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Evaluation of the Performance of Gel Emulsifier and Polyols on Improving the Technological, Sensory and Shelf-life Properties of Gluten-free Fermented Doughnut

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ABSTRACT

Doughnut is one of the snack foods that can be seen in the diet of different people and improving the characteristics of this product, such as increasing its shelf life and maintaining the softness of the texture and freshness, with minimal cost and changes in the production method will increase profitability for producers. So in the present research, different emulsifiers and polyols were used in the formulation of fermented gluten-free doughnut and the characteristics of the manufactured product were evaluated to be able to conclude that the type of additive and their combination what effect did it have on the quality of this popular snack. Gel emulsifier containing polysorbate 80, carboxymethyl cellulose and DATEM in 1% w/w (Based on rice flour) was prepared. Also, polyols of sorbitol and propylene glycol were added to the formulation of gluten-free fermented doughnut in an amount of 2% w/w of the flour used in the formulation and the mixture of two polyols was also added to the formulation of gluten-free fermented doughnut in order to investigation of the synergistic effect and physicochemical and sensorial properties and physical and chemical shelf life of the product were evaluated in a completely randomized design with factorial arrangement ($P \leq 0.05$). Results showed by adding gel emulsifier containing carboxymethyl cellulose and propylene glycol to the gluten-free fermented doughnut formulation, the amount of moisture, specific volume, porosity, L* value of the shell of the product increased further compared to other gels emulsifier used. It is while mentioned gel emulsifier has a greater ability to reduce the amount of a* value of the shell, the hardness of the texture (in each of the three time periods of two hours, the third day and the seventh day after baking) and the oil absorption of gluten-free doughnut samples. Regarding the evaluation of sensory properties, the results showed that the sample containing carboxymethyl cellulose and propylene glycol had more color, texture, taste and overall acceptance scores than other samples. Therefore, using a gel emulsifier containing CMC and propylene glycol is an available solution to increase the shelf life of gluten-free fermented doughnut.

1. Introduction

Doughnut consists of two main parts: the fried outer layer and the inner section. The fried part is on the surface, directly in contact with oil. This part undergoes the most moisture loss and absorbs the most oil, ideally having a golden-brown color and crispy texture. The inner part is similar to a cake texture and, if it does not receive enough heat during frying, starch gelatinization is delayed. The moisture of this part is higher than the surface, causing moisture migration during storage toward the fried part, which reduces surface crispness [1]. It is important to note that the key ingredient in doughnut and other baked products is wheat flour, whose gluten protein is responsible for creating soft and porous texture. This compound causes sensitivity in celiac disease.

Celiac disease is a lifelong intestinal disorder triggered by gluten consumption in sensitive individuals. It is one of the most common genetic disorders in the world. Gluten intake in celiac patients causes inflammation and swelling in the small intestine, resulting in incomplete absorption of essential nutrients such as iron, calcium, and fat-soluble vitamins, and sometimes leads to weight loss, diarrhea, anemia, fatigue, abdominal bloating, and folate deficiency [2&3]. The only treatment for celiac disease is lifelong adherence to a gluten-free diet [4].

Baked products, especially gluten-free ones, lose moisture and developing hardness, rough texture when stored at room temperature, a process known as staling. Staling in baked goods is categorized into two types: crust staling and crumb staling. Crust staling usually results from moisture migration from the crumb to the crust, creating a leathery texture. This is generally less of a concern to consumers than crumb staling, which significantly reduces sensory acceptance due to increased crumb firmness [5]. To improve shelf-life and maintain product characteristics during storage, various strategies can be employed. The use of additives is one such strategy.

Emulsifiers are a subset of surface-active agents that reduce surface tension between two immiscible phases, thereby stabilizing them together. Hence, they are widely used in food products. In aqueous systems, emulsifiers exhibit mesomorphism — the formation of liquid crystalline phases (mesophases or liquid crystals are special states of matter with fluidity like liquids but light-reflecting properties like crystals). When crystals are heated in an aqueous solution to around 60°C, a mesophase forms, which upon cooling becomes a gel. Mesophase formation depends on various factors such as emulsifier type, temperature, emulsifier concentration, and HLB. The fatty acid chain in emulsifier structures prevents water from reacting with the hydrophilic part (glycerol); upon hydration, emulsifiers form hydrophilic structures on the surface, enabling effective interaction with water. Hydrated emulsifiers are therefore highly functional [6]. Various emulsifiers can be used in gel emulsifier formulations; in this study, Polysorbate 80, Carboxymethyl Cellulose (CMC), and DATEM were used.

Polysorbate 80, commercially known as Tween 80, is used as an emulsifier in pharmaceutical, cosmetic-hygienic, and food products. At room temperature, it is an amber-yellow oily liquid with an HLB value of 15, making it an oil-in-water emulsifier. Due to its long polyoxyethylene chain, it is soluble in water [7]. CMC is a linear, long-chain, water-soluble polysaccharide and the most important chemically modified natural gum, with very high water-holding capacity [8]. In this context, Sciarini *et al*., (2012) demonstrated that adding CMC gum to gluten-free bread dough reduced crumb firmness, increased water absorption, maintained texture moisture, delayed staling, and improved final product shelf life [9].

Another emulsifier used in the formulation was DATEM (mono- and diacylglycerol esters of diacetyl tartaric acid), a non-ionic oil-in-water emulsifier used to improve the quality of baked goods. It is considered a dough conditioner, improving dough tolerance, gas retention, volume, texture, strength, and slicing properties when added to dough [10].

Polyols are other additives used in gel emulsifier formulations. These compounds bind free water in food systems, thereby eliminating the need for harmful chemical preservatives and controlling microbial growth to extend shelf-life. Polyols or polyalcohols contain many free hydroxyl groups and have the ability to absorb and retain water [11]. In this study, Sorbitol and Propylene Glycol were used as polyols to improve the quality of gluten-free fermented doughnuts.

In this regard, Borges and Salas-Mellado (2016) examined the effects of alpha-amylase, trehalose, sorbitol, and Polysorbate 80 on gluten-free bread made from rice flour. Results showed that adding sorbitol, trehalose, alpha-amylase, and polysorbate even at the lowest concentration (0.1%) improved specific volume, texture firmness, and sensory scores. Furthermore, moisture retention in the crust and crumb of the final product by these compounds helped reduce firmness and extend gluten-free bread shelf life [7]. Also, Ghayasi Tarzi *et al*., (2016) studied the effects of polyols (glycerin, propylene glycol, and sorbitol), invert syrup, and glucose syrup on specific volume and shelf life of oil cakes. Results showed that glycerin and propylene glycol had significantly different effects on water activity compared to sorbitol, invert syrup, and glucose syrup, and cakes containing glycerin and propylene glycol had longer shelf lives [12].

Therefore, in this study, emulsifiers and polyols were used in gel form in the formulation of gluten-free fermented doughnuts, and the physicochemical, technological, textural, visual, and sensory properties of the product were evaluated to determine how the type and combination of additives affect the quality of this widely consumed snack.

2- Materials and Methods

2-1- Materials

The rice flour used in the formulation of the gluten-free fermented doughnut samples was of the "Bartaar" brand and contained 10.36% moisture content, 8.05% protein, 0.94% ash, and 1.51% fat, and was purchased from reputable stores. The emulsifiers were obtained from Pars Behbood Asia Company, the polyols from Timer Network Sdn Bhd (produced in Malaysia), guar gum from Abdolghader Company (Shimi Center) (produced in India), and all chemicals were purchased from Merck Company (produced in Germany). The yeast was sourced from Khamir-Maye Razavi Company, and other materials required for the experiments, including frying oil (Bahaar brand, Tehran), salt, sugar, milk powder, and eggs, were purchased from a reputable store.

2-2- Methods

2-2-1- Preparation of Gel Emulsifier

Gel emulsifier samples containing emulsifiers Polysorbate 80, Carboxymethyl Cellulose (CMC), and DATEM, each at a level of 1% (based on the flour weight), and polyols Sorbitol and Propylene Glycol, each at a level of 2% (based on the flour weight), as well as a 1:1 mixture of these two polyols, were prepared. For this purpose, the gels were made using each emulsifier, polyol(s), water (for gel formation), and potassium stearate (at 2%). Potassium stearate is an emulsifier from the stearate salt family used to stabilize the formulation and increase viscosity. First, the mixture was prepared, and then, under continuous stirring, it was heated to 70°C. Upon cooling, gels were formed [13].

2-2-2- Preparation of Gluten-Free Doughnuts and Treatments

The basic doughnut ingredients included 55% rice flour, 5% sugar, 10% egg, 5% oil, 18% water, 0.5% guar gum, 3% yeast, 0.2% vanilla, 2.8% milk powder, 0.5% salt.

These were used for preparing the control sample.

To prepare the doughnuts, oil and eggs were first mixed in a mixer (model Sp 24, Disona, made in Germany) for 3 minutes. Sugar, yeast, guar gum, and water were then added (the gel emulsifiers were also added at this stage). Finally, the remaining dry ingredients, including rice flour, were added to the mixture, and mixing continued for 5 minutes until a uniform dough was obtained.

The prepared dough was left on the work surface for 5 minutes to undergo the initial fermentation stage. Then it was flattened on a flat surface to a thickness of 15 mm and cut with a mold (outer diameter: 8 cm, inner diameter: 3 cm). The shaped dough was placed on a tray and proofed in a proofer (model backcombi, Miwe, made in Germany) for 45 minutes at 43°C and 80% relative humidity to complete the fermentation. The doughnut samples were fried in a fryer (model DF 2008S, Beem, made in Germany) at 160°C for 6 minutes. After frying, the samples were placed on absorbent paper to remove excess oil and cool down (for 30 minutes at approximately 25°C). Finally, the doughnuts were packaged in polyethylene bags for quantitative and qualitative evaluations and stored at room temperature [14].

2-2-3- Evaluation of Quantitative and Qualitative Properties of Gluten-Free Fermented Doughnuts

2-2-3-1- Moisture and Oil Content Measurement

To measure moisture and oil content in the doughnut samples, the AACC (2000) methods were used [15].

2-2-3-2- Specific Volume Measurement

Specific volume of the doughnut samples was measured using the volume displacement method with rapeseeds, according to AACC method No. 72-10. A cube-shaped piece (25 mm per side) was cut from each sample using a serrated knife, weighed, and placed in a graduated cylinder filled with a known volume of rapeseeds. The increase in volume was recorded. Specific volume was calculated by dividing the volume by the sample's weight [15].

2-2-3-3- Porosity and Crust Color Measurement

Porosity and crust color were evaluated using image processing techniques. A 25-mm cube sample was cut using a serrated knife, and images of all three cross-sections were captured using a scanner (model: HP Scanjet G3010) at 600 dpi. These images were analyzed using Image J software to calculate the ratio of bright to dark pixels and estimate porosity. The average porosity of the three sections was reported as the final porosity value [16].

To determine the L*, a*, and b* color indices, images of the top and bottom crusts were also taken with the scanner. In ImageJ, the LAB color space plugin was activated, and the indices were calculated. The average values for both crust sides were reported as the color components [17].

2-2-3-4- Texture Evaluation

Texture firmness was assessed on days 1, 3, and 7 after production using a texture analyzer (model XT Plus, made in the UK). The maximum force required to penetrate the sample with a flat-ended cylindrical probe (2 cm diameter × 2.3 cm height) at a speed of 30 mm/min was recorded as the firmness index.

2-2-3-5- Peroxide Value Measurement

To measure the peroxide value of oil extracted from the doughnut samples, the Iranian National Standard No. 37 was followed [18]. The peroxide value (P) was calculated using the following formula:

Equation 1: $P = 1000 \times N \times V / W$

- V = Volume of sodium thiosulfate (mL)
- N = Normality of sodium thiosulfate solution
- W = Weight of fat (g)
- P = Peroxide value (in milliequivalents of oxygen per kilogram of fat)

2-2-3-6- Sensory Evaluation

For evaluating sensory attributes such as shape, airiness and porosity, texture firmness/softness, aroma, flavor, and taste—with respective weighting coefficients of 4, 2, 2, and 3, five-point hedonic scale was used (1: very undesirable, 2: undesirable, … 5: very desirable). Each doughnut sample was evaluated by 10 panelists. The overall acceptance of the samples was calculated using Equation 2:

Equation 2: $Q = \frac{\Sigma(P\times G)}{\Sigma P}$

- Q = overall acceptance
- P = attribute weighting coefficient
- G = attribute sensory score

2-2-4- Statistical Design and Data Analysis

The results of this study were analyzed using SPSS software version 16. A completely randomized design with a two-factor factorial arrangement was used. The first factor was the type of emulsifier (at three levels: Polysorbate 80, CMC, and DATEM), and the second factor was the type of polyol (at three levels: Sorbitol, Propylene Glycol, and a combination of both). The samples were prepared in triplicate, and the means were compared using Duncan's test at a 5% significance level ($P < 0.05$). Excel software was used to create graphs.

3- Results and Discussion

3-1- Evaluation of Quantitative and Qualitative Characteristics of Gluten-Free Fermented Doughnut

3-1-1- Moisture

The effect of different emulsifiers and polyols on moisture content of gluten-free doughnuts is shown in Figure 1. The sample containing CMC and propylene glycol had the highest moisture, while the samples with polysorbate 80 and sorbitol, and polysorbate 80 with a polyol mixture had the lowest moisture ($P<0.05$).

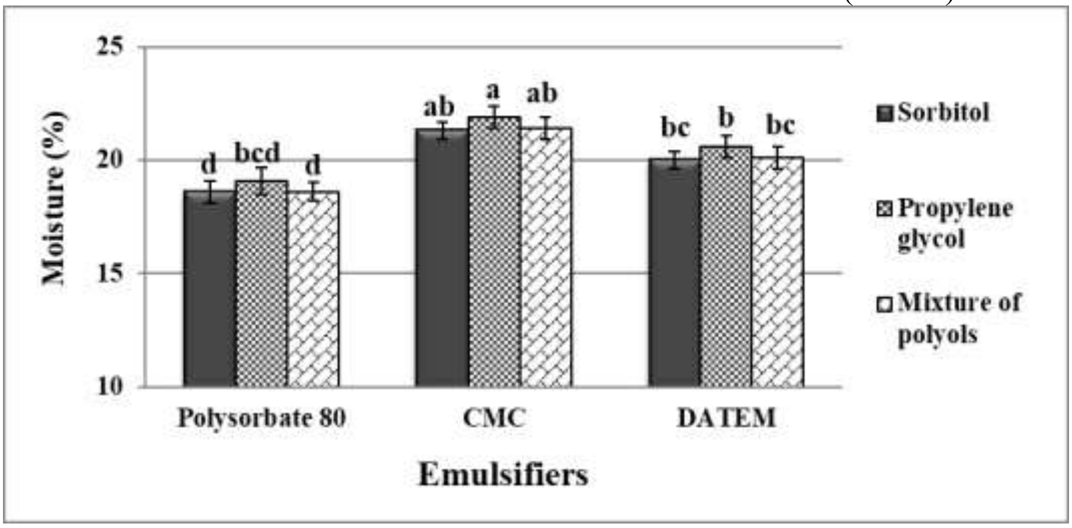

Fig 1. Effect of different emulsifiers and polyols addition on moisture content of gluten free doughnut (Means with different letters differ significantly in p<0.05)

Moisture is one of the qualitative characteristics of doughnuts that affects staling and shelf life of the product. As was mentioned, the addition of CMC compared to other emulsifiers had a greater effect in increasing the amount of moisture of gluten-free doughnut. In this regard, Zaghian *et al*., (2017) studied the effect of CMC, xanthan, and DATEM emulsifier on the characteristics of gluten-free cupcake based on rice starch and okara using the response surface method, and stated that with the increase of the quantity of all three variables from medium to high values, an increasing trend in the moisture content of the product is observed [19]. Gómez *et al*., (2007) reported that the reason for the increase in moisture in rice cake samples containing gum is related to the high water-holding capacity existing in the structure of both xanthan gum and the consumed CMC [20]. Nateghi and Rezaei (2021) also examined the effect of xanthan gum and CMC on the physicochemical and sensory properties of baguette bread and stated that the effect of CMC gum in increasing the percentage of moisture was much greater than xanthan gum. They stated in this regard that CMC gum, due to having chain groups, had a higher amount of hydroxyl groups than xanthan gum and was able to create more hydrogen bonds and consequently increase the moisture content of the product to a higher extent than xanthan gum [21].

But regarding the increase in the moisture content of the product containing DATEM emulsifier, Zomorodi and Faramarzi (2020), by examining the effect of flaxseed powder and DATEM emulsifier on the qualitative and sensory characteristics of doughnut, stated that with the increase in the amount of DATEM emulsifier in the product formulation, the moisture content increased. They attributed this issue to the ability of emulsifiers in absorbing water and helping to maintain the moisture of the product [22]. On the other hand, it was observed that the addition of propylene glycol compared to other polyols used in the formulation of gluten-free doughnut had a greater effect in increasing the moisture content of the product. In this regard, Ghiyasi Tarzi *et al.,* (2016) examined the effect of polyols (glycerin, polypropylene glycol, and sorbitol), invert syrup, and glucose syrup on the specific volume of dough and the shelf life of oil cake, and stated that cakes in whose formulation polypropylene glycol was used had more moisture content compared to other samples [12]. In this regard, Kasper *et al.,* (2007) stated that hygroscopic materials such as glycerin, sorbitol, and polypropylene glycol have an effective role in the moisture content of food products. These compounds, through the hydrophilic groups present in their structure such as hydroxyl and carboxyl groups, play a significant role in absorbing moisture of food products [23].

3-1-2-. Oil

The effect of adding different emulsifiers and polyols in the preparation of gel on the oil content of gluten-free doughnut samples is observed in Figure 2. As can be seen, the sample containing CMC and propylene glycol had the lowest amount of oil, and the two samples containing polysorbate 80 and sorbitol, and polysorbate 80 and the combination of polyols, had the highest amount of oil ($P<0.05$). According to the Iranian national standard No. 16980, the maximum oil content in doughnut is 25% [24], based on which all the samples are within the permissible range in terms of oil content.

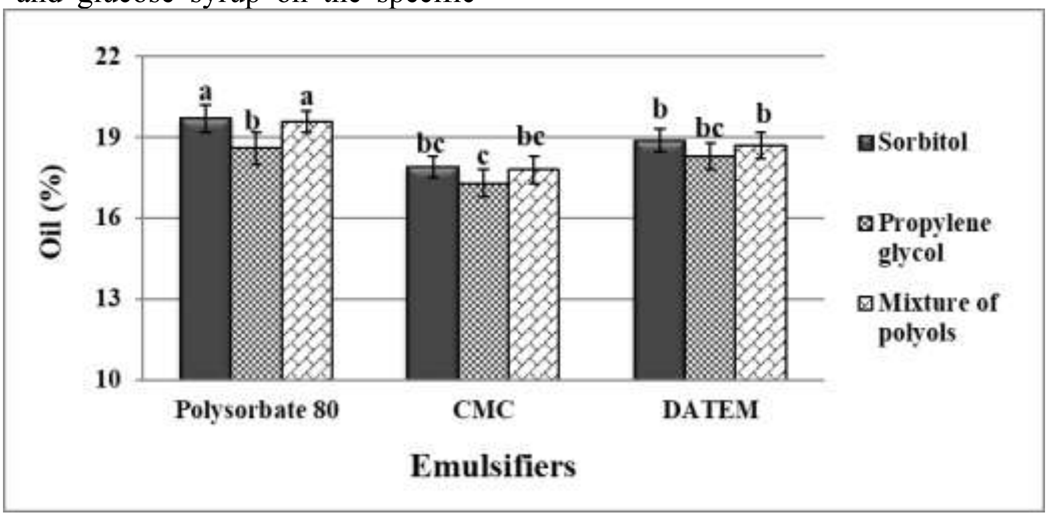

Fig 2. Effect of different emulsifiers and polyols addition on oil content of gluten free doughnut (Means with different letters differ significantly in p<0.05)

During the frying process, as a result of moisture evaporation, the existing water exits the product and oil molecules replace the water molecules, and for this reason, with the decrease of moisture, the amount of absorbed oil increases [25]. According to the results of the doughnut moisture evaluation section, it seems that CMC, compared to other emulsifiers, due to its greater effect in increasing the moisture of the doughnut, also has a greater ability to reduce the amount of oil absorption by the product during the frying process. In this regard, Fazeli *et al.,* (2019) studied the effect of xanthan gum, guar gum, and transglutaminase enzyme on the physicochemical and textural properties of gluten-free doughnuts and stated that with the increase of gum in the product formulation, a decreasing trend in the oil content of the product was observed. They explained that since in the absence of gums the dough moisture (free water) was very high, with the release of moisture during the frying process, more oil entered the doughnut samples [26]. According to the findings of Sakhalle *et al.,* (2011), the greater the moisture loss of the food material during frying, the higher the oil absorption [27]. Based on the results of Kaur *et al.,* (2015), the addition of arabic, guar, xanthan, and tragacanth gums to the formulation of gluten-free biscuits significantly affected the qualitative characteristics including water absorption capacity, oil absorption capacity, and emulsifying activity of the samples [29]. However, regarding the reduction of oil content in the product containing DATEM emulsifier and propylene glycol, it seems that these compounds, by increasing the moisture content of the final product and retaining it, reduce the oil content. Concerning the increase of moisture content in bakery products using the mentioned additives, further explanations have been provided in the moisture evaluation section.

3-1-3- Specific Volume and Porosity

Table 1 shows the effects on specific volume and porosity. The sample with CMC and propylene glycol had the highest specific volume, while polysorbate 80 with sorbitol and polysorbate 80 with polyol mixture had the lowest ($P<0.05$).

Table 1. Effect of different emulsifiers and polyols addition on specific volume, porosity and crust color values of gluten free doughnut

Emulsifiers	Polyols	Specific volume (ml/g)	Porosity (%)	Crust color values (-)		
				L*	a*	b*
Polysorbate 80	Sorbitol	3.00 ± 0.08^{d}	17.7 ± 0.5^{c}	42.06 ± 1.01^{c}	11.50 ± 0.53^{a}	16.51 ± 0.15^{a}
	Propylene glycol	3.30 ± 0.03^{c}	18.6 ± 0.4^{b}	48.21 ± 1.13^{b}	10.61 ± 0.32^{b}	16.33 ± 0.11^{a}
	Mixture of polyols	3.00 ± 0.02^{d}	17.8 ± 0.4^{c}	45.11 ± 0.9^{bc}	11.00 ± 0.08^{ab}	16.42 ± 0.02^{a}
CMC	Sorbitol	3.27 ± 0.04^{c}	18.7 ± 0.4^{b}	53.71 ± 1.17^{ab}	10.02 ± 0.02^{bc}	16.41 ± 0.13^{a}
	Propylene glycol	3.95 ± 0.05^{a}	19.5 ± 0.3^{a}	56.22 ± 0.72^{a}	9.42 ± 0.50^{c}	16.52 ± 0.14^{a}
	Mixture of polyols	3.33 ± 0.01^{c}	18.8 ± 0.5^{b}	53.03 ± 0.80^{ab}	10.06 ± 0.29^{bc}	16.50 ± 0.17^{a}
DATEM	Sorbitol	3.10 ± 0.02^{cd}	18.2 ± 0.4^{bc}	47.51 ± 0.09^{bc}	10.91 ± 0.13^{ab}	16.52 ± 0.07^{a}
	Propylene glycol	3.30 ± 0.02^{b}	19.1 ± 0.5^{ab}	54.18 ± 0.21^{ab}	10.10 ± 0.02^{bc}	16.41 ± 0.42^{a}
	Mixture of polyols	3.15 ± 0.04^{cd}	18.7 ± 0.5^{b}	49.33 ± 0.92^{b}	10.42 ± 0.54^{b}	16.63 ± 0.21^{a}

(Means with different letters in each column differ significantly in $p<0.05$)

In the formulation of doughnuts, oil is one of the factors responsible for maintaining the air bubbles incorporated into the dough during the mixing process. In fact, oil, by creating a protective layer around the incorporated air bubbles, plays an effective role in maintaining them in the dough and even preventing them from bursting due to expansion during the baking process [30]. Specific volume is one of the qualitative characteristics of doughnuts that affects staling and the shelf life of the product. As observed, the addition of CMC compared to other emulsifiers had a greater effect on increasing the specific volume of gluten-free doughnuts. In this regard, Nateghi and Rezaei (2021) investigated the effect of xanthan gum and CMC on the physicochemical and sensory properties of baguette bread and reported that by increasing the concentration of xanthan gum and CMC up to 1%, the specific volume of bread increased, with the effect of CMC gum on specific volume being greater than that of xanthan. They also stated that the reason for this is the hydrocolloid network formed by the gums, which strengthens the gas cells of the dough, leading to expansion during baking and ultimately reducing gas loss during baking, which improves the bread texture [21]. On the other hand, the presence of gum by increasing the water absorption capacity of the dough formulation and increasing specific volume significantly increased the bread volume. Similarly, Movahed *et al.,* (2017) studied the effect of hydroxypropyl methylcellulose gum on the quality properties of gluten-free baguette bread based on an equal mixture of corn flour and potato flour, and reported that with the increase in hydroxypropyl methylcellulose gum in the formulation, the specific volume of the product increased. They attributed the increase in volume to the hydrophilic property of the gum used, which was effective in improving dough expansion and carbon dioxide gas retention [29].

However, regarding the increase in specific volume of the product containing DATEM emulsifier, Zomorodi and Faramarzi (2020) by examining the effect of flaxseed powder and DATEM emulsifier on the qualitative and sensory properties of doughnuts, reported that with the increase of DATEM emulsifier in the formulation, the specific volume increased. They stated that DATEM emulsifier caused a proper distribution of air particles in the cake dough, which consequently increased dough viscosity, and this led to greater volume and better texture in the final product [22]. Mirhosseini and Abbasi (2021) studied the effect of sage seed and guar gums and DATEM emulsifier on the quality properties of gluten-free cupcakes based on oak and rice flour, and reported that DATEM emulsifier, by changing the surface tension of the medium and affecting the air retention capacity, reduced cake density. This emulsifier increased the amount of air trapped within the structure, leading to improved bread volume and texture and consequently reduced density [30].

On the other hand, the addition of propylene glycol compared to other polyols used in the gluten-free doughnut formulation had a greater effect on increasing the specific volume of the product. In this regard, Xi *et al.,* (2023) studied the effect of adding different types of propylene glycol alginate on the properties of a type of bread and reported that these compounds increased the specific volume of the product [31]. Zhao *et al.,* (2021) investigated the effect of hydrocolloids hydroxy methylcellulose and propylene glycol alginate on gluten-free bread and reported that these compounds increased the specific volume of gluten-free bread [32]. Ghiafeh Davoodi *et al.,* (2016) also studied the synergistic effect of hemectants with emulsifiers on the technological, imaging, and sensory properties of semi-leavened bread and reported that the addition of sodium stearoyl-2-lactylate emulsifier, compared to the sample containing emulsifier E471, had greater ability in preserving and maintaining air cells. This is because ionic emulsifiers such as DATEM and sodium stearoyl-2-lactylate have high ability in forming hydrogen bonds with the amide groups of gluten proteins. As a result, this strong network thickens the wall of air bubbles and prevents them from bursting due to expansion during the baking process, leading to an improvement in the specific volume of the final product [33].

Porosity is directly related to the number of gas cells and, more importantly, to their uniform distribution within the product structure [34]. Considering the results of the evaluation of texture and specific volume of doughnuts, it was expected that the porosity of the product would significantly change with the addition of the mentioned compounds. In this regard, Movahed *et al.,* (2017) reported that with the increase of hydroxypropyl methylcellulose gum in the formulation, the porosity of the product increased. They attributed the increase in porosity to the structural nature of hydroxypropyl methylcellulose gum, which has suitable ability in retaining and maintaining carbon dioxide gas [29]. Likewise, Maqsoud *et al.,* (2024) studied the effect of adding CMC and hydroxy methylcellulose on the physicochemical, textural, and sensory properties of gluten-free pancake, and their results showed that with the increase of these gums, the porosity of the product increased [35].

However, regarding the increase in porosity of the product containing DATEM emulsifier, Zomorodi and Faramarzi (2020) by examining the effect of flaxseed powder and DATEM emulsifier on the qualitative and sensory properties of doughnuts, reported that with the increase of DATEM emulsifier in the formulation, the porosity increased [22]. In this regard, Ashwini *et al.,* (2009) stated that among the advantages obtained by proper aeration process and the use of emulsifiers during emulsion production is the creation of a texture with fine, numerous, and uniform pores. in other words, a completely porous texture in the final product. By using emulsifiers, the air bubbles are distributed in small size and uniformly throughout the dough, and during baking, the release of air from these bubbles occurs properly, resulting in a product with suitable porosity and with small and uniform pores [36].

On the other hand, as observed, the addition of propylene glycol compared to other polyols used in the formulation of gluten-free doughnuts had a greater effect on increasing the porosity of the product. In this regard, Xi *et al.,* (2023) studied the effect of adding different types of propylene glycol alginate on the properties of a type of bread and reported that most of these compounds increased the porosity of the product [31].

3-1-4- Crust Color

The results showed that the sample containing CMC and propylene glycol had the highest and lowest levels of the L* and a* values of the crust, respectively (Table 1). Meanwhile, the lowest level of the L* value of the crust was observed in the two samples containing polysorbate 80 and sorbitol and polysorbate 80 and the mixture of polyols. These two samples also reported the highest level of the a* value of the crust ($P<0.05$). On the other hand, as can be seen, the addition of the above-mentioned compounds did not have a significant effect on the level of the b* value of the crust ($P<0.05$). Considering the section on the evaluation of the moisture content of the product, it seems that the compounds used, due to their ability to retain moisture and its more uniform release from the product texture during the baking process, cause the moisture to transfer more slowly and continuously from the crumb to the crust, and as a result, a smooth surface with the least amount of wrinkling in the final product is created, which this smooth and even surface has been effective in light reflection and increasing brightness. In fact, the surface changes of food materials are responsible for their brightness, and smooth and even surfaces, compared to wrinkled surfaces, have a greater ability to reflect light and increase the L* value. Lazaridou *et al.,* (2007) also reached this conclusion by adding several gums to the formulation of bread containing rice flour and corn starch that the use of gum in dough products caused an increase in the brightness of the crust color [37]. Also, Nateghi and Rezaei (2021) investigated the effect of xanthan gum and CMC on the physicochemical and sensory properties of baguette bread and stated that the sample containing 0.75% CMC gum and 0.75% xanthan gum had the

highest level of the L* value. They stated in this regard that this group of additives, by retaining moisture and preventing water loss during the baking process, reduce surface changes of the crust of the final product, which can be effective in increasing this color values [21].
However, regarding the increase in the L* value of the product containing DATEM emulsifier, Zamradi and Faramarzi (2020) stated in their study on the effect of flaxseed powder and DATEM emulsifier on the quality and sensory properties of doughnuts that with the increase in the level of DATEM emulsifier in the product formulation, the level of the L* value of the product increased. They attributed this matter to the ability of these compounds to retain moisture and its slower release from the product [22]. On the other hand, considering the section on the evaluation of the moisture content of the product and also given the constant frying time, it seems that the compounds used, due to their ability to retain, cause the frying process not to be fully completed, and this in turn has led to a reduction in the desirable redness of the doughnut crust. However, regarding the reduction of the a* value of the product containing DATEM emulsifier, Zamradi and Faramarzi (2020) stated in their study on the effect of flaxseed powder and DATEM emulsifier on the quality and sensory properties of doughnuts that with the increase in the level of DATEM emulsifier in the product formulation, the level of the a* value of the product decreased. They attributed this matter to the ability of emulsifiers to absorb water and help retain product moisture [22]. Also, Kim and Walker (1992) related the reduction of the a* value due to the use of DATEM emulsifier to the ability to homogenize and create very fine emulsion droplets, which causes the whitening of the dough [38].

3-1-5- Texture Firmness

As expected, the sample containing CMC and propylene glycol had the lowest, and the two samples containing polysorbate 80 and sorbitol and polysorbate 80 with the polyol combination had the highest texture firmness at two hours, three, and seven days after production ($P<0.05$) (Table 2).
Overall, the lack of moisture loss, especially during storage time, plays a vital role in maintaining the freshness of the texture of bakery products. It should also be noted that the occurrence of staling in bakery products such as bread and fermented doughnuts is related to the moisture content and the function of the water available in the crumb of these products [39]. It has been proven that there is an inverse relationship between the moisture content of bread and its staling degree [40]. In fact, water can act as a plasticizer and be effective in reducing crumb firmness. Moreover, since increasing the amount of water available to starch increases the likelihood of its crystallization, the significant tendency of hygroscopic compounds to absorb water and their high capability in water retention causes less water to be available for the starch. Consequently, less starch swells, gelatinizes, and recrystallizes during storage, which ultimately leads to reduced firmness and delayed staling of the product [41].

Table 2. Effect of different emulsifiers and polyols addition on firmness of gluten free doughnut during storage

Emulsifiers	Polyols	Firmness (N)		
		2h after baking	3 days after baking	7 days after baking
Polysorbate 80	Sorbitol	15.4±0.2^{a}	20.1±0.1^{a}	24.2±0.5^{a}
	Propylene glycol	14.1±0.3^{ab}	18.3±0.1^{b}	21.6±0.3^{b}
	Mixture of polyols	15.5±0.9^{a}	20.0±0.0^{a}	23.9±0.4^{a}
CMC	Sorbitol	13.2±0.2^{bc}	16.1±0.3^{c}	20.8±0.5^{bc}
	Propylene glycol	12.5±0.1^{c}	15.3±0.2^{d}	19.4±0.3^{c}

	Mixture of polyols	13.3±0.1^{bc}	15.9±0.1^{c}	20.5±0.6^{bc}
	Sorbitol	14.3±0.0^{ab}	18.5±0.1^{b}	23.2±0.5^{ab}
DATEM	Propylene glycol	13.2±0.1^{bc}	16.6±0.1^{c}	20.8±0.2^{bc}
	Mixture of polyols	13.9±0.2^{b}	18.1±0.0^{b}	22.9±0.2^{ab}

(Means with different letters in each column differ significantly in p<0.05)

In the present study, considering the fermented doughnut moisture evaluation section, it was evident that adding CMC and propylene glycol had the greatest effect on reducing the firmness of the final product's texture. In line with this, Maghsoud *et al.,* (2024) investigated the effect of adding CMC and hydroxypropyl methylcellulose on physicochemical, textural, and sensory properties of gluten-free pancakes and stated that the addition of these gums reduced the firmness of the product's texture. They attributed this effect to the capability of the gums used to retain moisture in the product and stated that following a high moisture level, starch retrogradation and staling are delayed [35]. Nateghi and Rezaei (2021) also examined the effect of xanthan gum and CMC on the physicochemical and sensory properties of baguette bread and reported that the effect of CMC in reducing crumb firmness was considerably greater than that of xanthan gum. They explained that the reduction in firmness in bread is due to the influence of hydrocolloids on the starch structure, such that hydrocolloids cause changes in the starch structure, which results in better distribution and retention of water in the starch and reduces the texture resistance of the bread.
However, regarding the reduction of firmness in the product containing DATEM emulsifier, Zamoudi and Faramarzi (2020) examined the effect of flaxseed powder and DATEM emulsifier on the quality and sensory properties of doughnuts and stated that with increasing the amount of DATEM emulsifier in the product formulation, the firmness of the product texture decreased. They attributed this effect to the ability of emulsifiers to absorb water and help retain the moisture of the product [22]. Ghiafeh Davoodi *et al.,* (2016) also investigated the synergistic effect of homogenates with emulsifiers on the technological, imaging, and sensory properties of semi-volume bread and stated that the lowest firmness was related to the sample containing 0.2% DATEM emulsifier, 0.2% sodium stearoyl lactylate emulsifier, and 0.5% polypropylene glycol. They linked this effect to the capability of these compounds to react with starch and protein as well as to prevent moisture loss in the final product [33].
On the other hand, as observed, the addition of propylene glycol had a greater effect on reducing firmness compared to other polyols used in the gluten-free doughnut formulation. It seems that propylene glycol and other polyol compounds reduce the firmness of the final product by absorbing moisture and preventing its loss. In this regard, Ghiyasi Tarzi *et al.,* (2016) studied the effects of polyols (glycerin, polypropylene glycol, and sorbitol), invert syrup, and glucose syrup on the specific volume of dough and shelf life of butter cake and stated that cakes formulated with polypropylene glycol had higher moisture content compared to other samples [12].
In this regard, Kasper *et al.,* (2007) stated that hygroscopic substances such as glycerin, sorbitol, and polypropylene glycol play an effective role in the moisture content of food products. These compounds, through the hydrophilic groups in their structure such as hydroxyl and carboxyl groups, play a significant role in the moisture absorption of food products [23].

3-1-6- Peroxide Value

The results showed that the sample containing CMC and propylene glycol had the lowest peroxide value, while the two samples containing polysorbate 80 and sorbitol and polysorbate 80 combined with polyols had the highest peroxide values

(P<0.05) (Figure 3). It should be noted that a peroxide index higher than 6 mEq/Kg in a product indicates rancidity and that the product is unfit for consumption [42]. Therefore, it is clear that controlling and reducing this parameter is of special importance. According to the Iranian National Standard No. 16980, the peroxide value for oil extracted from doughnuts should be a maximum of 3 mEq/Kg [24], and based on the results, the peroxide values of all produced fermented doughnut samples were within the permissible standard range.

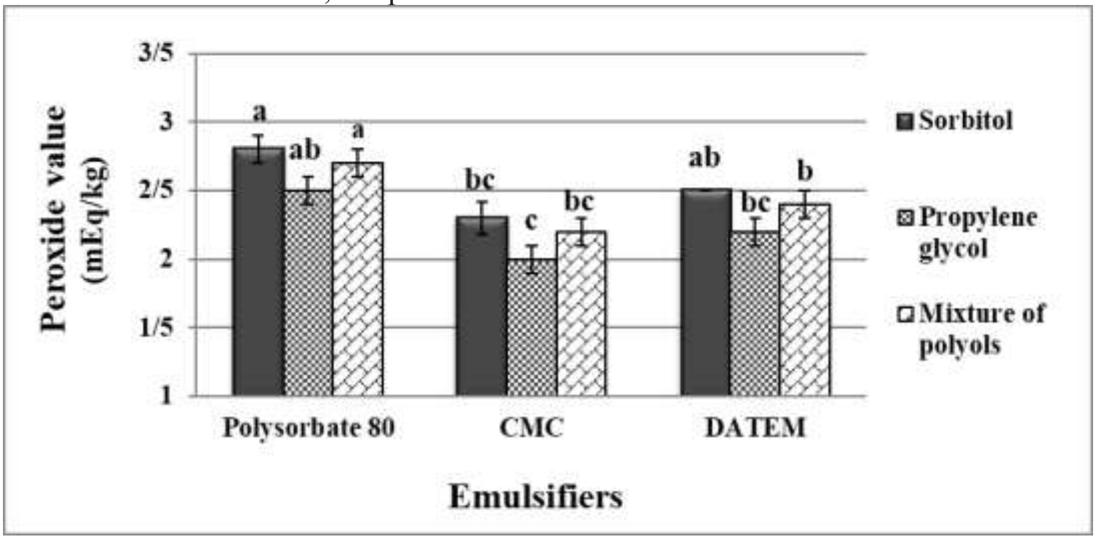

Fig 3. Effect of different emulsifiers and polyols addition on peroxide value of gluten free doughnut (Means with different letters differ significantly in p<0.05)

Factors that increase the peroxide index include heat, unsaturation, contamination of the fat with rancid fat, and exposure to air. Therefore, according to the results of the moisture evaluation and the amount of absorbed oil in doughnuts, it was expected that in any sample where less oil was absorbed, the peroxide value would be lower. In this regard, it seems that in the sample containing CMC and propylene glycol, since less oil was absorbed by the product and, on the other hand, due to the higher moisture content of the product, the core temperature of the product likely increases more slowly, which prevents an increase in peroxide value. In this context, Sabbaghi (2021) investigated the application of hydrocolloid compounds (xanthan and CMC) in doughnut formulation aimed at reducing oil absorption and stated that a high oil content in the product due to processes such as flavor reversion and oxidation causes off-flavors and reduces consumer desirability. Therefore, efforts to reduce the fat content in fried foods have great importance compared to other quality properties [43]. Overall, researchers have stated that the role of hydrocolloid compounds in fried foods, besides reducing oil absorption, includes maintaining the shape and stability of the product during processing, reducing solids loss from the product surface during frying, and improving the organoleptic properties of the product. Also, Paramasivam *et al.,* (2022) studied the effect of gums on the structure, texture, and characteristics of low-fat banana chips and stated that adding CMC in the product formulation reduced the peroxide value. These researchers explained the reduction in peroxide value with hydrocolloid addition by stating that these compounds have oxygen barrier capabilities and thus reduce this parameter [44].

3-1-7- Overall Acceptance in Sensory Evaluation

The sensory panelists gave the highest overall acceptance scores to the two samples containing CMC and propylene

glycol, and the lowest scores to the two samples containing polysorbate 80 and sorbitol, and polysorbate 80 combined with polyols ($P < 0.05$).
In sensory evaluation, the first parameter that the panelists assess is the color of the product. For this reason, this parameter is of special importance. According to the results of the moisture evaluation and color parameters, it appears that in the sample containing CMC and propylene glycol, moisture transfers slowly and more continuously from the core to the crust, resulting in a smooth surface with minimal wrinkling in the final product. This smooth surface affects light reflection and increases brightness, which likely explains why the sensory evaluators gave this sample a higher score.

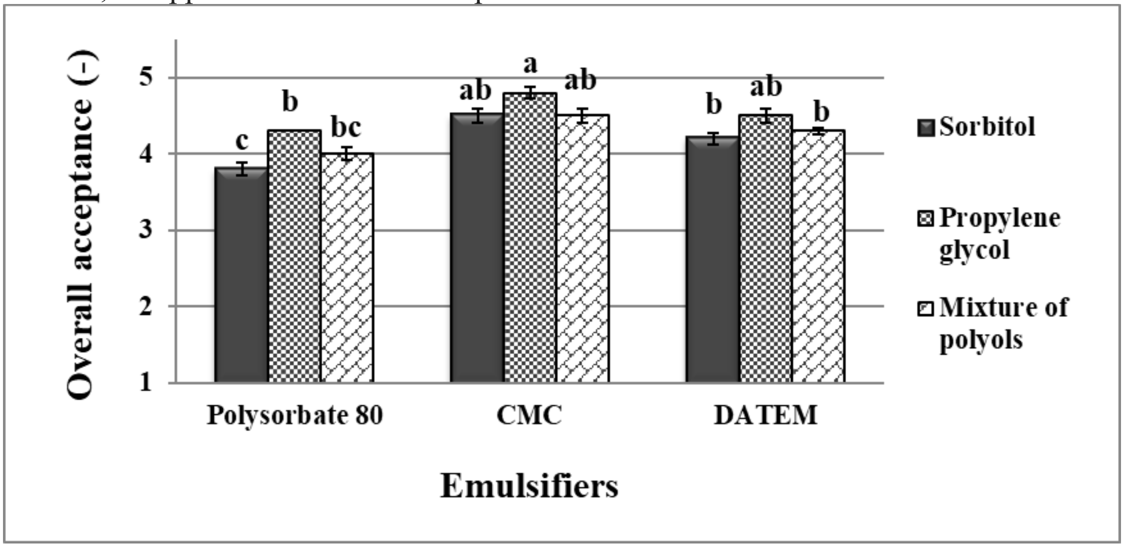

Fig 4. Effect of different emulsifiers and polyols addition on overall acceptance of gluten free doughnut in sensory evaluation
(Means with different letters differ significantly in p<0.05)

Also, in sensory testing, when scoring texture, doughiness or abnormal softness, hardness, crispness, and brittleness lead to point deductions. As observed in the texture analysis section, the addition of CMC and propylene glycol in the gluten-free doughnut formulation reduced the firmness of the texture. Therefore, based on these results, it was expected that the sensory evaluators would also assign higher scores to the sample containing CMC and propylene glycol among the produced samples.
On the other hand, researchers believe that the perception of flavor intensity and release of flavor compounds depend on the type of texture of the final product. Boland *et al.,* (2006) attributed this phenomenon to different interactions between flavor compounds and the texture structure [45]. Thus, based on previous studies and the results from texture analysis and sensory texture evaluation, it was predicted that because the sample containing CMC and propylene glycol had a softer texture, the sensory panelists would give this sample the highest flavor score, which ultimately led to the highest overall acceptance score for this sample.

4- Conclusion

The aim of this study was to investigate the possibility of improving the technological, sensory, and shelf-life properties of gluten-free fermented doughnuts by adding gel emulsifiers containing CMC, DATEM, and polysorbate 80 emulsifiers, as well as polyols including propylene glycol, sorbitol, and their mixture. Based on the results, CMC showed a higher ability than the other gel emulsifiers used to improve the quantitative and qualitative characteristics of the produced samples. Furthermore, propylene glycol demonstrated performance similar to CMC and had a synergistic effect on enhancing the final product's properties. Ultimately, it can be stated that using a gel emulsifier containing CMC and propylene glycol significantly contributed to improving the technological, sensory, and shelf-life characteristics of gluten-free fermented doughnuts.

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مقاله علمی_پژوهشی

ارزیابی عملکرد ژل امولسیفایر و پلی‌ال‌ها بر بهبود خصوصیات تکنولوژیکی، حسی و ماندگاری دونات تخمیری بدون گلوتن

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چکیده

دونات از جمله میان‌وعده‌هایی می‌باشد که در رژیم غذایی افراد مختلف جامعه دیده می‌شود و بهبود خصوصیات این محصول همچون افزایش مدت زمان ماندگاری آن و حفظ نرمی بافت و تازگی با صرف کمترین هزینه و تغییرات در روش تولید سبب افزایش سودآوری برای تولیدکنندگان می‌گردد. از این‌رو در تحقیق پیش‌رو از امولسیفایرها و پلی‌ال‌های مختلف در فرمولاسیون دونات بدون گلوتن تخمیری استفاده شد. بدین منظور نمونه‌های ژل امولسیفایر حاوی امولسیفایرهای پلی سوربات ۸۰ کربوکسی متیل سلولز و داتم هریک در سطح ۱ درصد (بر اساس وزن آرد مصرفی)، تهیه شدند. همچنین از پلی‌ال سوربیتول و پروپیلن گلایکول به میزان ۲ درصد (بر اساس وزن آرد مصرفی) و مخلوط دو پلی‌ال نیز به منظور بررسی اثر هم‌افزایی با نسبت برابر به فرمولاسیون دونات تخمیری بدون گلوتن اضافه شد و ویژگی‌های فیزیکوشیمیایی، خصوصیات حسی و ماندگاری فیزیکی و شیمیایی محصول تولیدی در یک طرح کاملاً تصادفی با آرایش فاکتوریل مورد ارزیابی قرار گرفت ($P\leq۰/۰۵$). نتایج نشان داد که با افزودن ژل امولسیفایر حاوی کربوکسی متیل سلولز و پلی‌ال پروپیلن گلایکول به فرمولاسیون دونات تخمیری بدون گلوتن، میزان رطوبت، حجم مخصوص، تخلخل، مؤلفه L^* پوسته محصول در مقایسه با سایر ژل امولسیفایرهای مورد استفاده افزایش بیشتری یافت. این در حالی بود که ژل امولسیفایر مذکور از قابلیت بیشتری در کاهش میزان مؤلفه a^* پوسته، سفتی بافت (در هر سه بازه زمانی دو ساعت، روز سوم و روز هفتم پس از پخت) و میزان جذب روغن نمونه‌های دونات بدون گلوتن برخوردار بود. در خصوص ارزیابی خصوصیات حسی نیز نتایج نشان داد نمونه حاوی کربوکسی متیل سلولز و پروپیلن گلایکول از امتیاز رنگ، بافت، طعم و پذیرش کلی بیشتری نسبت به سایر نمونه‌ها برخوردار بود. بنابراین می‌توان گفت استفاده از ژل امولسیفایر حاوی کربوکسی متیل سلولز و پروپیلن گلایکول راهکاری در دسترس به منظور افزایش ماندگاری دونات تخمیری بدون گلوتن می‌باشد.