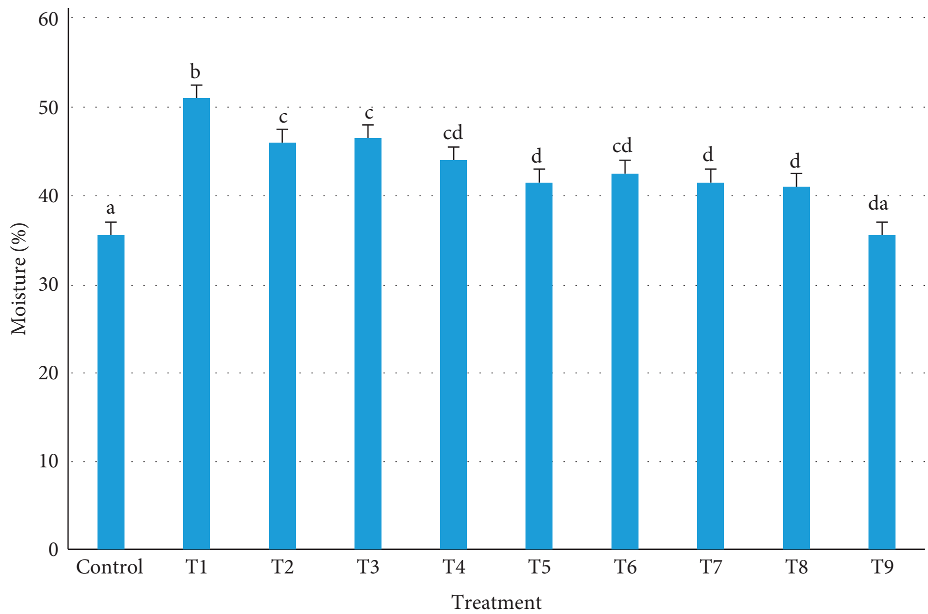

Figure 1: Moisture content of cookies prepared with varying levels of CF, DSF, and MS. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

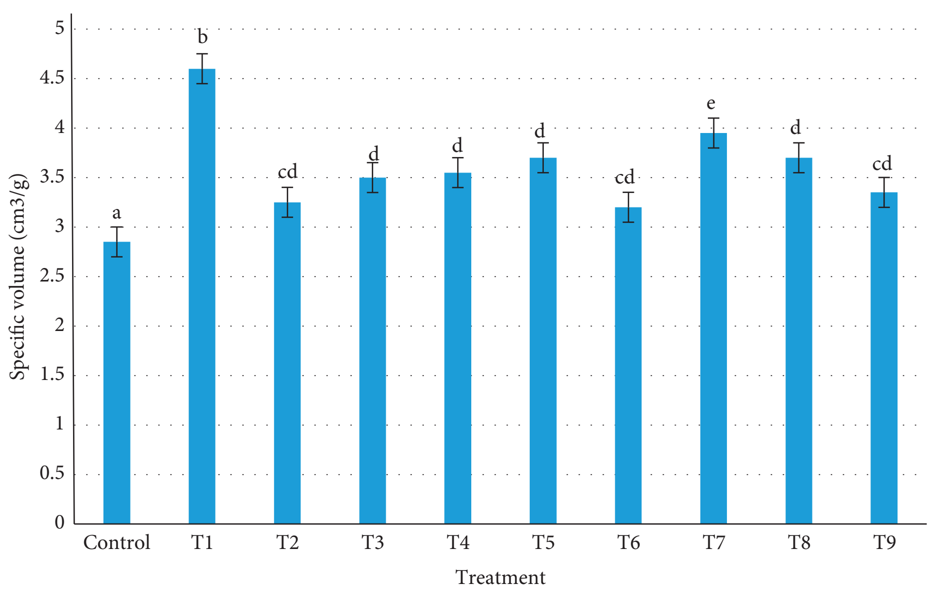

Figure 2: Specific volume of cookies prepared with varying levels of CF, DSF, and MS. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

negative relation was found between the lightness of the cookie and protein content due to an increase in Maillard reaction [47].

Reference [18] stated that supplementation with CF in GF biscuits significantly lowered $L*$ and elevated $a*$ and $b*$. Similarly, [14] reported that addition of alfalfa seed flour to GF rice cookies decreased $L*$ and increased $a*$ and $b*$. The changes in color indices were attributed to the native pigmentation of flour and the Maillard reaction during baking. Reference [26] found that cookies containing CF indicated lower L^* and higher values of $a*$ and $b*$ than the control justified by naturally darker color and higher sugar content of CF, leading to more browning during baking. This darker color was considered desirable since most GF products possess lighter colors than products with gluten. Moreover, consumer demand is higher for these dark-colored GF products [23]. In addition, [49] reported increased values of a^* and $b*$ and decreased value of $L*$ by increasing the level of CF incorporated into cookies.

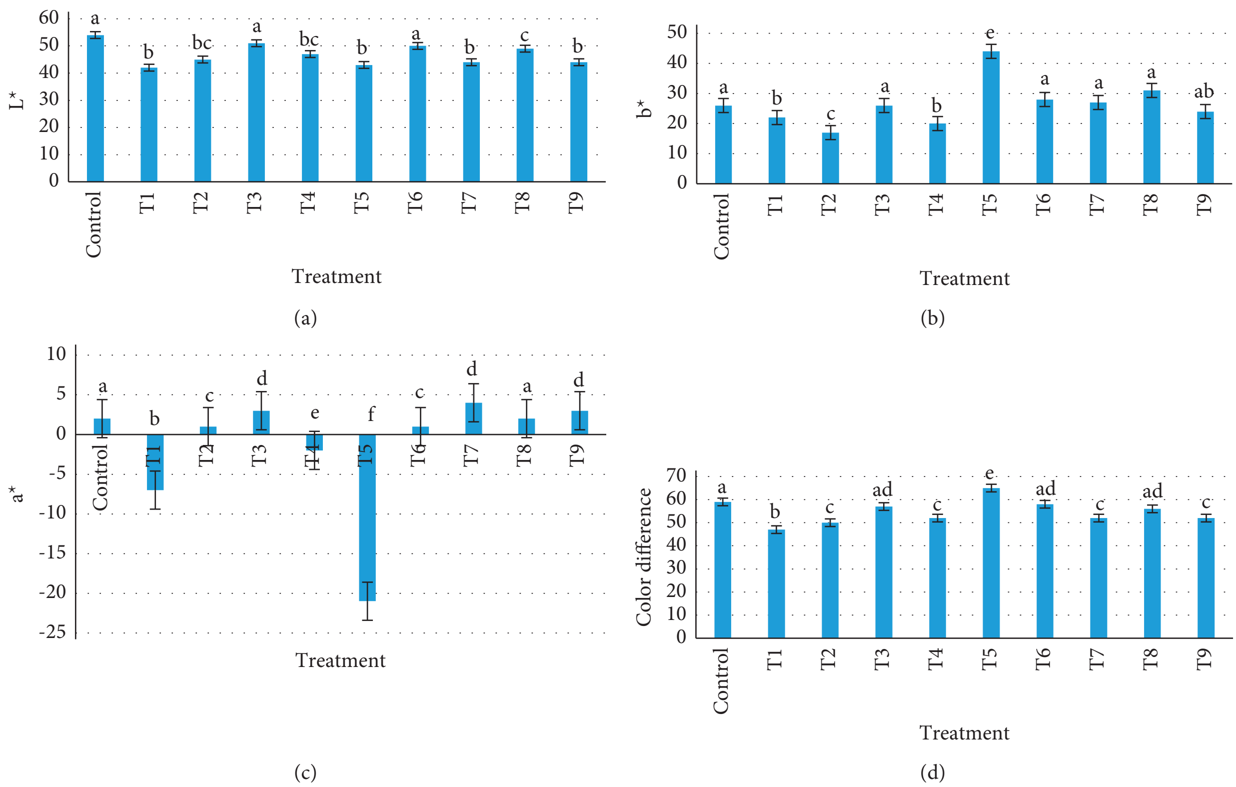

Figure 3: Color parameters of cookies prepared with varying levels of CF, DSF, and MS. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

3.2. Apparent Viscosity of Cookie Dough. As shown in Figure 4, the lowest and the highest viscosity were obtained in control (442 cP) and T1 (2425 cP), respectively, compared to the other treatments ($p < 0.05$). This can be ascribed to the high hydroxyl groups in DSF and maintaining the water. Moreover, the fibrous structure of CF is the other reason influencing viscosity. Fiber entanglement also helps resist flow and increases the viscosity [23]. Reference [50] showed the viscosity increase of GF cake batters by increasing the quinoa flour content. The authors declared that the increase of viscosity was associated with the amount of water available in the system, which was influenced by the level of proteins in the flour. Since quinoa flour absorbed water, there was less free water for promoting particle movement in batters, leading to increased viscosity. The effect of flour's protein content on viscosity has been proved by some other researchers [48].

3.3. Texture Characteristics. Figure 5 indicates the effect of different flours on the hardness of treatments. As shown, by increasing the storage time, the hardness increases significantly. This increase is defined as the staling process for water departure from crumb to crust and starch recrystallization, which changes the bread texture [51]. On the first day of storage, the control showed the highest hardness (22.15 N), and T1 indicated the lowest hardness (13.5 N) ($p < 0.05$). Four days after storage, the highest (22.39 N) and lowest (13.87 N) hardness were observed in the control and T1, respectively ($p < 0.05$). In line with our results, [26] illustrated that cookies prepared from RF demonstrated the highest hardness value due to the absence of enough viscosity to inhibit air bubble loss during baking. It was further mentioned that RF replacement with CF up to 40% decreased the hardness of cookies considerably [26]. According to [24], increasing the level of chestnut flour and xanthan-guar gum blend decreased the bread staling considerably by reducing the amylopectin retrogradation, bread hardness, and moisture loss. Similarly, [52] reported a decrease in cookie hardness by increasing the amount of chiku fiber added to cookie formulation.

Reference [53] pointed out that the mixture of CF and brown rice (60 : 40%) decreased GF snacks' hardness significantly. It was emphasized that the high sugar content of CF probably delayed starch gelatinization through interacting with starch linkages and reducing water activity that resulted in stabilization of the amorphous regions of starch granules and texture changes during frying. Reference [54] stated that the desirable texture of dry food products such as cookies could be destroyed during storage, possibly due to the recrystallization of sucrose in cookies with high sugar and low moisture that was confirmed by [55].

Results of the texture characteristics of dough treatments are demonstrated in Figure 6. The lowest hardness and chewiness were recorded in T1, while the highest values were observed in the control dough ($p < 0.05$). In the case of adhesiveness, T8 showed the highest value, while T6 and control exhibited the lowest values ($p < 0.05$). Reference [56]

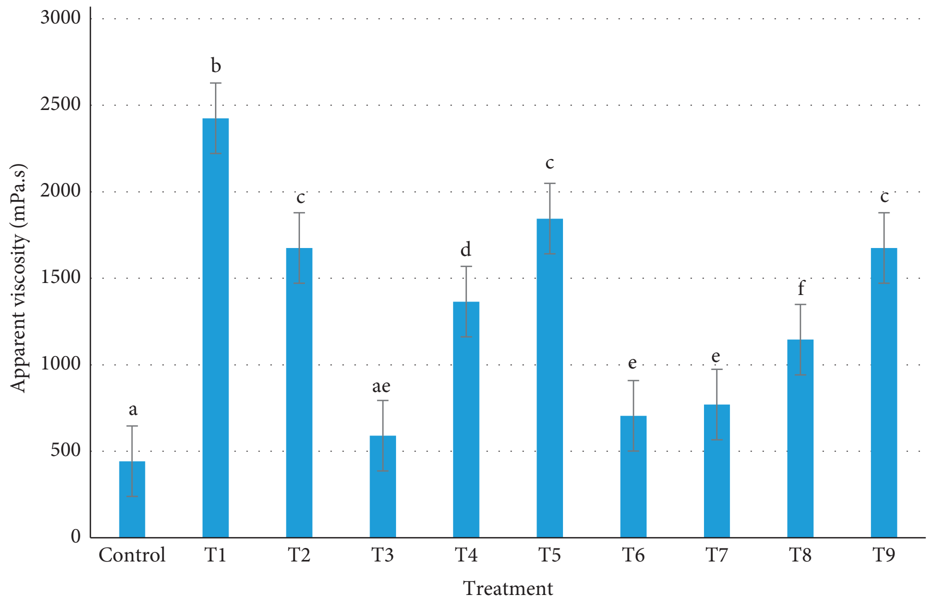

Figure 4: Apparent viscosity of cookies prepared with varying levels of CF, DSF, and MS. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

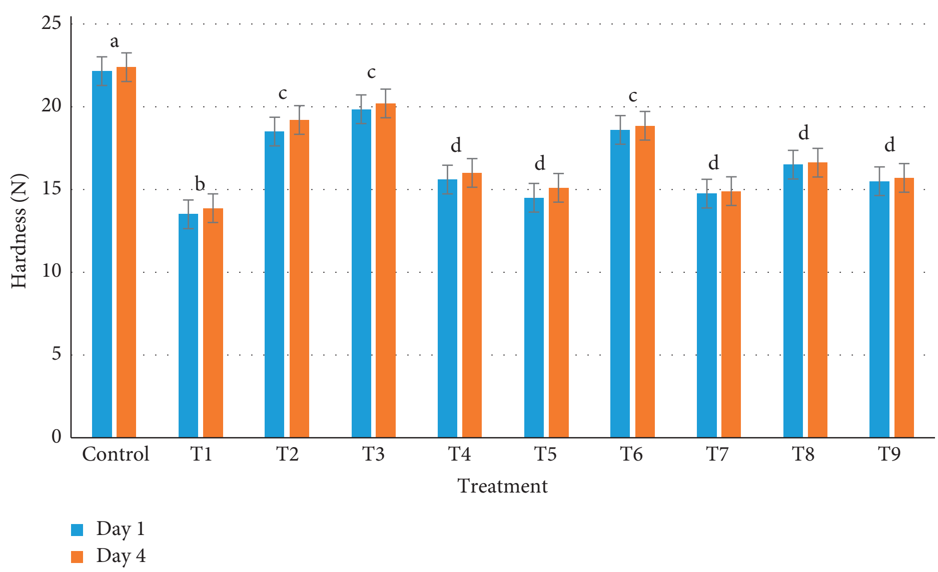

Figure 5: Hardness of cookies prepared with varying levels of CF, DSF, and MS during storage. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

observed a change in GF cookies' textural properties by incorporating king palm flour. It has been noted that by adding king palm flour, the adhesiveness of dough treatments decreased compared to the control due to the existence of fibers. Incorporating fiber sources in bakery products increased the water binding capacity because of the hydroxyl groups existing in the fiber structure and facilitated hydrogen bonding with water, affecting textural characteristics [57].

3.4. Sensory Properties. Gaining favorable sensory characteristics is a tremendous challenge in developing GF products. GF products exhibit different appearances, colors, texture, aroma, and taste compared to wheat flour products. Generally, GF bakery products exhibit lower sensory acceptability due to the undesirable appearance, darker color, more complex texture, and dry sandy feeling in the mouth [41].

Table 2 indicates the influence of RF replacement with CF, DSF, and MS on GF treatments' sensory characteristics. The results illustrated that incorporating gluten replacers in cookie formulation had little influence ($p < 0.05$) on different treatments' flavor and chewing ability. The lowest scores were recorded in control and T2 concerning firmness, while the highest values were those of T3 and T5. The control and T4 showed the lowest overall acceptability, while T6

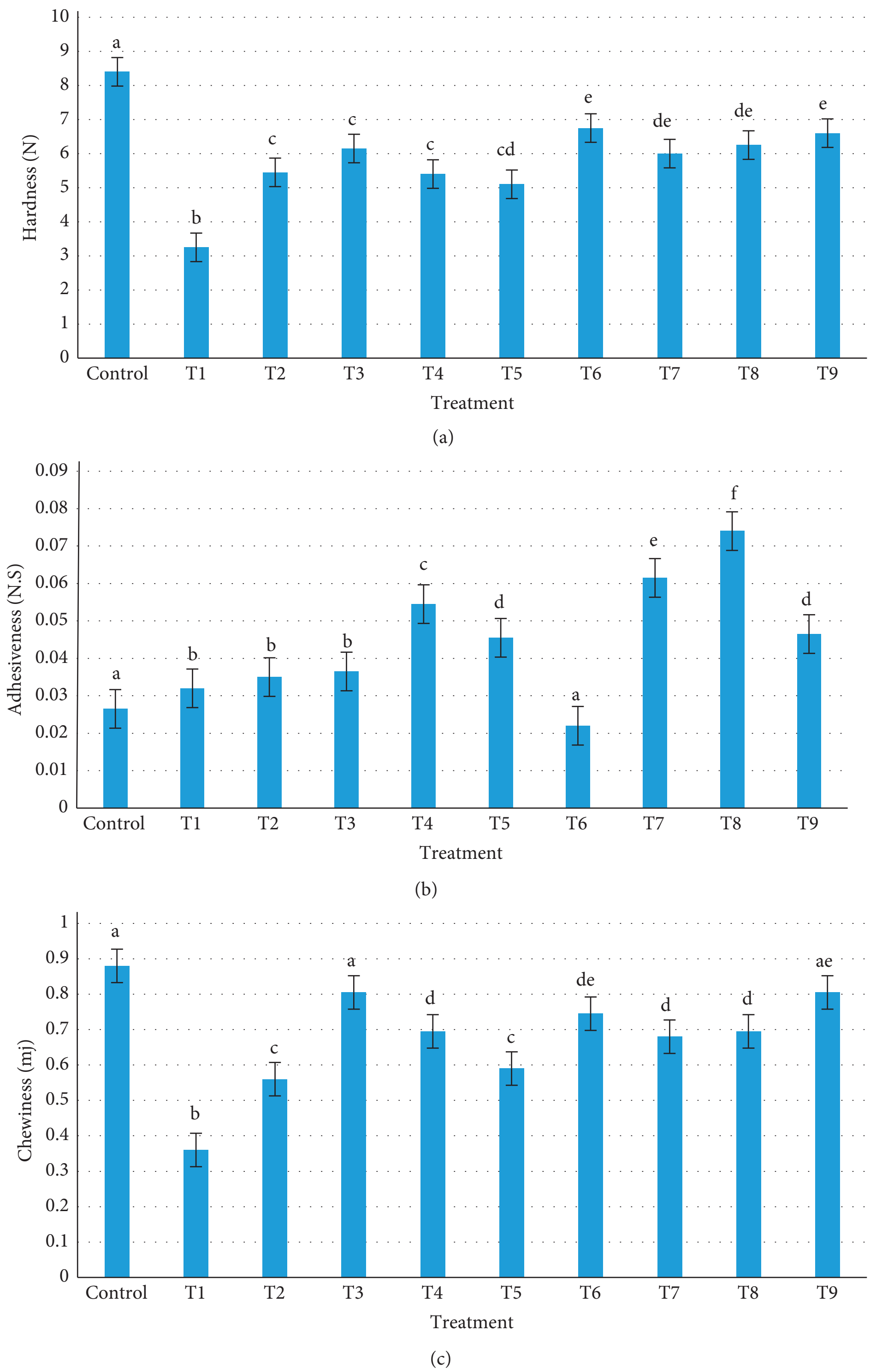

FIGURE 6: Textural characteristics of cookies prepared with varying levels of CF, DSF, and MS. For the treatments' descriptions, see Table 1. The treatments with different lowercase letters are significantly different ($p < 0.05$).

received the highest score ($p < 0.05$). Consistently, [58] expressed that treatments containing 100% RF demonstrated the lowest overall acceptability, but the incorporation of soybean flour improved the sensory characteristics. Besides, cookies containing 85% RF and 15% soybean flour obtained the most significant overall acceptance. In the study [52], the addition of 7% concentrated chiku fiber powder to GF cookie resulted in the highest overall acceptability. Similarly, [41] reported that RF replacement with almond flour ended with higher overall acceptability scores by panelists.

Table 2: Sensory characterization of GF cookies formulated with varying levels of CF, DSF, and MS.

Treatments[A]	Flavor	Firmness	Chewing ability	Overall acceptability
Control	3.5 ± 0.83^{a}	2.83 ± 1.16^{a}	3.16 ± 0.75^{a}	3.0 ± 0.63^{a}
T1	4.0 ± 1.4^{a}	3.8 ± 0.44^{b}	3.8 ± 0.8^{a}	4.0 ± 0.7^{b}
T2	3.6 ± 1.1^{a}	2.6 ± 0.54^{a}	3.4 ± 0.54^{a}	3.4 ± 0.89^{b}
T3	3.75 ± 0.5^{a}	4.25 ± 0.5^{c}	3.25 ± 0.5^{a}	3.75 ± 0.5^{b}
T4	3.0 ± 0.7^{a}	4.0 ± 0.7^{ab}	3.6 ± 0.89^{a}	3.0 ± 0.11^{a}
T5	3.6 ± 1.1^{a}	4.2 ± 0.44^{c}	3.2 ± 0.83^{a}	3.8 ± 1.0^{b}
T6	3.6 ± 1.1^{a}	3.4 ± 0.89^{b}	3.6 ± 1.1^{a}	4.2 ± 0.83^{b}
T7	3.83 ± 0.75^{a}	3.5 ± 1.0^{b}	3.83 ± 0.75^{a}	3.83 ± 0.4^{b}
T8	3.25 ± 0.95^{a}	3.25 ± 1.5^{b}	3.5 ± 1.29^{a}	3.5 ± 1.0^{b}
T9	4.0 ± 1.1^{a}	3.8 ± 1.3^{b}	3.4 ± 1.1^{a}	3.4 ± 0.54^{b}

[A]For the treatments' descriptions, see Table 1. Means followed by different lowercase letters within a column are significantly different ($p < 0.05$). A higher value indicates higher overall acceptability.

4. Conclusions

In the present study, GF cookies were prepared from CF, DSF, and MS as gluten replacers. The physicochemical analysis results revealed that incorporating the ingredients, as mentioned earlier, increased the treatments' specific volume and moisture content compared to the control. Regarding color analysis, a decrease of lightness and increase of redness and yellowness were observed in cookies due to the natural pigmentation of the ingredients and the occurrence of Maillard reaction during baking. Moreover, supplementation of these ingredients improved the texture and sensory characteristics of the cookies. Overall, it can be concluded that a GF cookie with acceptable qualitative properties can be prepared using 20% DSF, 30% CF, and 0.9% MS.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Mehrdad Mohammadi participated in conceptualization, supervision, data curation, formal analysis, investigation, methodology, original draft preparation, and manuscript review and editing. Nasim Khorshidian contributed to conceptualization, data curation, resources, software, original draft preparation, and manuscript review and editing. Mojtaba Yousefi worked on investigation, software, validation, and visualization. Amin Mousavi Khaneghah was involved in supervision, validation, original draft preparation, and manuscript review and editing. All authors contributed equally to this work.

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