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Research Article

Utilizing Sweet Corn "Milk" Residue to Develop Fiber-Rich Pasta: Effects of Replacement Ratio and Transglutaminase Treatment on Pasta Quality

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The rising demand for fiber-rich food products has fuelled the exploration of innovative approaches to enhance their dietary fiber content. Although adding dietary fiber-rich materials into pasta formula can increase the dietary fiber content, this approach counters several technological problems as the cooking and textural properties of the resulting pastas are usually negatively affected. This study is aimed at utilizing sweet corn "milk" residue (SCMR), a food by-product, and transglutaminase to develop fiber-rich pasta. Durum wheat semolina was replaced by SCMR powder at the ratio of 0 (control), 5, 10, 15, and 20% to make SCMR-fortified pasta. The chemical compositions and cooking and textural properties of the fortified pasta were then quantified. As the replacement ratio increased, the dietary fiber content, total phenolic content (TPC), and antioxidant properties of pasta were considerably improved while the cooking and textural attributes were negatively impacted. At 20% SCMR fortification, the dietary fiber content and TPC of the pasta were increased by 3.2 and 1.2 times, respectively, while the cooking loss increased by 73% as compared to those of the control pasta. Meanwhile, the chewiness, cohesiveness, tensile strength, and elongation rate at break of the 20% SCMR-fortified pasta were reduced by 19%, 26%, 21%, and 65%, respectively, compared to those of the control pasta. To improve the cooking properties and the textural properties of the fortified pasta, transglutaminase was added to the pasta dough with 20% SCMR. The effect of transglutaminase was enzyme-dose dependent. The cooking and textural qualities of pasta were improved as enzyme concentration increased 0 to 0.75 U/g protein and declined as the enzyme concentration increased from 0.75 to 1.25 g/U protein. At the optimal concentration of transglutaminase (0.75 U/g protein), the cooking loss reduced by 16% while the chewiness, cohesiveness, tensile strength, and elongation rate increased by 18%, 11%, 31%, and 32% compared to those without transglutaminase. *Novelty Impact Statement*. This study focuses on developing the dietary fiber-enriched pasta using sweet corn "milk" residue and transglutaminase enzyme. The results showed that replacing 20% durum wheat semolina with SCMR powder significantly enhanced the dietary fiber and total phenolic content of the pasta but negatively affect the cooking and textural properties of the pasta. Adding transglutaminase at 0.75 U/g protein to the SCMR-semolina blended dough successfully restored the adverse effects of SCMR on the cooking and textural properties. This study showed that dietary fiber-enriched pasta with improved cooking and textural properties can be prepared using the combination of SCMR and transglutaminase.

1. Introduction

Fiber-rich food products has attracted considerable interest due to the numerous health benefits associated with dietary fiber consumption [1]. These benefits include a healthier gut microbiome [2], improved digestion [2], weight management [3], a reduced risk of stroke [4], type 2 diabetes [5], cardiovascular disease [6], and some types of cancer.

Consequently, an increasing recognition of the health benefits of fiber has led to an escalating demand for fiber-rich food products recently.

One potential source of dietary fiber is food by-products, which are often overlooked and discarded during food processing. Recently, food by-products have emerged as valuable resources for the production of functional foods such as antioxidant [7] and dietary fiber-enriched foods [8] and prebiotics [9]. The utilization of food by-products not only contributes to food sustainability [10] but also brings additional economic benefit for food producers/farmers. Sweet corn "milk" residue (SCMR), consisting of the solids remaining after the extraction of sweet corn "milk" residue, is one example of food by-products. With the large production of corn worldwide [11] and increasing popularity of sweet corn "milk," it can be envisaged that sweet corn "milk" residue can be produced in large quantity, posing a need to develop an approach to reuse this by-product. Although sweet corn "milk" residue possesses favorable nutritional attributes, its unpalatable nature renders this by-product unsuitable for direct consumption. Consequently, exploring innovative approaches to utilize sweet corn "milk" residue for the production of functional foods is of great interest.

Pasta, a widely consumed staple food worldwide, is typically produced using refined flour with low in dietary fiber content. Recently, there is a growing interest in developing dietary fiber-rich pasta [12] by incorporating fiber-rich ingredients into pasta formula such as cereal brans [13, 14], fruit pomaces [15, 16], and fruit and vegetable by-products [17, 18]. Although incorporation of fiber-rich ingredients into pasta can produce healthier products that meet the consumer demands, this practice often encounters several technological problems that need to be resolved [12]. Dietary fibers often weaken the gluten networks [19] and negatively affect the cooking qualities and textural properties of pasta products [12]. In most cases, addition of dietary fiber materials into a pasta formula resulted in an increase in the cooking loss [12, 15, 16] and a decrease in the extensibility, tensile strength, and sensory attributes [12, 20]. However, the majority of the studies investigating pasta fortified with agricultural by-products have not presented effective solution for improving the cooking, textural, and sensory properties of the fortified pasta.

In this study, SCMR was added to pasta recipe for partial replacement of durum wheat flour to produce fiber-rich pasta. The influence of SCMR ratios on the pasta quality was evaluated. Additionally, different transglutaminase (TG) dosages were used in treatment of the SCMR supplemented dough to enhance the quality attributes of the resulting pasta. Through this study, the potential of SCMR as a valuable ingredient in the development of fiber-rich pasta is elucidated, while the potential improvements in pasta qualities by TG treatment is also examined.

2. Materials and Methods

2.1. Materials. Sweet corn (*Zea mays* convar. *saccharata* var. *rugosa*) "milk" residue was obtained from a local corn "milk" business. The fresh residue was dried and passed through a 425 μm sieve before packed in airtight container and stored at 4°C before use. The durum wheat semolina was obtained from the Vietnam Flour Mills Co., located in Vietnam.

The TG preparation was acquired from Rama Production Co. (Thailand) while other enzyme preparations including α-amylase, glucoamylase, and protease were obtained from Novozymes (Denmark). Unless otherwise stated, chemicals were procured from either Sigma (USA) or Merck Co. (Germany). Organic solvents were purchased from Chemsol Vina Co. (Vietnam).

2.2. Methods

2.2.1. Pasta Preparation. Durum wheat semolina was replaced with various ratios, including 0%, 5%, 10%, 15%, and 20%. The selection of this replacement range is aimed at ensuring that the dietary fiber content of the pasta would be equal to or greater than 6%, meeting the requirement for labeling as a fiber-rich food product according to both the CODEX Alimentarius and the European Commission for nutrition claim labeling guidelines [21]. Additionally, the chosen ratios considered the ease of pasta production, as excessively high replacement ratios could make dough kneading and extrusion significantly more challenging. SCMR powder and semolina were weighed and mixed in the flour mixer at a speed of 100 rpm for 5 min, resulting in mixture 1. The amounts of semolina and SCMR powder varied based on the replacement ratio, and a total of 300 g was used for each batch. Specifically, at 0%, 5%, 10%, 15%, and 20% replacement ratio, the semolina content was 300 g, 285 g, 270 g, 255 g, and 240 g, respectively, while the corresponding SCMR powder content was 0 g, 15 g, 30 g, 45 g, and 60 g. Next, table salt (0.5 g/100 g blend flour) was dissolved in deionized water (47 g/100 g blend flour) at 42°C and then poured into mixture 1. The resulting mixture was mixed at a speed of 100 rpm for 2 min, then kneaded at a speed of 120 rpm for 15 min with a dough hook (SM-8005, Ichiban Ltd., Tokyo, Japan) to form the pasta dough. Next, the pasta dough was extruded in the extruder (HR2365/05, Philips Co., Guangdong, China) and cut to form pasta strands of 400 mm in length. The obtained pasta strands were dried at 50°C in the convective dryer until the moisture content reached 11-12%. The pasta samples were preserved in the zip bags packed with desiccants for further analysis.

To prepare TG-treated pasta with a 20% replacement ratio, a similar procedure as above was applied except transglutaminase preparation was added to mixture 1 and the dough was incubated for 10 min at 40°C after kneading. The transglutaminase concentration range was selected based on a previous study [22].

2.2.2. Chemical Analysis. The moisture content was assessed using an ML-50 moisture analyzer (ML-50, A&D Co., Japan.) at a temperature of 105°C. Crude protein was quantified using Kjeldahl Nessler following the AOAC 2001.11 method. Specifically, a 0.5 g sample was digested with 5 mL concentrated H_2SO_4 until the solution became transparent. The digested solution was then adjusted pH to 6.0 and made up to 50 mL using deionized (D.I.) water. After that, 0.25 mL of the resulting solution was mixed with 5.75 mL polyvinyl alcohol (PVA) 0.01% (w/w) in water and 0.25 mL Nessler reagent. The mixture was vortexed and allowed to stand at room temperature for 15 min before recording the absorbance at 460 nm. The standard curve was constructed using NH_4Cl standard solution. Total lipid was determined by the Soxhlet method using diethyl ether solvent. Ash content was determined by ashing the 1 g sample in a muffle furnace (EF11/8, Lenton Co., UK) at 600°C for 24 h. The quantification of insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) was conducted using AOAC 991.42 and 993.19 methods, respectively, and 1 g of sample was used for each quantification. Samples were subsequently incubated with α-amylase, protease, and glucoamylase to digest starches and proteins. Soluble and insoluble fiber contents were then quantified using the gravimetric method. The combined value of IDF and SDF represents the total dietary fiber (TDF) content. Starch was determined using the AOAC 996.11 method, and 2 g of each sample was digested with 0.4 mL α-amylase and 1.2 mL glucoamylase for each quantification. After digestion, the resulting solution was made up to 50 mL using D.I. water. The glucose content was then determined using the DNS method and converted to starch content using a ratio of 0.9.

For total phenolic content (TPC), carotenoid content, and antioxidant activity determination, 4 g of sample was extracted with 40 mL aqueous ethanol (80%). The mixture was shaken for 8 hours at 30°C with a rotating speed of 200 rpm and further filtered using filter paper. The total phenolic content was assessed using the Folin–Ciocalteu reagent spectrophotometric method. Specifically, 1 mL of 10% Folin–Ciocalteu reagent was added to 0.2 mL of the sample extracts or gallic acid standard solutions. Subsequently, 0.8 mL of a 10% Na_2CO_3 solution and 3 mL of distilled water were added and well mixed. The resulting mixture was placed in the dark at room temperature for 2 h before the absorbance at 760 nm was recorded. Antioxidant activity was determined by the DPPH (di(phenyl)-(2,4,6-trinitrophenyl) iminoazanium) [23] and FRAP (ferric reducing antioxidant power) assays. The carotenoid content was determined using a previously described method [24].

2.2.3. Color Measurement. $L*$, $a*$, and $b*$ color values based on the CIE-Lab color system were measured using a Model CR-300 colorimeter (Konica Minolta, Japan). The color difference ΔE was calculated by the formula:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}, \qquad (1)$$

where L_0^*, a_0^*, and b_0^* are the color values of the control pasta sample without SCMR addition; L^*, a^*, and b^* are the color values of the analyte sample.

2.2.4. Cooking Quality. Optimal cooking time (OCT), cooking loss, swelling index (SI), and water absorption index (WAI) were assessed by a method outlined in the study conducted by Foschia et al. [25].

2.2.5. Texture Properties. The texture of the cooked pasta samples was assessed using a texture analyzer (TA-XT Plus, Stable Micro Systems, UK), and data was processed by Exponent Connect Lite 7.0 software. Following cooking until the optimal cooking times were reached, the pasta strands were rinsed with deionized water and placed at room temperature for 10 min prior to analysis. The P35 probe, configured with a test speed of 1 mm/s, 70% axial compression, and a rest time of 2 s between two compression cycles was used. The force-time curve was utilized to obtain measurements of the cohesiveness and chewiness of the cooked pasta samples. For elongation rate and tensile strength determination, a 15 cm pasta strand was affixed to a pair of parallel rollers and 1 mm/s was the setting of the stretching speed. Elongation rate and tensile strength were calculated as previously described [22].

2.3. Statistical Analysis. Each pasta sample was conducted three times independently, and the results were reported as mean ± standard deviation. Statistical analysis was performed using Minitab 16 software (Minitab Co.), employing a one-way analysis of variance and Turkey's post hoc test. A significance level of $p < 0.05$ was considered statistically significant.

3. Result and Discussion

3.1. Effects of Replacement Ratio of Durum Wheat Semolina by Sweet Corn "Milk" Residue Powder on Pasta Quality

3.1.1. Effects on Chemical Constituents. Different ratios of SCMR powder were employed to replace durum wheat semolina, ranging from 0% to 20%. Proximate composition and antioxidant properties of the SCMR-fortified pasta are presented in Figure 1 and Table 1, respectively. The protein content of pasta samples with different replacement ratios ranging from 0 to 15% was statistically unchanged. There was a slight reduction in protein content when comparing the pasta with a 20% replacement ratio and the control pasta. This was explained by the difference in the protein content of semolina and SCMR powder which were determined as 11.92 ± 0.14 and 9.16 ± 0.29% dw, respectively. The lipid and ash content of pasta samples exhibited a gradual increase with the progressive replacement of semolina with SCMR powder (Table 1). In contrast, the starch content of pasta samples was progressively reduced as the replacement ratio increased (Table 1). These differences were attributed to disparities in chemical composition between semolina and SCMR powder. The lipid content of SCMR powder was 9.86 ± 0.39% dw, which was approximately 5.5 times higher than that of semolina (1.80 ± 0.24% dw). The ash content of SCMR powder was 1.81 ± 0.01% dw, being 1.7 times greater than that of semolina (1.06 ± 0.02% dw). On the other hand, the starch content of SCMR was 26.31 ± 1.52% dw, which was 2.5 times lower than that of semolina (66.41 ± 1.25% dw). Noticeably, the dietary fiber contents were greatly enhanced by the incorporation of SCMR powder. As the 20% replacement ratio, the IDF,

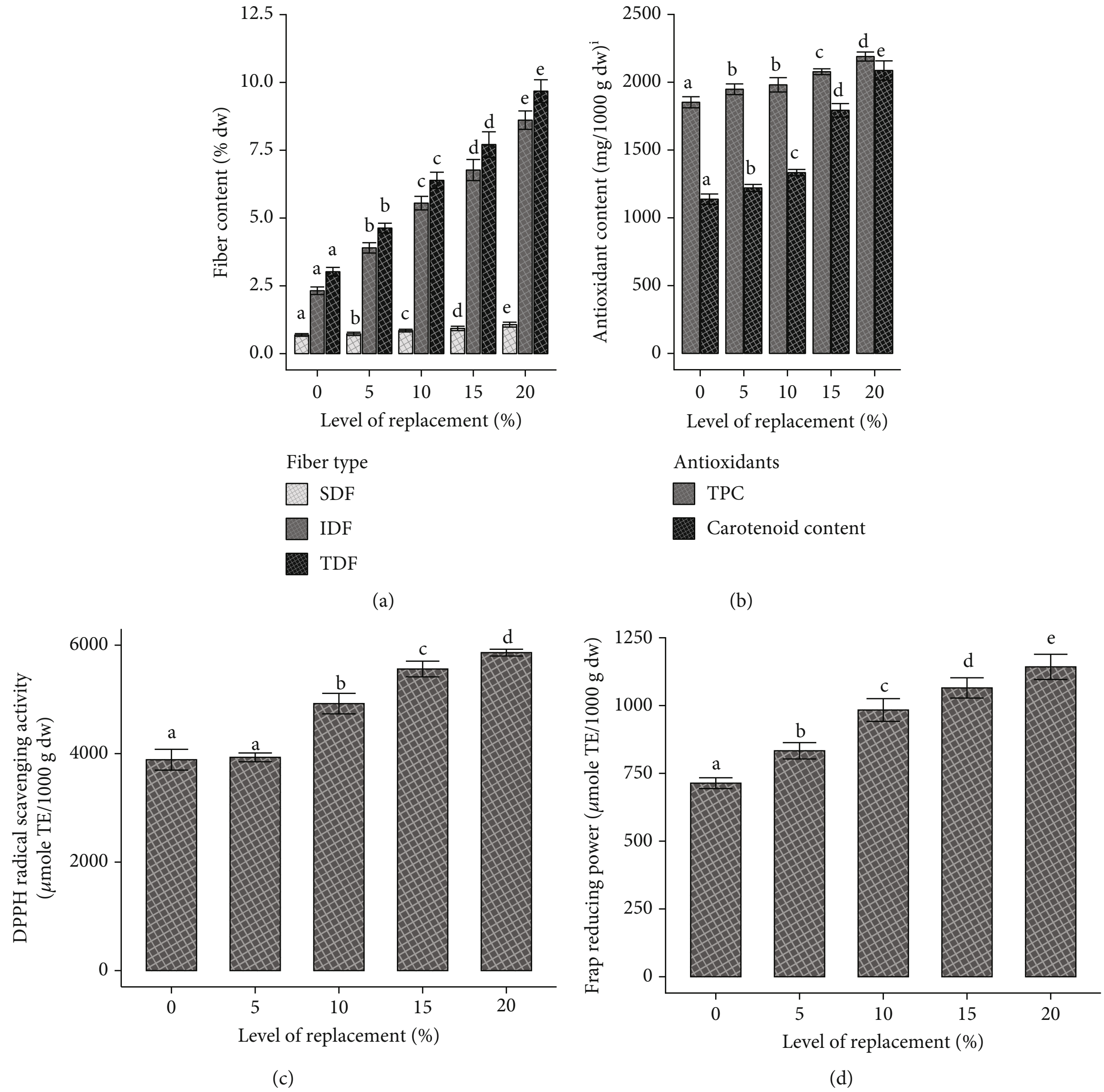

Figure 1: The dietary fiber content, antioxidant content, and antioxidant activities of sweet corn "milk" residue- (SCMR-) fortified pasta samples with different replacement ratios: (a) dietary fiber content—soluble dietary fiber (SDF), insoluble dietary fiber (IDF), and total dietary fiber (TDF); (b) carotenoid and total phenolic content (TPC); (c) DPPH radical scavenging activity; (d) ferric reducing powder activity of SCMR-fortified pasta samples. Results are presented as mean ± standard deviation ($n = 3$). Values that are associated with different letters (A–E) within the same category of value are significantly different according to Tukey's comparison test ($p < 0.05$). [i]TPC is expressed as mg gallic acid/1000 g dw.

SDF, and TDF of the pasta sample were increased by 3.7, 1.6, and 3.2 times compared to those of the control pasta (Table 1). Additionally, the TPC and carotenoid content of the pasta sample at a 20% replacement ratio were 18% and 83% higher than those of the control pasta, respectively (Table 1). The antioxidant properties as determined by DPPH and FRAP assay were also gradually increased with the increase in replacement ratio, being improved by 51% and 60% in the pasta at a 20% replacement ratio compared to those of the control pasta, respectively. Collectively, the replacement of durum wheat semolina by the SCMR powder in pasta preparation positively affected the chemical composition of pasta samples, in which the dietary fiber and antioxidant content were increased while the starch content was reduced. The pasta samples with a replacement ratio of 10% or higher exhibited dietary fiber contents exceeding 6%. This indicates that these pasta products meet the criteria set for high-fiber food products, as outlined by both the CODEX Alimentarius and the European Commission for nutrition claim labeling guidelines [21].

3.1.2. Effects on Pasta Color. CIE-Lab color parameters of pasta samples with different replacement ratios were quantified and shown in Table 1. Generally, the addition of SCMR powder to pasta significantly altered the yellowness of pasta samples as indicated by the increasing of $b*$ value while the

Table 1: Proximate composition and color parameters of sweet corn "milk" residue- (SCMR-) fortified pasta samples with different replacement ratios.

	SCMR-fortified pasta samples with various replacement ratios (%)[i]				
	0%	5%	10%	15%	20%
Crude protein (%, dw)	11.47 ± 0.23^{b}	11.39 ± 0.45^{ab}	11.28 ± 0.37^{ab}	11.16 ± 0.32^{ab}	10.76 ± 0.33^{a}
Lipid (%, dw)	0.76 ± 0.06^{a}	1.04 ± 0.07^{b}	1.59 ± 0.14^{c}	1.86 ± 0.13^{d}	2.15 ± 0.09^{e}
Total carbohydrate (%, dw)	86.84 ± 0.21^{c}	86.60 ± 0.53^{bc}	86.04 ± 0.41^{ab}	85.82 ± 0.31^{a}	85.63 ± 0.31^{a}
Starch (%, dw)	68.72 ± 1.13^{d}	66.32 ± 1.45^{cd}	64.32 ± 1.25^{c}	61.38 ± 2.16^{b}	57.18 ± 1.84^{a}
Ash (%, dw)	0.94 ± 0.06^{a}	0.97 ± 0.05^{a}	1.09 ± 0.03^{b}	1.16 ± 0.07^{b}	1.46 ± 0.06^{c}
$L*$	89.13 ± 0.50^{b}	89.21 ± 0.27^{b}	88.69 ± 0.48^{ab}	88.34 ± 0.24^{a}	88.48 ± 0.07^{a}
$a*$	1.21 ± 0.03^{b}	1.21 ± 0.06^{b}	1.11 ± 0.10^{ab}	1.01 ± 0.03^{a}	1.07 ± 0.09^{a}
$b*$	10.34 ± 0.28^{a}	11.21 ± 0.24^{b}	12.31 ± 0.34^{c}	13.05 ± 0.09^{d}	13.64 ± 0.22^{e}
ΔE	0.00 ± 0.00^{a}	0.90 ± 0.06^{b}	2.06 ± 0.17^{c}	2.84 ± 0.26^{d}	3.39 ± 0.21^{e}

[i]The results are presented as mean ± standard deviation ($n = 3$). Significant differences between values within the same row do not share the same superscript letters (a-d) (Turkey's comparison test, $p < 0.05$).

redness ($a*$) and lightness ($L*$) were marginally affected. Increasing in yellowness with the increase in replacement ratio could be attributed to the carotenoid content in SCMR powder, which was determined as 6.42 ± 0.09 mg/g dw. In general, the color difference, quantified by ΔE, in all pasta samples with SCMR incorporation was below 5, suggesting that the naked eye could not perceive any noticeable color difference between the SCMR-fortified pasta and the control pasta. This minimal effect on the color of SCMR powder incorporation could be an advantage point since the addition of a variety of agro/food by-products to pasta recipe was reported to induce the darkening effect of the color of food products which can negatively affect the consumer acceptability [26].

3.1.3. Effects on the Cooking Properties of Pasta. Optimal cooking time (OCT), cooking loss (CL), swelling index (SI), and water absorption index (WAI) of pasta samples with replacement ratio from 0% to 20% are presented in Table 2.

As the ratio of SCMR powder in the pasta recipe increased from 0% to 20%, the cooking time was reduced by 3 min, from 15.4 min to 12.4 min (Table 2). Similar results were observed when pasta was incorporated with black rice bran [14], grape pomace [15], and olive pomace [16]. Cooking loss substantially increased as the replacement ratio increased (Table 2). Comparing the cooking loss of pasta with a 20% supplement ratio and that of the control pasta, the cooking loss increased by 73%. The cooking loss of all pasta samples remained below 8%, meeting the threshold for being considered good-quality pasta. Both SI and WAI of SCMR-incorporated pasta samples remained statistically unchanged as the replacement ratio increased from 5% to 20% but were slightly lower than that of the control pasta (Table 2). Collectively, these observations on cooking attributes of SCMR-incorporated pasta samples indicated that the replacement of durum wheat semolina with SCMR powder negatively impacted the cooking qualities of the pasta, which could be the result of weakening effect of SCMR powder on the gluten networks. A similar result was obtained in pasta fortified with grape pomace [15], olive pomace [16], and okara [20]. The optimal cooking time and cooking loss depend on the capacity of the gluten networks to encapsulate and retain the starch granule during cooking. Previous studies have reported that the inclusion of different sources of dietary fiber into wheat flour-based products led to negative impacts on gluten networks [19]. These negative impacts include the weakening effect due to the dilution of gluten protein and steric hindering on the gluten network development, the alternations in secondary structures of gluten proteins, and the reduction of the disulphide bond content in the gluten networks [19]. The high water absorption of dietary fiber can reduce the hydrate level of gluten proteins, resulting in the formation of more inelastic β-sheet conformations at the expense of β-spiral structures [27]. Consequently, the viscoelasticity of the gluten networks is reduced [27]. Additionally, the addition of most dietary fiber sources reduced the content of disulphide bonds, which play a critical role in maintaining the tertiary structure of gluten proteins and strengthening the gluten networks. The weaker and less elastic gluten networks would entrap starch granules less efficiently, allowing more rapid water diffusion into the pasta structure. Consequently, the OCT was reduced while more starch granules and other exudates leached to water, leading to an increase in cooking loss.

3.1.4. Effects on Textural Properties. A decrease in cohesiveness was observed with the increased replacement ratio. Cohesiveness is a measure of the strength of internal bonds enforcing the pasta structure [28, 29]. Cohesiveness was found to correlate with gluten network strength [29]. A less developed gluten network could not entrap well the starch granules during cooking, leading to a less cohesive pasta. A reduction in cohesiveness of SCMR-incorporated pasta with the increased replacement ratio agreed that SCMR addition weakened the structural strength and elasticity of the gluten network and the resulting pasta [30]. Chewiness is a measure of chewing energy required to adequately masticate a specific amount of food to obtain a texture suitable for swallowing [31]. As the replacement ratio increased, the chewiness of

Table 2: Cooking and textural properties of sweet corn "milk" residue- (SCMR-) fortified pasta samples with various replacement ratios.

	SCMR-fortified pasta samples with different replacement ratios (%)[i]				
	0%	5%	10%	15%	20%
Optimal cooking time (min)	15.4 ± 0.1^{e}	14.2 ± 0.2^{d}	13.6 ± 0.3^{c}	13.3 ± 0.1^{b}	12.4 ± 0.1^{a}
Cooking loss (%)	4.15 ± 0.13^{a}	4.81 ± 0.16^{b}	5.25 ± 0.19^{c}	6.19 ± 0.24^{d}	7.18 ± 0.20^{e}
Swelling index (SI)	2.28 ± 0.03^{b}	1.92 ± 0.03^{a}	1.86 ± 0.07^{a}	1.91 ± 0.04^{a}	1.86 ± 0.09^{a}
Water absorption index (WAI)	1.89 ± 0.03^{b}	1.50 ± 0.03^{a}	1.44 ± 0.05^{a}	1.49 ± 0.04^{a}	1.46 ± 0.07^{a}
Cohesiveness	0.58 ± 0.02^{e}	0.53 ± 0.01^{d}	0.50 ± 0.00^{c}	0.46 ± 0.01^{b}	0.43 ± 0.00^{a}
Chewiness (g)	1439 ± 15^{b}	1360 ± 29^{d}	1325 ± 30^{c}	1276 ± 23^{b}	1162 ± 13^{a}
Tensile strength (kPa)	38.1 ± 0.7^{d}	35.8 ± 0.6^{c}	34.6 ± 0.5^{c}	32.0 ± 0.9^{b}	30.1 ± 1.4^{a}
Elongation rate (%)	73.2 ± 1.9^{d}	67.8 ± 3.9^{d}	60.3 ± 4.4^{c}	40.9 ± 2.9^{b}	25.8 ± 0.3^{a}

[i]The results are presented as mean ± standard deviation ($n = 3$). Significant differences between values within the same row do not share the same superscript letters (a-d) (Turkey's comparison test, $p < 0.05$).

pasta samples declined (Table 2). Chewiness of the pasta with a 20% replacement ratio was reduced by 19% compared to that of the control pasta (Table 2). The reduction in chewiness indicated a decrease in the internal forces within the pasta structure which was a result of a less developed gluten-starch matrix. Regarding the elongation rate, the pasta with a 20% replacement ratio exhibited a value of approximately one-third as compared to that of the control pasta. Tensile strength decreased by 20%, from 38.1 to 30.1 kPa, as the replacement ratio rose from 0 to 20% (Table 2). The decrease in elongation rate and tensile strength with increasing replacement ratio could be attributed to the weakening effect of SCMR powder on the gluten networks, leading to the formation of weaker and less elastic gluten networks. Reduction in these two attributes is undesirable and normally causes a reduction in sensory score of the pasta.

As a whole, the substitution of durum wheat semolina with SCMR powder resulted in a considerable enhancement of the dietary fiber content and antioxidant properties in the pasta products. However, negative impacts on cooking qualities and textural attributes were observed by the fortification of SCMR into pasta formula which could potentially result in a significant reduction in the overall acceptability of the pasta [22]. Hence, in order to effectively utilize SCMR powder for the production of high-quality fiber-rich pasta products, it is crucial to develop technological solutions that enhance the cooking qualities and textural properties of the SCMR-fortified pasta. The main cause for quality degradation of SCMR-fortified pasta is the negative impacts of SCMR powder on the gluten networks. Therefore, a method to improve the gluten network should be efficient to resolve the pasta quality. In literature, different methods were proposed to improve gluten networks such as the use of different enzyme preparations (i.e., glucose oxidase [32], transglutaminase [33]) and redox agents [34]. In this study, the effects of transglutaminase on the cooking and textural properties of SCMR-fortified pasta were investigated because of its ability to strengthen the gluten networks by catalyzing isopeptide bond formation between lysine and glutamine residues [35]. The results are presented in the next section.

3.2. Effects of Transglutaminase Treatment with Different Enzyme Concentrations on the Pasta Quality. Different enzyme concentrations ranging from 0 to 1.25 U/g protein were applied in dough treatment with transglutaminase preparation. The impacts of enzyme concentration on pasta quality are presented in Table 3.

3.2.1. Effects on the Cooking Properties of Pasta. With the gradual increase in TG concentration from 0 to 0.75 U/g protein, the pasta samples exhibited a slight increase in the OCT from 12.4 to 14.1 min (Table 3). Simultaneously, there was a notable reduction in cooking loss of approximately 16%, decreasing from 7.35% to 6.21% (Table 3). Under the enzyme action, the formation of inter- and intracrosslinks within proteins occurred, inducing a strengthening effect on the protein network. Consequently, the starch granules were encapsulated better, hindering water penetration and leading to a slower rate of starch gelatinization, and thus, cooking time was increased with increasing TG concentration from 0 to 0.75 U/g protein. Meanwhile, since the starch granules in pasta were encapsulated in a stronger protein network, preventing the starch diffusion, the cooking loss of pasta was reduced. As the enzyme concentration rose from 0.75 to 1.25 U/g protein, a reduction from 14.1 min to 12.3 min in OCT was observed, while an elevation from 6.21% to 6.82% in cooking loss was noted (Table 3). These observations indicated that at enzyme concentration higher than 0.75 U/g protein, the efficiency of TG treatment on improving pasta quality was declined. It was reported that the extensive crosslinks formed at high TG concentration resulted in uneven distribution of protein network across the pasta structures [36]. As a result, certain starch granules were inadequately enveloped by the protein network, leading to their easier gelatinization and a greater tendency to leach out during the pasta cooking. Our findings align with previous research that indicated the positive effects of employing transglutaminase on the pasta quality including semolina pasta [37], wheat bran-fortified pasta [13], and corncob-fortified pasta [22]. These effects generally improved at lower TG concentrations but began to decline at higher levels of TG. In contrast to the impacts on OCT and cooking loss, the SI and WAI of the pasta samples statistically remained the same as the enzyme concentration ranged from 0 to 1.25 U/g protein.

Table 3: Cooking and textural properties of pasta samples fortified with 20% sweet corn "milk" residue (SCMR) powder and treated with transglutaminase (TG) at various enzyme concentrations.

	Control pasta[j]	SCMR-fortified pasta samples with 20% replacement ratio treated with TG at various enzyme concentrations (U/g protein)[i]					
		0	0.25	0.50	0.75	1.00	1.25
Optimal cooking time (min)	15.4 ± 0.1^{e}	12.4 ± 0.1^{a}	12.7 ± 0.1^{b}	13.2 ± 0.1^{c}	14.1 ± 0.2^{d}	12.9 ± 0.1^{b}	12.3 ± 0.2^{a}
Cooking loss (%)	4.15 ± 0.13^{a}	7.35 ± 0.07^{e}	6.93 ± 0.06^{d}	6.74 ± 0.2^{cd}	6.21 ± 0.02^{b}	6.68 ± 0.11^{c}	6.82 ± 0.03^{cd}
Swelling index	2.28 ± 0.03^{b}	1.85 ± 0.03^{a}	1.88 ± 0.03^{a}	1.86 ± 0.01^{a}	1.87 ± 0.00^{a}	1.87 ± 0.01^{a}	1.86 ± 0.04^{a}
Water absorption index	1.89 ± 0.03^{b}	1.45 ± 0.02^{a}	1.41 ± 0.08^{a}	1.47 ± 0.03^{a}	1.44 ± 0.01^{a}	1.42 ± 0.02^{a}	1.46 ± 0.05^{a}
Cohesiveness	0.58 ± 0.02^{d}	0.44 ± 0.01^{a}	0.45 ± 0.01^{ab}	0.46 ± 0.00^{b}	0.49 ± 0.00^{c}	0.46 ± 0.01^{ab}	0.45 ± 0^{ab}
Chewiness (g)	1439 ± 15^{c}	1165 ± 67^{a}	1183 ± 10^{ab}	1250 ± 30^{b}	1376 ± 46^{c}	1212 ± 34^{ab}	1144 ± 61^{a}
Tensile strength (kPa)	38.1 ± 0.7^{cd}	30.5 ± 1.8^{a}	34.1 ± 1.5^{b}	36.1 ± 1.3^{bc}	40.1 ± 1.7^{d}	36.1 ± 0.6^{bc}	35.0 ± 1.3^{b}
Elongation rate (%)	73.2 ± 1.9^{e}	25.7 ± 1.9^{a}	28.1 ± 3.1^{abc}	29.5 ± 1.6^{bc}	33.9 ± 2.8^{d}	30.1 ± 1.5^{c}	26.4 ± 0.9^{ab}

[i]The results are presented as mean ± standard deviation ($n = 3$). Significant differences between values within the same row do not share the same superscript letters (a-d) (Turkey's comparison test, $p < 0.05$). [j]The control pasta is the pasta sample without SCMR powder and transglutaminase addition.

3.2.2. Effects on Pasta Textural Properties. Cohesiveness enhanced from 0.44 at 0 U/g protein to 0.49 at 0.75 U/g protein, achieving the maximum value among the TG-treated pasta samples (Table 3). With an increase in the enzyme concentration from 0.75 to 1.25 U/g protein, the cohesiveness experienced a reduction from 0.49 to 0.45 (Table 3). Similarly, the chewiness also increased from 1165 g to 1376 g as the enzyme concentration rose from 0 to 0.75 U/g protein but reduced to 1144 g as the concentration further increased to 1.25 U/g protein (Table 3).

Elongation rate and tensile strength also experienced an upward trend as the enzyme dose increased from 0 to 0.75 U/g protein (Table 3). However, as enzyme concentration increased from 0.75 to 1.25 U/g protein, a detrimental effect on elongation rate and tensile strength was observed (Table 3). Compared to treatment with 0.75 U/g protein, the treatment at 1.25 U/g protein caused a 22.1% and 12.7% reduction in elongation rate and tensile strength, respectively.

Similar to cooking qualities, the improvement effects of TG treatment on textural properties of pasta at enzyme concentration from 0 to 0.75 U/g protein could be explained by the strengthening effects on the protein networks as a result of additional intermolecular crosslinks formed between lysine and glutamine residues under the transglutaminase action. As the enzyme concentration exceeded 0.75 U/g protein, the extensive formation of crosslinks resulted in the negative impacts on the protein networks and pasta quality.

4. Conclusion

Partial replacement of semolina by sweet corn "milk" residue in pasta preparation significantly improved the dietary fiber content and antioxidant activities of pasta. However, the replacement also resulted in detrimental impacts on the cooking and textural properties of the pasta, including a reduction in cohesiveness, chewiness, tensile strength, and elongation rate, while observing an escalation in cooking loss, with these changes becoming more pronounced as the replacement ratio increased. The incubation of pasta dough, where 20% of semolina was substituted with SCMR powder, with transglutaminase enzyme at concentrations ranging from 0.25 to 0.75 U/g protein for a duration of 10 min, exhibited a substantial enhancement in cooking quality and textural properties. Notably, the degree of improvement increased with higher enzyme concentrations. However, as the enzyme concentration rose from 0.75 to 1.25 U/g protein, the improvement effects of transglutaminase were shown to progressively diminish. This was evident through the rise in cooking loss and the reduction in optimal cooking time, cohesiveness, chewiness, elongation rate, and tensile strength. Based on our study finding, it is indicated that using a replacement ratio of 20% durum wheat semolina by SCMR and treating the dough with transglutaminase enzyme at a concentration of 0.75 U/g protein hold potential for producing fiber-rich pasta with appropriate textural and cooking properties. To further improve the quality of SCMR-fortified pasta, other factors such as SCMR particle size and the water content in the pasta formula could be investigated. Additionally, conducting in vitro digestion and in vivo studies would provide valuable insights into the health benefits associated with SCMR-fortified pasta, especially the effect of SCMR-fortified pasta on the glycemic index.

Data Availability

Data are available upon reasonable request from the corresponding author.

Conflicts of Interest

None of the authors of this study have any financial interest or conflict with industries or parties.

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