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RESEARCH ARTICLE
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DEVELOPMENT OF EGG SUBSTITUTED MUFFINS USING MODIFIED TAMARIND SEED GUM

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Abstract
This study explores the innovative application of tamarind seed gum (TSG) modified via ultrasonic-assisted octenyl succinic anhydride (OSA) treatment, as a functional egg substitute in muffin formulation. Tamarind seeds were transformed into a biocompatible, water-soluble polymer exhibiting desirable gel-forming and mucoadhesive properties. Muffins were prepared by substituting eggs with the modified TSG at various levels (25, 50 and 75%, respectively). The formulations were evaluated through physicochemical and sensory analyses. Result indicated that increasing level of TSG substitution led to reduction in crude protein, crude fat and energy value while moisture, crude fiber, carbohydrate and specific volume were increased. Sensory analysis revealed that 25% egg substitution yield the optimum texture, flavor and overall acceptability. These findings demonstrate that modified TSG is a viable plant-based alternative to eggs in baked goods.

Keywords: Modified TSG, muffins, physicochemical, egg substitution

1. Introduction
The *Tamarindus indica* L. belongs to the Fabaceae family of dicotyledons and is indigenous to tropical and subtropical regions. In Pakistan, tamarind is mostly cultivated in tropical region i.e. Karachi and least researched food item. The byproduct obtained from tamarind is properly extracted, treated and modified before being used in industries (Israel and Murthy, 2019). One kilogram of tamarind fruit contains 320 to 700 g seeds and considered as agro waste but owing to its valuable ingredients, can be commercially used in various industries. The tamarind seed is an abundant source of carbohydrate especially polysaccharide gum. Tamarind seed flour is chemically defined as branched polymer. Tamarind seed polysaccharide has a molecular weight of 1735 kDa (Shao et al., 2019). Monomers with a molar ratio of 3:2:1, primarily made up of the sugars: xylose, galactose and glucose. An A-D-1-glucopyranosyl main chain and D-xylopyranosyl lateral chains are joined to every 2nd, 3rd and 4th D glucopyranosyl unit by a 1-6 linkage to form the branching polysaccharide found in tamarind seeds (Shukla et al., 2018). It is a water-soluble, branched, nonionic polymer with mucoadhesive, gel-forming and hydrophilic qualities. Additionally, it is compostable, biocompatible, non-irritating and non-carcinogenic.
Research on the chemical alteration of polysaccharides by ultrasound is limited. Moreover, dual modification has gained popularity due to the inadequacy of a single alteration to comprehensively meet the unique requirements of starch characteristics for food and industrial uses. OSA has received

FDA approval for utilization as a polysaccharide modifier in food products, with a maximum permissible concentration of 3.0% w/w (He et al., 2024). The structure and properties of high-quality modified polysaccharides are significantly impacted by the combined actions of chemical OSA modification and ultrasonic treatment (Zhang et al., 2020).

Baked products are widely consumed across the globe. The food industries had experienced difficulties to prepare variety of nutritious and safe food due to increased global urbanization and growing consumer awareness. Bakery industry has embraced technological advancements to meet the evolving demands for functional foods (Punia and Dhull, 2019). Eggs are also the primary component of various baked goods like cakes and muffins, having high nutritional value and exhibited functional properties such as foaming, tenderization, coagulation, glazing, flavoring, binding, leavening and emulsification (Hedayati *et al*., 2022). The vegetarian and non-vegetarian egg substitutes are used in low cholesterol, low calorie and vegan products (Ahmad *et al*., 2021). Another concern of health is egg allergy that is the second most prevalent immunoglobulin E-mediated food allergy in children and newborns. The egg whites contain the main egg allergens that leads to the potentially fatal condition of anaphylaxis. Such problems have prompted researchers to introduce appropriate egg extenders and egg substitutes (Zhu *et al.,* 2018). As a result, the current study was designed to access the effective use of waste product of tamarind to develop egg substituted bakery product.

2. Materials and methods

The study was conducted in the Department of Food Science and Technology at GCWUF and chemicals and standards were acquired from Merck KGaA, (Germany) and Sigma-Aldrich (Japan).

2.1. Preparation of ultrasonic assisted OSA-TSG

A 2 g TSG was used to prepare 35% (w/v) gum solution. The solution pH was adjusted to 8 by sodium hydroxide solution. The gum solution was alkalized by maintaining the temperature at 35°C for 20 min. Afterwards, OSA (3.0%) was added to gum solution at pH 8 and diluted three times with anhydrous ethanol. The ultrasonication of gum solution was done by using ultrasonic processor probe for 60 min at 600 W. Each ultrasonic treatment was followed by 25 min pause and the esterification process was completed within 6 hr. Afterward, again pH was set with HCl solution. Then, vaccum filtration was done and suspension rinsed four times: three times with distilled water and once with 95% (v/v) ethanol solution to remove the unesterified chemical residues. Finally, sample was dried and sieved using 100 mesh standard sieve (Zhang *et al.*, 2020).

2.2. Muffin formulation

The ultrasonic assisted OSA-TSG gel was added to the prepared batter at various level of 25, 50 and 75%, respectively. All ingredients were weighed separately before being thoroughly mixed. A list of all the ingredients used to make muffins was shown in Table 1. A single bowl was utilized for the mixing process. A Kitchen-Aid Professional Mixer was used to mix the ingredients. After measuring, the batter transferred into muffin trays and baked for 25 min at 200°C. Afterward, cooled for 20 min. Finally, muffins were taken out of the pans and kept in plastic bags (Punia *et al*., 2019).

Table 1. Treatment plan for preparation of muffins

Ingredients (g or mL/100g)	**Control**	**Egg substitution (%)**		
	TC	**TES_{25}**	**TES_{50}**	**TES_{75}**
Cake flour	33.0	33.0	33.0	33.0
Sugar	27.5	27.5	27.5	27.5
Milk	16.5	16.5	16.5	16.5
Egg	13.8	10.3	6.9	3.5
Fat	8.4	8.4	8.4	8.4
Ultrasonic assisted OSA-TSG	-	3.5	6.9	10.3
Baking powder	0.8	0.8	0.8	0.8

TC= Control

TES_{25} = Substitution of egg with ultrasonic assisted OSA-TSG at 25%

TES_{50} = Substitution of egg with ultrasonic assisted OSA-TSG at 50%
TES_{75} = Substitution of egg with ultrasonic assisted OSA-TSG at 75%

2.3. Compositional analysis
The compositional analysis (moisture content, crude protein, crude fat, crude fiber, ash content and nitrogen free extract (NFE)) were determined according to method of AACC (2019).

2.4. Energy value
The energy value of muffins was determined based on the Atwater equation (Karigidi *et al.*, 2022).

$$Energy\ value\ (Kcal/100g) = \{(Carbohydrate \times 4) + (Protein \times 4) + (Lipid\ \times 9)\}$$

2.5. Specific volume
Seed displacement method was utilized to find out the specific volume of muffin. The specific volume of the samples was determined by dividing the muffin volume by its weight (AACC, 2019).

2.6. Color analysis
The color of the muffin was assessed using an Ultra Scan PRO colorimeter. The color parameters a* (+ redness and - greenness), b* (+ yellowness and -blueness) and L* (luminosity: 100 white and 0 black) were determined (Giacomozzi *et al.,* 2018).

2.7. Sensory evaluation
The muffins were evaluated for crust shape, crumb grain size, crumb color, mouthfeel, texture and overall acceptability. Sensory evaluation was carried out by trained taste panelist using 9 point hedonic scale (Punia *et al*., 2019).

2.8. Statistical Analysis
The data were analyzed statistically using CRD with Statistix 8.1 software. Means were calculated by Tukey test (Montgomery *et al.*, 2013).

3. Results and discussion

3.1. Compositional analysis of egg substituted muffins
The compositional analysis plays significant role to determine the product nutritional quality. Every muffin with added modified gum had more moisture content, crude fiber, ash and NFE (Table 2). It was observed that egg substituted muffins with added modified gum showed lower crude fat content and increased moisture level at all levels due to higher capacity of water absorption. Eggs are the rich source of proteins and are substituted with the ultrasonic assisted OSA-TSG in muffins that's why protein content declined significantly. Aljobair (2022) revealed that moisture content increased significantly from 21.44 to 24.38% by the addition of chia seed flour as egg substitute in cake. Likewise, Ratnayake *et al.* (2012) explicated that sugarcane fiber, guar gum and xanthan gum increased the moisture content in eggless sponge cake. The addition of flaxseed gum decreased the protein content and increased the level of carbohydrate in eggless muffin (Ahmad *et al.,* 2021).

Table 2. Compositional analysis of egg substituted muffins with ultrasonic assisted OSA-TSG

Treatments	Moisture content (%)	Crude Fat (%)	Crude Protein (%)	Crude Fiber (%)	Ash content (%)	NFE (%)
TC	15.35±0.11^{d}	15.35±0.92^{a}	10.04±0.17^{a}	0.94±0.01^{c}	0.59±0.02^{c}	57.38±0.64^{d}
TES_{25}	15.77±0.13^{c}	14.62±0.38^{b}	9.67±0.10^{b}	0.96±0.02^{bc}	0.71±0.03^{b}	58.64±0.61^{c}
TES_{50}	16.15±0.13^{b}	13.81±0.21^{c}	8.14±0.14^{c}	1.05±0.03^{b}	0.73±0.01^{ab}	60.68±0.66^{b}
TES_{75}	16.65±0.14^{a}	12.68±0.22^{d}	7.67±0.11^{d}	1.12±0.02^{a}	0.78±0.02^{a}	62.09±0.59^{a}

3.2. Energy value of egg substituted muffins
The reduction in energy value of muffins is due to replacement of egg with gum (Table 3). The current results are comparable with the previous research of Borneo *et al.* (2010), revealed that chia gel in cake as egg substitute reduced the energy value of significantly from 335 to 325 Kcal/100g. Likewise, Aljobair (2022) illuminated that energy value decreased by adding chia seed flour and sugarcane, xanthan gum and guar gum in eggless cake.

3.3. Specific volume of egg substituted muffins

The substitution of fat with ultrasonic assisted OSA-TSG did not affect the muffin's volume significantly as mentioned (Table 3). Similar outcomes are noticed in the research conducted by Anwar *et al.* (2020), unveiled that specific volume of chia flour incorporated eggless cake was reduced from 2.20 to 1.52 cm^3/g. Furthermore, Rasouli *et al.* (2022) studied the effect of egg replacement with modified starch and whey protein concentrate in cake. Likewise, Ahmad *et al.* (2021) expounded that flaxseed meal reduced the specific volume of eggless muffins.

3.4. Color analysis of egg substituted muffins

The mean squares regarding crust L*, a* and b* value showed momentous effect due to different treatments as depicted in Table 3. The current results are in conformity with the work of Yeganeh *et al*. (2024), who revealed that curst b* value decrease in psyllium seed gum and soy flour enriched eggless rice cake.

The mean squares regarding crumb L* and a* value presented substantial differences within the treatments however b* value was varied non-significantly as mentioned in Table 4. Current findings are in harmony with outcomes of Crawford *et al.* (2024), prepared egg substituted cake with aquafaba, hydroxypropyl methylcellolose and xanthan gum. Likewise, Ratnayake *et al.* (2012) expounded that sugarcane fiber, xanthan gum and guar gum as egg replacer.

Table 3. Energy value and crust color of egg substituted muffins with ultrasonic assisted OSA-TSG

Treatments	Energy value (Kcal/100g)	Specific volume (cm^3/g)	Crust color		
			L*	a*	b*
TC	337.17±2.25^{a}	2.09±0.02^{a}	60.44±0.31^{c}	9.04±0.17^{a}	14.20±0.20^{a}
TES_{25}	329.76±1.52^{b}	2.04±0.01^{ab}	60.70±0.35^{c}	8.88±0.10^{ab}	14.00±0.26^{ab}
TES_{50}	320.67±2.08^{c}	2.01±0.01^{b}	61.76±0.45^{b}	8.80±0.18^{ab}	13.70±0.12^{b}
TES_{75}	311.67±1.52^{d}	1.92±0.04^{c}	62.73±0.25^{a}	8.62±0.13^{b}	13.53±0.07^{b}

Table 4. Crumb color and specific volume of egg substituted muffins with ultrasonic assisted OSA-TSG

Treatments	Crumb color		
	L*	a*	b*
TC	70.89±1.50^{b}	0.13±0.04^{a}	13.59±0.43^{a}
TES_{25}	72.52±0.98^{ab}	0.08±0.06^{ab}	13.04±0.21^{ab}
TES_{50}	73.56±0.58^{a}	-0.03±0.04^{bc}	12.73±0.25^{b}
TES_{75}	74.40±0.43^{a}	-0.13±0.09^{c}	12.16±0.15^{c}

3.5. Sensory evaluation of egg substituted muffins

The sensory quality characteristics of egg substituted muffins were assessed through 9-point hedonic scale sensory evaluation. There were significant differences between muffin samples ($p > 0.05$) for crust shape, crumb grain size, crumb color, texture, mouthfeel and overall acceptability as shown in Figure 1. The egg substitution (25%) in muffins was considered best treatment and mostly preferred by panelist. Similar results were obtained in the research conducted by Ashwini *et al*. (2009), evaluated the effects of gums alone or in conjunction with emulsifier on quality attributes of eggless cake and revealed that highest score for crumb grain size was recorded in eggless cake prepared with gum Arabic and carrageenan with glycerol monosterate. Ahmad *et al.* (2021), found that customers generally liked and approved of muffins made with up to 25% flaxseed flour instead of egg. Further, Aljobair (2022) revealed that prepared eggless cakes with chia seed gel were acceptable with the addition of chia seed flour for chia gel eggless cake.

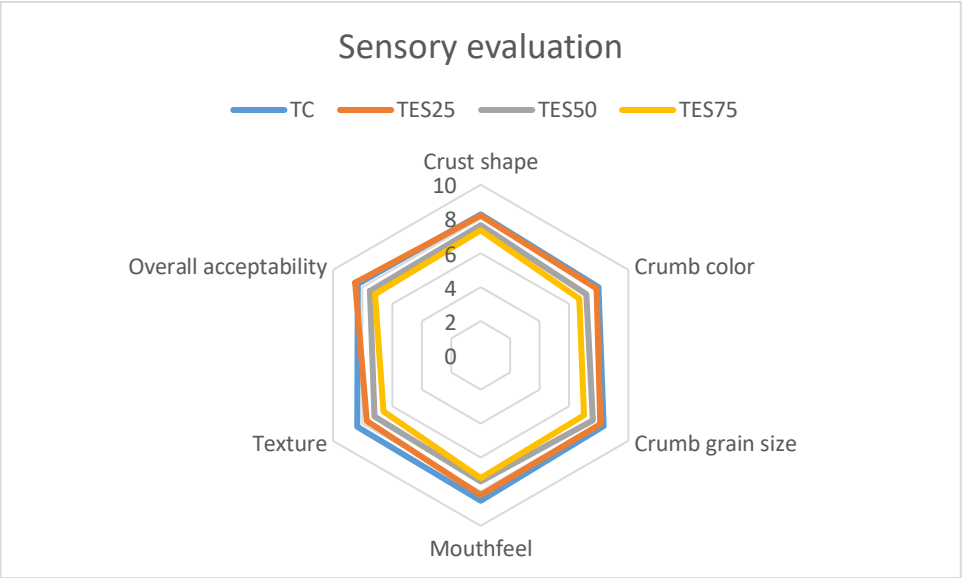

Figure 1. Sensory evaluation of egg substituted muffins with ultrasonic assisted OSA-TSG

Conclusion

Ultrasonic-assisted OSA-modified TSG demonstrates significant potential as a plant-based egg substitute in bakery applications. Its incorporation in to muffin formulation notably enhance the nutritional profile by reducing fat while increasing moisture and fiber content. A 25% substitution was identified as optimal, yielded positive sensory qualities and higher consumer acceptability, whereas higher even substitution levels (50 and 75%) resulted in lower sensory scores. In addition to promoting sustainability in food production, the value-adding of tamarind seed waste meets the growing need for vegan and allergy-free substitutes. Future research should focus on evaluating long-term stability and scalability of modified TSG for industrial applications as well as its potential in various food matrices.

Data availability statement

Upon a reasonable request, data supporting the research outcomes will be provided by the corresponding author.

Conflict of interest statement

The authors have no conflicts of interest.

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