Research Article

Development of rice-based gluten-free muffins enriched with tigernut dietary fiber

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Abstract The effects of tigernut dietary fiber (TDF: 5, 10, and 20% w/w) inclusion in rice muffin formulations on the functional and pasting properties of composite powders, as well as the nutritional and sensory properties of muffins were investigated. The results showed a significant ($p < 0.05$) proportional increase in the water and oil holding capacity as TDF increased in the powder blends. Moreover, pasting viscosity was found to decrease with the inclusion of TDF. TDF muffins showed improved nutritional quality, with increased protein (~14%), insoluble fiber (~128%) and total fiber (~34%) contents compared to 100% rice muffins. Also, TDF-muffins had lower baking losses (~22%) and better texture, including firmness and chewiness. Sensory scores of TDF-muffins (up to 10% w/w) showed similar consumer acceptability for all parameters considered. Overall, this study suggests tigernut fiber as a functional additive that balances the growing consumers' demands for healthy and quality gluten-free rice muffins.

Keywords tigernut, dietary fiber, rice flour, gluten-free, muffin

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1. Introduction

The gluten in wheat flour is a type of insoluble protein composed of glutenin and gliadin, which helps dough rise and gives it a chewy texture. However, several reports have linked gluten to allergic reactions, gut inflammation and contribute to a variety of diseases, including atopy, asthma, and hair loss in some people (Ostermann-Porcel et al., 2020). Because of this, there has been a growing market for gluten-free foods made by replacing flour (Baixauli et al., 2008; Gularte et al., 2012), the most common ingredient in baked goods, with other ingredients. Due to its lack of color, low prolamin level, and hypoallergenicity, rice is a great component for the production of gluten-free products. However, rice flour alone has a number of limitations, including low dietary fiber content and poor texture and mouthfeel, which has led to a growing interest in baking ingredients that can compensate (Sae-Eaw et al., 2007; Segura and Rosell, 2011). Researchers have added ingredients such as black carrot, xanthan gum, shiitake mushroom, and

carrot to improve the nutritional content of muffins (Olawuyi and Lee, 2019; Singh et al., 2015). Tigernut (*Cyperus esculentus*) is a perennial herbaceous plant belonging to the Asteraceae family and is believed to be native to the Mediterranean coast or Africa (Adejuyitan et al., 2009). The composition of tigernuts is dominated by starch at about 60%, followed by fat at about 15 to 20 percent. It contains about 6.1% protein and 13.3% crude fiber and has a strong nutty taste (Adel et al., 2015). Also known as chufa, and yellow nutsedge, tigernuts have traditionally been used for both edible and medicinal purposes and are considered a superfood (Ocana et al., 2016). Typically, tigernut is prominently consumed for its nutritious milk, known as 'Horchata De Chufa' (Djomdi et al., 2020). However, there has been extensive research on the incorporation of tigernut residue after juicing the milk, as a functional ingredient to enhance the physical and sensory attributes of various food products, including bread, biscuits, pasta (Aguilar et al., 2015; Ahmed and Hussein, 2014; Albors et al., 2016). Also, tigernuts are rich in insoluble fiber, which can improve digestion (Adejuyitan et al., 2009). Due to its ability to absorb water, insoluble fiber is known to be good for preventing constipation by increasing stool volume and stimulating the intestines (Brigagão et al., 2021). It has also been shown to reduce postprandial blood sugar, insulin and blood cholesterol (Pathania and Kaur, 2022). In this study, to make gluten-free muffins, we replaced the wheat flour with rice flour and added tigernut insoluble dietary fiber (TDF) to compensate for the nutritional limitations of rice flour. Muffins were prepared with different TDF contents (0, 5, 10, and 20%) to find the optimal TDF content with good nutritional, textural, and sensory properties.

2. Materials and methods

2.1. Materials

Rice flour (Tureban, Goyang, Korea) and tigernut (Food synergy, Uijeongbu, Korea) were purchased from market. Other ingredients, eggs, sugar, margarine, baking powder, were purchased from a common market in Daegu, Korea.

2.2. Preparation of insoluble dietary fiber from tigernut pomace

In order to extract tigernut milk, tigernuts were mashed into a slurry, steeped overnight in water (1:20 g/mL), then filtered using a muslin cloth. Residue was washed exhaustively under running water until transparent filtrate was obtained to ensure complete removal of adhered milk. To produce tigernut pomace, the residues from milk extraction were dried and ground into powder (RT-04, Mill Powder Tech., Tainan, Taiwan). Using an ultrasound-assisted technique, the insoluble dietary fiber fraction from tigernuts was extracted from the tigernut pomace (Kaur et al., 2021; Rouhou et al., 2018). Briefly, tigernut pomace was submerged in distilled water (1:25, pH 6), and ultrasound processed for 30 min at 60℃ using a KHC-1SUMP from Kyung il Ultrasonic in Ansan, Korea. The supernatant (water soluble fiber) was removed after chilling, and the remaining material was then treated with 85% ethanol (1:4). After centrifuging the supernatant out, the remaining material was immediately washed with ethanol and water. Throughout this study, the insoluble residue was ground into powder, filtered through a sieve (425 μM), dried in a lab dryer at 50℃ for 18 h, and designated as TDF. TDF (g/g) at concentrations of 5% (5-TDF), 10% (10-TDF), and 20% (20-TDF) was used to replace rice flour.

2.3. Muffin preparation

The muffin preparation was evaluated using a method previously reported by Olawuyi and Lee (2019), with modifications. Briefly, rice flour or flour blends (150 g), salt (1 g), and baking powder (1 g) were mixed and sieved into a dry bowl. Using a mixer, mix sunflower oil (50 g), melted margarine (40 g) and sugar (80 g) for 5 min. In a separate bowl, whisk the eggs (150 g), then slowly add them to the mixer to form a homogeneous cream. Add the flour to the mixer and mix for another 5 min. During the final mixing, preheat the oven and bake the dough at 180℃ for 30 min to make the muffins. Let the baked muffins cool at room temperature for 45 min and then store them at 4℃. According to AACC instructions, the proximate composition of muffins, including ash, protein, and fat was determined (AACC, 2000).

2.4. Determination of functional properties of composite powders

2.4.1. Pasting property

According to the American Association of Cereal Chemists Method, measurements were carried out using a Rapid Visco-Analyser (RVA, Model 3D, Newport Scientific, Ltd., Warriewood NSW, Australia) (Pais et al., 2000). The heating and cooling cycle was set to 13 min, where the sample suspension (10% dw) was held at 50℃ for 1 min, then heated from 50℃ to 95℃ at a rate of 12.16℃/min and held at 95℃. It was cooled from 95℃ to 50℃ at a rate of 11.84℃/min for 2.5 min and held at 50℃ for 2 min. The parameters recorded were peak viscosity, trough viscosity, final viscosity, and pasting temperature.

2.4.2. Water holding capacity and oil acceptance capacity

In a 50 mL tube, 1.0 g of rice flour with 0%, 5%, 10%, and 20% TDF was dispensed, and then 10 mL of water or oil were added in separate tubes and weighed. After reacting for 1 hour in a shaking incubator at room temperature, the water or oil and flour were separated in a centrifuge at 3,134 $\times g$ for 20 min. The supernatant (unadhered oil) was removed and weighed to determine the water holding capacity and oil acceptance capacity (Heywood et al., 2002).

2.5. Measurement of physical and textural properties of muffins

Muffins' physical characteristics, such as baking loss, height, volume, densities, and color, were assessed. The difference between the weight of the dough before baking and the weight of the muffin after baking was used to compute the baking loss (%). Using a vernier caliper, the height of the muffin was calculated from its highest point to its base.

Muffin volumes were measured by the fluid substitution method as described in AACC 10-91 (Pais et al., 2000). The muffins were removed from the oven at room temperature, cooled for 2 h and weighed using a precision balance (Mettler Instruments, Greinfensee, Switzerland). By dividing the weight by the volume and the specific volume by its reciprocal, the density was obtained.

The color measurements of the muffins were performed using a chromameter (CR-300, Minolta, Osaka, Japan) to measure the lightness (L, lightness), redness (a, redness), and yellowness (b, yellowness) values in triplicate, and the standard white plate used here had L, a, and b values of 96.98, 0.53, and 1.72, respectively. The L values were scaled from 100 (white) to 0 (black), the values from +60 (red) to -60 (green), and the b values from +60 (yellow) to -60 (blue).

The texture of the muffins was measured using a rheometer (Compac-100D, Sun Scientific Co., Tokyo,

Japan). The sample size was 1.5 cm in width, length, and height, and the experiments were performed with an entry speed of 1 mm/s, a maximum stress of 10 kg, and an entry depth of 50% of the height. Six replicates were carried out for each sample.

2.6. Determination of insoluble and soluble dietary fiber contents

For this analysis, muffins were first defatted with hexane. The soluble (SDF), insoluble (IDF) fiber contents of the muffins were determined using Dietary Fiber Assay Kit (Megazyme International Ireland Ltd., Wicklow, Ireland) according to AOAC method 985.29 (AACC, 2000).

2.7. In-vitro digestibility assay of muffins

In-vitro starch digestibility of muffin samples was carried out according to previous method Foschia et al. (2015) with some modifications. The 0.4 g of the defatted muffin powder and 10 mL phosphate buffer (pH 5.2) was mixed and 5 beads were added to simulate the intestinal environment. The 10 mL enzyme solution (Porcine Pancreatic-alpha amylase + Amyloglucosidase) was added for oral and pancreatic digestion. The reaction was carried out in a shaker (37℃, 150 rpm) and 0.5 mL samples were taken at specific times (20 min, 40 min, 60 min, 80 min, 100 min, 120 min). To inactivate the enzymes in these samples, they were placed in a tube containing 4.5 mL absolute EtOH. The Dinitro salicylic acid (DNS) method was used to measure the reducing sugars released during *in vitro* digestion. In a conical tube, 900 μL DNS reagent and 900 μL glucose sample were added. The tube was lightly capped to prevent liquid loss due to evaporation and heated to 90℃ for 15 min to give a reddish-brown colour. To stabilize the colour,

300 μL of 40% potassium sodium tartrate was added and after cooling, the absorbance was measured at 575 nm using an ultraviolet/visible spectrophotometer (UV-2550, Shimadzu corp., Tokyo, Japan).

2.8. Sensory evaluation

The sensory evaluation of muffins was conducted by 30 graduate students from Food Application Technology Major, Kyungpook National University, Korea. The evaluation parameters were crumb colour, flavor, taste, mouthfeel, and overall acceptability. The evaluation rating was based on a 9-point scale (1-very disliked, 9-very liked). To improve the accuracy of the sensory evaluation, the evaluators were trained on the terminology and criteria beforehand and were instructed to rinse their mouths with water after evaluating each sample. The sensory test was approved by Kyungpook National University Industry Foundation (Approval No: 2021-0075).

2.9. Statistical analysis

All data were analyzed using the SPSS statistical package (SPSS, version 12.0, Chicago, IL, USA). All experiments were performed in at least triplicate unless otherwise noted. Analysis of variance and Duncan's multiple range test were performed at the 5% significance level to identify significant differences in means. Pearson's correlation (r, p<0.05) was used to determine the relationship between characteristics.

3. Results and discussion

3.1. Pasting properties of flours

To model the movement of flour in suspension and its capacity for forming a consistent batter, the changes in the pasting qualities of rice flour caused
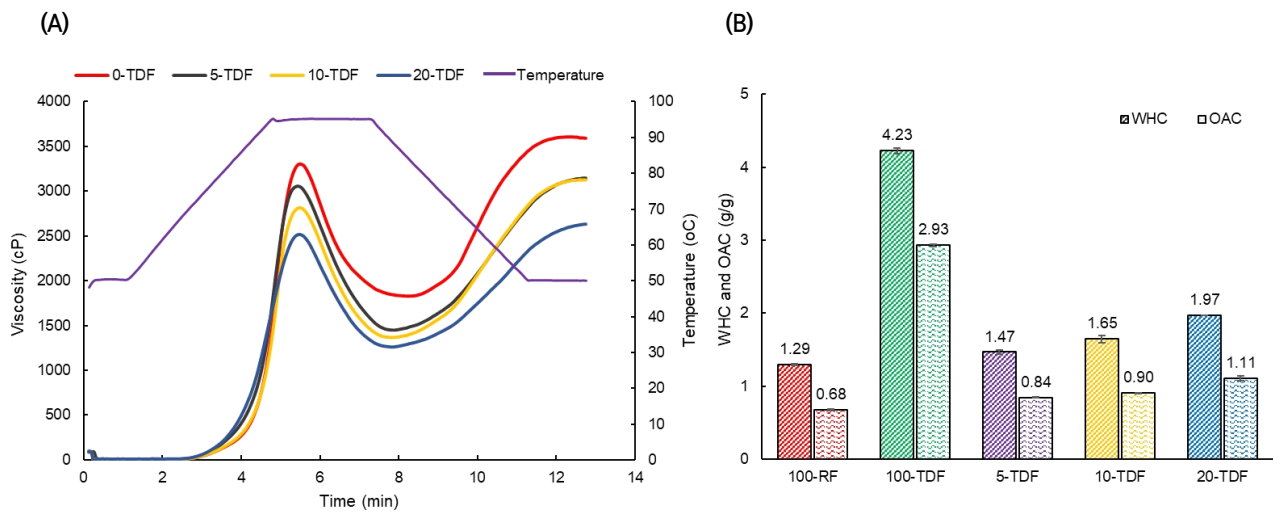
(A)

(B)

Fig. 1. Pasting (A) and functional (B) properties of rice flour (RF). TDF denotes tigernut dietary fiber and prefixes represent the % substitution level in rice powder. WHC, water holding capacity; OAC, oil acceptance capacity. Values on the bar represent average from triplicate results.

by the addition of TDF at various concentrations were observed (Olawuyi and Lee, 2019). Fig. 1(A) shows the data on the variance in rice flour viscosities as a function of TDF content. Peak, trough, and final viscosities all indicated an inverse declining pattern as TDF content rose. At 6 min, all samples showed maximum peak viscosity. Similar with previous study, the addition of fibrous ingredients to flour results in lower pasting viscosities owing to the hydrophilic and hydration properties of fibers (Nieto Calvache et al., 2016). These results speculate that the dietary fiber was able to absorb a lot of water in the experimental system, inhibiting the starch from rising, and also that the chains of the dietary fiber encapsulated the starch particles, inhibiting the rice starch from absorbing water, causing a decrease in the viscosity of the dough (Wang et al., 2017).

3.2. Water holding capacity (WHC) and oil acceptance capacity (OAC)

Fig. 1(B) presents the results of WHC and OAC of

rice flour incorporated with varying TDF content. WHC and OAC tended to increase with increasing TDF content. Tigernut fiber (100-TDF) showed significantly higher WHC at 422.75 g/g than rice flour (0-TDF) at 129.40 g/g ($p < 0.05$). Similar trends were observed for OAC with 100-TDF having a value of 293.01 g/g and 0-TDF at 67.66 g/g. These results are likely due to the moisture binding ability of dietary fiber (Brigagão et al., 2021). According to reports, dietary fibers with irregular structures have a high water-holding capacity and are able to quickly absorb liquids like water (Aguado, 2010; Kirbas et al., 2019).

3.3. Nutritional and physical properties of muffins

Table 1 illustrates the physical characteristics of the TDF-infused rice muffins. Every muffin had a comparable moisture content (18.01-19.42%). The muffins' ash content fell as the TDF level rose, but their protein and fat contents dramatically increased (6.44-7.35% and 22.90-25.82%). Baking loss reduced significantly different ($p < 0.05$) upon increased adding

Table 1. Proximate composition and physical properties of rice muffins

Characteristics	0-TDF[1]	5-TDF	10-TDF	20-TDF
Moisture (%)	19.42±1.01[a]	18.01±0.47[a]	19.11±0.55[a]	19.00±1.00[a]
Protein (%)	6.44±0.32[c]	6.86±0.09[bc]	7.21±0.02[ab]	7.35±0.08[a]
Fat (%)	22.90±0.03[c]	25.04±0.46[b]	25.34±0.00[b]	25.82±0.20[a]
Ash (%)	1.24±0.05[b]	1.36±0.02[a]	1.24±0.01[b]	1.11±0.06[c]
Baking loss (%)	7.64±0.52[a]	7.08±0.82[ab]	6.84±0.67[ab]	5.96±0.03[b]
Height (cm)	5.77±0.09[a]	5.37±0.05[b]	5.08±0.09[c]	4.95±0.03[d]
Volume (cm³)	173.06±7.78[a]	151.45±4.40[b]	145.40±3.56[b]	135.07±2.17[c]
Density (kg/m³)	0.43±0.02[c]	0.49±0.01[b]	0.51±0.01[b]	0.56±0.01[a]
Specific volume (m³/kg)	2.34±0.11[a]	2.04±0.05[b]	1.95±0.06[b]	1.80±0.03[c]

[1]TDF denotes tigernut dietary fiber and prefixes represent the % substitution level in rice powder. Mean±SD (n=3) within each row followed by different superscript letter ([a–d]) are significantly different ($p < 0.05$).

of TDF (Table 1). Ostermann-Porcel et al. (2020) also noted that when the amount of biji powder in the muffin formulation rose, the baking loss of rice muffins decreased. As the TDF content increased, the muffins' density increased while their height, volume, and specific volume dropped. Previous studies have reported that the density of muffins increases with decreasing dough viscosity (Ostermann-Porcel et al., 2020; Rahmati and Mazaheri Tehrani, 2014). It is reasonable to assume that in this investigation, the lower viscosity of the dough and the higher density of the muffins were related to the addition of progressively higher concentrations of dietary fiber.

3.4. Muffins crumb and crust color

The changes in L, a, and b values for the muffins are shown in Table 2. Higher TDF content was observed to significantly decrease the brightness (L value) and yellowness (b value) color of muffin crumb and crust ($p < 0.05$). However, the redness (a value) increased. Similar with this study, the reduction in brightness by the addition of tigernut dietary fiber to noodles has been reported (Kehinde Oke et al., 2022). The components or interactions between ingredients can affect a product's color, and it has been noted that customers perceive muffins with darker color to be healthier (Walker et al., 2014). Furthermore, visual observation of the cross-sections of the muffins, as shown in Fig. 2,

Table 2. Instrumental colour values of muffins

Muffins[1]	Crust			Crumb		
	L*	a*	b*	L*	a*	b*
0-TDF	62.85±5.93[a]	10.71±3.35[a]	39.10±2.63[a]	77.17±0.82[a]	−3.58±0.58[d]	41.20±1.11[a]
5-TDF	58.75±4.80[a]	11.95±2.06[a]	37.36±1.44[a]	70.75±0.70[b]	−1.80±0.38[c]	34.87±0.62[b]
10-TDF	55.50±1.53[ab]	11.86±1.95[a]	36.97±1.70[ab]	66.13±1.78[c]	−0.63±0.25[b]	32.74±0.73[c]
20-TDF	50.13±1.90[c]	13.30±0.23[a]	33.56±0.63[b]	64.08±4.12[c]	0.82±0.09[a]	29.53±1.20[d]

[1]TDF denotes tigernut dietary fiber, and prefixes represent the % substitution level in rice powder. Mean±SD (n=3) within each column followed by different superscript letters ([a–d]) are significantly different ($p < 0.05$).
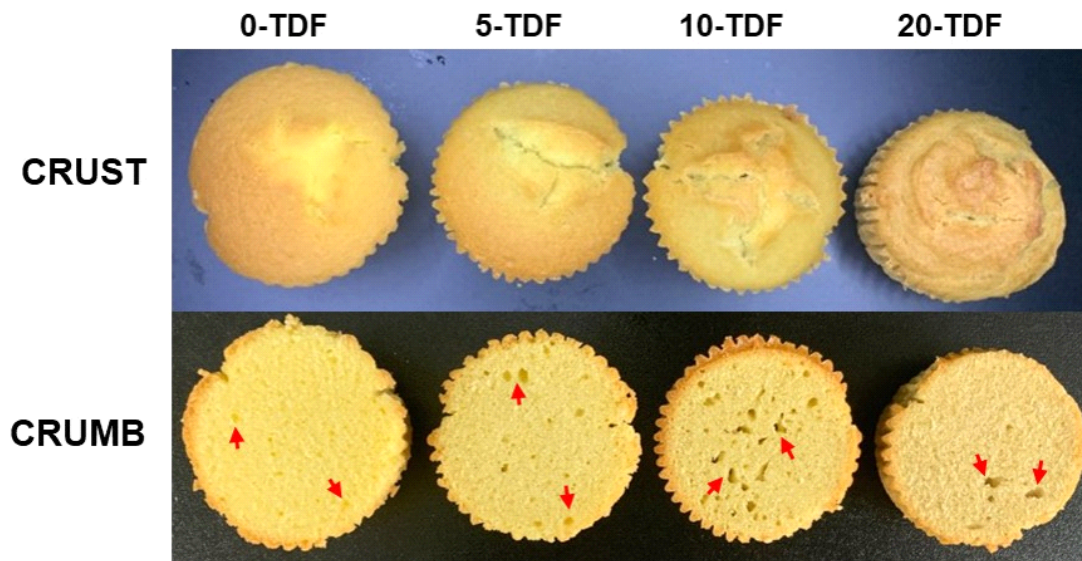
Fig. 2. Visual appearance of the crust and crumb of rice muffins. TDF denotes tigernut dietary fiber and the prefixes represent the % substitution level in rice powder.

revealed that the higher the content of TDF, the darker the color and the larger the pore size.

3.5. Dietary fiber content and in-vitro digestibility of muffins

The contents of insoluble- (IDF), and soluble- (SDF) dietary fiber in muffins according to TDF inclusion is presented in Fig. 3(A). The total dietary fiber content is expressed as the summation of IDF and SDF. The total dietary fiber content, increased significantly as the composition of TDF increased in muffin. Moreover, IDF content was relatively higher than SDF in muffins supplemented with TDF. For instance, %IDF increased from 12.83% in 0-TDF to 29.28% in 20-TDF. However, %SDF showed a decreasing trend, decreasing from 21.43% to 16.54%, respectively. Previous studies have reported that
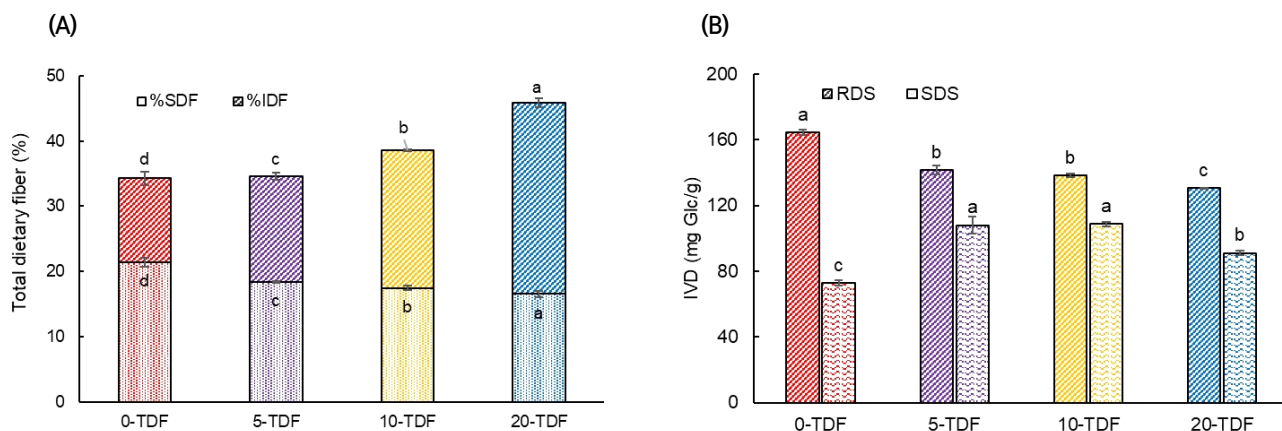

Fig. 3. Total dietary fiber contents (A) and in-vitro digestibility (IVD) properties (B) of rice muffins. TDF denotes tigernut dietary fiber, and the prefixes represent the % substitution level in rice powder. SDF, soluble dietary fiber; IDF, insoluble dietary fiber; RDS, rapidly digestible starch; SDS, slowly digestible starch (mg glucose/g muffin). Values are mean±SD (n=3), and bars with different letters are significantly different at p<0.05.

the %IDF of tigernuts is significantly higher than that of other grains and soybeans, and higher %IDF is effective in improving digestive function by promoting intestinal activity (Alfredo et al., 2009; Sanchez-Zapata et al., 2009). Thus, it is expected that the muffins in this study may also support healthy digestive function.

For starch digestibility of muffins, the progressive addition of TDF content resulted in decreasing rapidly digestible starch (RDS) and proportionately higher slowly digestible starch (SDS) contents (Fig. 3(B)). RDS was highest for 0-TDF at 164.49 (mg Glc/g) and lowest for 20-TDF at 160.47 (mg Glc/g), while SDS was highest for 0-TDF at 72.77 (mg Glc/g) and lowest for 10-TDF at 108.79 (mg Glc/g). SDS-rich foods are reported to prevent diabetes and obesity by releasing glucose slowly and lowering insulin response (Gelencsér et al., 2007).

3.6. Textural properties of muffins

When comparing the texture of the muffins with and without TDF, there was no significant difference ($p < 0.05$) in springiness (Fig. 4). Cohesiveness was highest for muffins without rice flour (97.61 g), and a gradual decrease in cohesiveness was observed with increasing TDF content (85.60-92.67 g). Hardness

and chewiness increased with increasing TDF content, with muffins containing 10% TDF showing the highest values, and further addition of TDF in muffins (up to 20% TDF) decreased hardness and chewiness properties. The partial drop in hardness of the muffins with 20% TDF may be related to reports that volume reduction above a specific level can effect the decrease in hardness. Studies have indicated a favorable correlation between higher dietary fiber content and an increase in hardness (Ktenioudaki and Gallagher, 2012; Lu et al., 2010). The effect of TDF incorporation in muffin formulation was shown to mostly influence the chewiness quality out of all the textural attributes. The energy required to break down a food so that it may be swallowed can be determined by how chewy it is. (Mau et al., 2017). Improvement in chewiness of muffins which may be associated to the rise in fibrous content in the muffin, is considered a beneficial property of muffins which ensures prolonged mastication period of food before swallowing, offering a form of satiety (Olawuyi and Lee, 2019).

3.7. Sensory evaluation of muffins

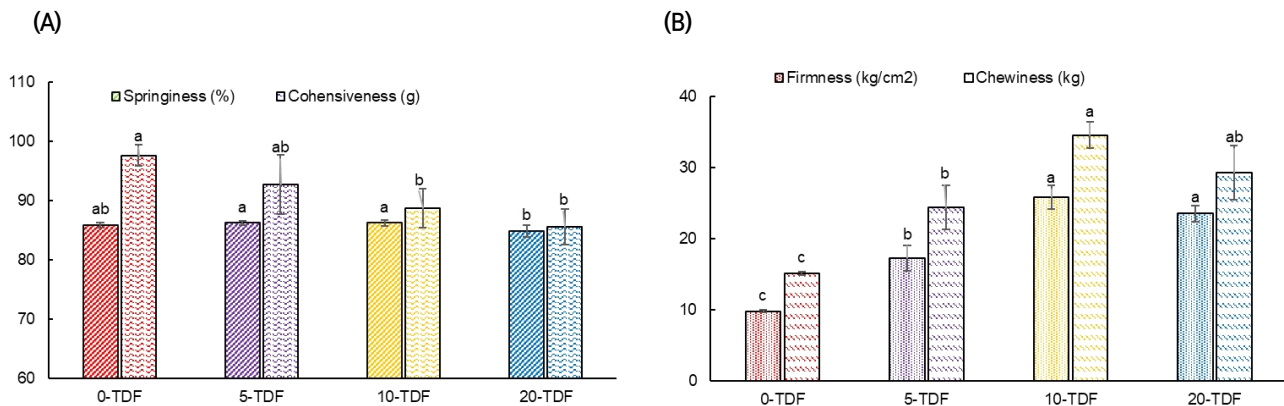The muffin crumb had been used in an experiment

(A)

(B)

Fig. 4. **Textural properties of rice muffins.** TDF denotes tigernut dietary fiber and the prefixes represent the % substitution level in rice powder. Values are mean±SD (n=3) and bars with different letters are significantly different at $p < 0.05$.

Table 3. Sensory evaluation of rice muffins

Muffins[1]	Crumb color	Flavor	Taste	Mouthfeel	Overall acceptability
0-TDF	7.90±1.30[a]	6.87±1.22[a]	6.67±1.09[a]	6.57±1.25[a]	6.93±1.26[a]
5-TDF	6.47±1.33[b]	6.80±1.32[a]	6.33±1.21[ab]	6.57±1.52[a]	6.80±1.40[a]
10-TDF	5.93±1.64[bc]	6.17±1.15[ab]	6.33±1.37[ab]	5.90±1.56[ab]	6.50±1.22[a]
20-TDF	5.43±1.45[c]	5.70±1.24[b]	5.60±1.40[b]	5.20±1.35[b]	5.53±1.36[b]

[1]TDF denotes tigernut dietary fiber and the prefixes represent the % substitution level in rice powder. Mean±SD (n=3) within each column followed by different superscript letters ([a-c]) are significantly different (p<0.05).

evaluating sensory perception. Table 3 presents the panelists' average sensory ratings for muffins. For color of muffins, 0% TDF had the highest score of 7.90, and the preference for color decreased as the TDF content increased. The taste, flavour and mouthfeel showed similar trends. On the other hand, no significant distinctions were found (p<0.05) in these sensory parameters at low TDF concentration (5% TDF). In addition, the inclusion of TDF in rice muffins (up to 10%) showed similar and insignificant scores for overall acceptability. Additionally, according to Palacio et al. (2018), the addition of dietary fiber to the muffin improved key organoleptic metrics, which had a favorable impact on consumer preference as a whole. Considering all factors, including sensory evaluation, it can be concluded that 10-TDF is a significantly preferable sample.

4. Conclusions

In this study, dietary fiber from tigernuts was added to the formulation of gluten-free rice muffins in the aim to enhance their nutritional and sensory properties. The effects of RDF inclusion were evaluated by various quality parameters. Improvements in important nutritional, physical and textural properties were observed according to TDF composition. In specifics, the proportional increase in the insoluble dietary fiber content, and slowly digestible starch contents of TDF muffins compared to rice muffins confirmed the potentials of TDF as a food fortificant. Moreover, enhanced fibrous contents in TDF-fortified muffins translated to improved textural sensory properties. As a result, this study concluded that the inclusion of TDF in muffin formulation up to 10% could be suitable to obtain quality gluten-free rice muffins.

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