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The Effect of Inulin Substitution as A Fat Replacer on Physicochemical and Sensory Properties of Muffins

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ABSTRACT

The increasing rates of obesity and related health problems are largely attributed to the excessive consumption of high-fat foods. Thus, a fat substitute is proposed to replace the same functions of fats in food products. This study explored the potential of inulin as a fat substitute to produce low-fat muffins. Five batches of muffins, each with varying levels of inulin replacing oil (ranging from 0 to 100%), were prepared to examine how this substitution would impact the physicochemical and sensory properties of the muffins. Calorie content was determined using a bomb calorimeter, whilst the moisture, fat and fibre content were determined based on the AOAC International standard method. The muffin's texture was analysed using a texture analyser, and the height was measured by calculating the average of different parts of the muffin. The acceptance level of muffins was conducted using a 9-point Hedonic scale. The addition of 15% inulin reduced the fat content by 68.05% and calories by 12.63% compared to the control without significantly affecting the physicochemical properties and sensory acceptability. Additionally, inulin provided the advantage of increasing fibre content by 82.76% when compared to the control sample. Increasing the amount of inulin also increased height and improved the aerated structure of muffins. The study provides evidence for the effectiveness of inulin as a fat replacer, which can help produce low-fat food products with good functional properties and nutritive value for health.

Keywords: Bakery products, fat replacer, nutritional content, physicochemical, sensory properties

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INTRODUCTION

The overconsumption of energy contributes to obesity and heightens the susceptibility to non-communicable diseases, such as diabetes, cancer, and cardiovascular conditions, in multiple countries. A significant global health concern arises from the threefold increase in obesity rates from 1975 to 2016, as highlighted by NCD Risk Factor Collaboration (NCD-RisC) (2017). Numerous countries have adopted policies to encourage healthier eating habits in response to this challenge. Consequently, consumers are displaying an escalating inclination toward reduced-fat products and an expanding curiosity about natural fat replacers renowned for their superior functionalities (Mozaffarian et al., 2018)

Bakery products are among the foods that contain relatively high fat. This fat is needed to improve the product's sensory characteristics and quality, including physical characteristics and textures that contribute to overall palatability. Fat serves multiple crucial purposes, such as enhancing lubrication, influencing sensory perception, and ensuring product stability and shape (Renzyaeva, 2013; Rios et al., 2014). However, frequent consumption of high-fat foods causes consumers to worry about excess energy intake, which can cause weight gain. However, fat is an important macronutrient for human health; too many leads to obesity, diabetes type II, cardiovascular diseases (CVDs) and metabolism disorders (Barroso et al., 2017).

Saturated and trans-fat replacement ingredients have become more common in producing healthy food products. A fat replacer serves as a substance that can mimic some or all the fat activities while using fewer calories. It is important for reducing the risks associated with fat as well as for reaching the desired properties of the finished product without degrading its inherent qualities (Colla et al., 2018). Moreover, the ideal fat replacer would not only indirectly mitigate risks but also enhance the functional properties of the food, contributing to health benefits upon consumption (Kraus, 2015).

Inulin has been part of daily food intake for centuries and contributes to nutritional benefits as well as exhibits important technological properties (Moghadam et al., 2019; Wang et al., 2019; Wei et al., 2023). Inulin also has numerous biological activities, such as reducing the risk of colon cancer, arteriosclerosis, and osteoporosis, regulating food intake by reducing appetite, controlling diabetes and obesity, stimulating the immune system, enhancing absorption of calcium, magnesium, and iron, and maintaining low levels of triglycerides and cholesterol (Shoaib et al., 2016).

Short-chain inulin has a good, mildly sweet mouthfeel and is highly soluble. Meanwhile, long-chain inulin is used as a texture modifier or can act as a fat replacer due to its poor solubility and viscosity (Meyer et al., 2011). It is highlighted that long-chain inulin molecules possess a distinctive capacity to imitate fat, rendering them valuable as fat replacers, as well as exhibiting the capability to form microcrystals (Ahmed & Rashid, 2019). These microcrystals establish a network structure through effective water retention, forming minor aggregates that can subsequently combine to create an expansive gel network (Bayarri et al., 2011).

Many previous studies have been conducted to replace some of the fat in various baked products (Rodríguez-García et al., 2014; Sayed & Khalil, 2017; Zahn et al., 2010), which reduced significant reduction of fat content in the products. Inulin emerged as the most efficient option for substituting dietary fat in baked goods, reducing overall energy content without compromising consumer satisfaction. Fat replacement by up to 50% inulin did not affect consumer acceptability (Rodríguez-García et al., 2014). Adding inulin at 8% resulted in acceptable attributes comparable to muffins made with full fat (Ren et al., 2020).

Consumers highly value muffins due to their pleasurable taste and resilient consistency. Nevertheless, the increased caloric content from incorporating fats or oils has resulted in heightened consumer concerns regarding the product (Martínez-Cervera et al., 2013). A muffin normally contains approximately 50% fat, providing a smooth and soft texture. Therefore, there is a need to provide consumers with low-calorie foods without compromising the quality and acceptance of the food product. This study aims to determine the influence of replacing fat with inulin in muffins on nutritional composition, textural properties, and sensory acceptability.

MATERIALS AND METHODS

Muffin Butter Preparation

The formulation and procedure to prepare muffin butter were taken from Gisslen (2016) with slight modifications. The muffin batter mixture was prepared by weighing wheat flour, icing sugar, baking powder, salt, egg, fresh milk, vanilla extract, and oil (Table 1). The dry ingredients of wheat flour, sugar, baking powder, and salt were shifted into a bowl to prepare the control muffin sample. Meanwhile, in a separate bowl, all liquid elements encompassing egg, fresh milk, vanilla extract, and oil were vigorously whisked using a handheld wire whisk. Subsequently, the liquid constituents were combined with the blend of dry ingredients, and the mixture was carefully mixed using a spatula. This process continued until all the flour moistened, forming a batter with a slightly lumpy texture. In muffins containing inulin, the powder was included in the dry components and blended using a whisk to ensure uniform dispersion, followed by slow incorporation with the wet ingredients. Each formulation containing inulin employed a specific quantity of water, as indicated in Table 2.

The batter was then panned and baked immediately in an oven with a temperature of 180°C for 20 min; otherwise, the muffin would lose its volume. The process was repeated for three replications with the addition of inulin levels, as stated in Table 2. Water content was adjusted in all formulations to allow inulin to act as a fat mimetic and obtain a constant batter viscosity during the preparation of muffins.

Table 1

The weight and baker's percentage of ingredients for preparation of control muffin

Ingredients	Weight of ingredients (g)	Baker's percentage (%)
Wheat flour	260	100
Sugar	120	46.2
Baking powder	10	3.8
Salt	6	2.3
Eggs	50	19.2
Milk	200	76.9
Vanilla extract	5	1.9
Oil *	130	50
Total	751	300.3

Note. *The oil replacement with inulin solution was varied at 0, 25, 50, 75, and 100%, respectively

Table 2

Variation in the amount of oil, inulin, and water in the formulated muffin

% Fat replacement level	% Corn oil (Weight, g)	% Inulin solution	
		Inulin (g)	Water (g)
0	50.0 (130)	0 (0)	0 (0)
25	37.5 (97.5)	5 (13)	7.5 (19.5)
50	25.0 (65)	10 (26)	15.0 (39)
75	12.5 (32.5)	15 (39)	22.5 (58.5)
100	0 (0)	20 (52)	30.0

Note. Expressed as baker's percentage, inulin is added in a solution form

Determination of Texture

The muffin's consistency was evaluated through applying texture profile analysis (TPA) utilising a TA.XT Plus texture analyser (Stable Micro Systems, United Kingdom). The TPA protocol utilised in this investigation was adapted from the methodology proposed by Bender et al. (2017) with modest modifications. Three replicates were prepared for each muffin formulation. A cylindrical probe made of aluminium with a diameter of 75 mm (referred to as P/75) was utilised to compress the muffin according to its vertical dimension to conduct the analysis. The TPA test employed a dual compression cycle, with compression levels reaching up to 40%. The experimental circumstances consisted of a pre-test velocity of 5 mm/s, a compression velocity of 1 mm/s, and a post-test velocity of 5 mm/s. The texture profile was evaluated to assess its firmness, adhesiveness, springiness, cohesiveness, and chewiness.

Determination of Muffin Height

Muffin height was measured using a centimetre (cm) ruler. The height of the muffin was measured specifically from the highest point (referred to as the pinnacle) to the lowest point (the base of the muffin cup). These measurements were taken before the muffin was baked and after it had cooled for one hour at room temperature, which was maintained at 25°C (Arifin et al., 2019). Thirty muffins were analysed, with each formulation consisting of three muffin samples. For each muffin, ten measurements were recorded from various sides.

Determination of Nutritional Composition

The moisture, fat, and fibre content of the produced muffins were assessed in accordance with Horwitz (2006).

Determination of Calorie Value

The calorie value in the muffin was determined by using a bomb calorimeter (IKA C2000, Germany) to measure the heat released on the complete combustion of the food samples. Following the procedure by Basolo et al. (2020), approximately 1 g of the sample was weighed and placed in a combustion capsule, then inserted in the oxygen-bomb head. For thorough combustion, the fuse wire was connected to the bomb head and subsequently brought into contact with the pellet. Prior to inserting the bomb head, 1 ml of water was introduced into the bomb calorimeter. A temperature-controlled water volume of 2 L was poured into an associated container and then positioned within the calorimeter. The oxygen bomb was carefully placed into the container after ensuring an airtight seal and the calorimeter electrodes were affixed to the oxygen bomb head. Once the pellet weight was recorded, the samples underwent combustion. The samples were run in triplicate, and the average results were calculated. The total calories of the muffin were calculated below:

Total calories of muffin = Total pellet calories (kcal/g) x Total dry weight of samples

Determination of Sensory Evaluation

A hedonic test determined the sensory acceptability of the different muffin formulations. The muffin was cut into quarters and packed in plastic for each formulation. For each panellist (n = 30), the sample of muffins with different levels of inulin (0, 12.5, 25, 37.5, and 50% expressed as baker's per cent) was presented on a tray. A 9-point hedonic scale for odour, moistness, softness, sweetness, taste, and overall flavour was used in the sensory evaluation. A balanced presentation order was used, and all panellists were provided drinking water to cleanse their palettes between the samples.

Statistical Analysis

The data was analysed through a oneway analysis of variance (ANOVA), and subsequently, Tukey's test was employed to compare the means of the samples. This analysis was carried out at a significance level of 0.05 ($p < 0.05$). The statistical software utilised for data analysis was IBM SPSS (version 25). The results were expressed as mean values of the three replicated samples ± standard deviation.

RESULTS AND DISCUSSION

Textural Properties

In general, substituting inulin into the formulation did not affect the textural properties of vanilla muffins. Table 3 shows the textural properties of muffins for different levels of inulin. Having similar textural properties of muffins between different formulations gives us a sign that inulin was able to produce acceptable qualities as a full-fat muffin. Long-chain inulin was reported as having the capability to produce microcrystals, which aggregate together, interact with water, and finally agglomerate to generate a gel network (Bayarri et al., 2011), which could mimic the functions of fat in baked by lubricating the dry ingredients.

Table 3
Texture properties for different concentrations of inulin

Fat replacement level (%)	Firmness	Adhesiveness	Springiness	Cohesiveness	Chewiness
0	3363.78 ± 256.06 [a]	-4.45 ± 6.18 [a]	0.86 ± 0.01 [a]	0.61 ± 0.01 [ab]	2063.16 ± 145.54 [a]
25	3391.93 ± 793.60 [a]	-19.73 ± 17.66 [a]	0.86 ± 0.01 [a]	0.59 ± 0.04 [ab]	1986.44 ± 459.21 [a]
50	3869.44 ± 319.20 [a]	-52.92 ± 8.09 [ab]	0.87 ± 0.01 [a]	0.56 ± 0.01 [b]	2219.12 ± 274.62 [a]
75	3917.79 ± 143.46 [a]	-36.443 ± 27.40 [a]	0.87 ± 0.01 [a]	0.58 ± 0.03 [ab]	2239.49 ± 84.75 [a]
100	3866.20 ± 123.60 [a]	-131.73 ± 69.22 [b]	0.84 ± 0.11 [a]	0.64 ± 0.04 [a]	2463.46 ± 94.23 [a]

Note. Different superscript letters in the same column represent significant differences ($p < 0.05$). Values are mean ± standard deviation

Although there is no significant difference in the firmness of the muffin, the trend shows that the addition of inulin increased the firmness of the muffin (Table 3). This finding is similar to Harastani et al. (2021) in that they used inulin and green banana flour to reform muffins. The replacement of 50% inulin leads to the lowest cohesiveness of the muffin. The results also showed an increase in the cohesion trend in both directions, whether full fat or one 100% inulin replacement.

This situation may be caused by the ability of either fat or inulin to retain water, which in turn increases the cohesiveness of the muffin. Bojnanska et al. (2015) found that increasing the level of inulin in bread dough (15–25%) resulted in higher water absorption compared to lower levels of inulin. This increase in water absorption contributed to enhanced cohesiveness in the bread. Meanwhile, fat in baked products is a binding agent, holding ingredients together and preventing them from falling apart (Colla et al., 2018).

The most obvious effect is shown when 100% fat replacement has caused a significant decrease in adhesiveness. It means that increasing inulin substitution might weaken the strength and integrity of the product, but overall, the substitution revealed that inulin improves the textural properties of muffins. This finding is almost the same as that of Liu et al. (2016). The previous study showed that substituting fat with inulin may significantly influence texture parameters in bakery products (Harastani et al., 2021; Sayed & Khalil, 2017; Zahn et al., 2010). Since adding a fat replacer at a certain level can cause significant changes in texture and physical properties, complete fat replacement is not recommended in baked products.

Muffins Height and Volume

The height and cross-section measurements of baked muffins for each formulation are shown in Table 4 and Figure 1, respectively. This study shows that the height of the muffin increased with the increase of inulin. There is a significant increment in the height of muffins added, with 15% and 20% inulin showing values of 61.46% and 62.89%, respectively. The addition of 5% and 10% inulin did not have much effect on its height compared to the control (Table 4). This result differs from Liu et al. (2016), in which the specific volume and the height decreased after certain levels of inulin substitution. The height or volume of muffins significantly increased by more than 60% when 15% and 20% of inulin were added. The degree of polymerisation (DP) of certain inulin can impact the volume of baked items. According to Ziobro et al. (2013), the loaf volume increased with the application of inulin with an average DP of 10. In contrast, the volume decreased when inulin was used with an average DP of 23. Their study also showed a similar trend to the current finding in which, although the volume increased, the internal structure was less uniform and more open.

The cross-sectional diagram depicted in Figure 1 demonstrates that incorporating inulin can potentially enhance the aerated structure of muffins. The analysis of muffin cross sections reveals that increasing the inulin content from 5 to 20% (equivalent to a complete substitution of fat) leads to an enlargement of the bubble size. The number of bubbles exhibited a decline, simultaneously with an expansion in the dimensions of the bubbles, as the concentration of inulin increased. This discovery aligns with a research study by Rodríguez-García et al. (2014). Muffins that contain 100% fat replacement level clearly

Table 4
Height measurement for different concentrations of muffin after baking

Fat replacement level (%)	0	25	50	75	100
Muffin height (cm)	4.68 ± 0.19 [b]	4.40 ± 0.08 [b]	4.40 ± 0.14 [b]	5.19 ± 0.22 [a]	5.39 ± 0.08 [a]
Per cent of the increment (%)	57.27	54.54	54.54	61.46	62.89

Note. Initial height = 2 cm, n = 30; Different superscript letters in the same row represent significant differences ($p < 0.05$)

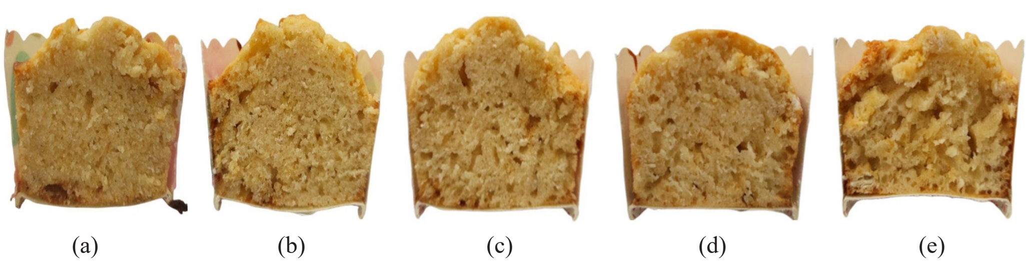

Figure 1. Muffins with different percentages of inulin cut in half after cooling: (a) 0% fat replacement, (b) 25% fat replacement, (c) 50% fat replacement, (d) 75% fat replacement, and (e) 100% fat replacement

showed uneven bubble size. It shows that fat replacement can be added to the muffin with only a maximum of 75%. The internal texture of the muffin would depend on the type of fat replacer used in the formulation in which inulin was found to give an irregular porous structure as compared to hydroxypropyl methylcellulose (HPMC) (Ren et al., 2020).

The present analysis reveals that the control sample containing 100% corn oil exhibits smaller, evenly distributed bubbles than formulations supplemented with inulin. Nevertheless, using 100% oil in the muffin exhibits a limited specific volume within a highly condensed and tightly knit grain structure. The cross-section of muffins containing inulin also showed heterogeneous distributions of air cells in the crumb. The irregular crumb in the muffin containing inulin, especially at the higher level, might be due to high hydration dough in which part of the oils was substituted with a certain amount of water. In this case, the water-to-flour weight ratio increased as the inulin increased. Higher water addition would significantly increase specific volume and pore size in the experimental bread, thus simultaneously decreasing the number of pores (Schoenlechner et al., 2010).

Nutritional Composition

There was an increase in moisture content in the muffin with the increase of inulin. Replacing oils with inulin in the muffin significantly increased moisture content from 24.04 ± 0.30% in the control sample to 32.70% ± 0.36% in 100% fat replacement (Table 5). A similar result was reported by Zahn et al. (2010) when 50% margarine was replaced with inulin in muffins. The increase in trend is due to the use of carbohydrate-based fat replacers that possess high water binding capacity and require a higher amount of water in the formulation. These features provide benefits in creating a paste that can mimic the texture and consistency of fats by offering flow properties or lubricants that closely resemble those found in the food system (Colla et al., 2018). Water binding capacity can be influenced by the inulin's polymerisation degree. The inclusion of High-Soluble Inulin (HSI) (DP < 10) and Granulated Inulin (GR) (DP ≥ 10) preparations reduced the dough's water absorption by 1.6–4.0% compared to the control, whereas High Performance Inulin (HPX) (DP > 23) enhanced water absorption by 1.6–4.8% (Ziobro et al., 2013).

The muffins that underwent a 75% fat replacement demonstrated a significant reduction of 68% in fat content compared to the control sample, which consisted of corn oil muffins. This reduction in fat content did not have any discernible impact on the degree of acceptability indicated by the panellists. Although the 100% fat replacement can reduce up to 95% of fat (Table 5), the resulting muffins are less acceptable compared to formulations with less fat replacement (Table 6). Majzoobi et al. (2018) have reported similar results, indicating that complete fat replacement in cake leads to diminished quality, as evidenced by asymmetric structure, reduced volume, light crust, and a tougher texture.

Including inulin in the formulations resulted in a notable increase in the fibre content in the muffin, which aligns with the research conducted by Ng et al. (2021) and Zahn et al. (2010). The use of inulin in food products could influence organoleptic attributes, affecting consumer acceptability. Inulin found in foods serves as both soluble dietary fibre and prebiotics. Furthermore, it is worth noting that inulin possesses the additional benefit of being resistant to enzymatic digestion within the human small intestine. This characteristic renders it highly desirable as a dietary fibre source in numerous processed food items (Chaito et al., 2016).

Calorie Value of Muffins

Inulin has been recognised as a fat substitute capable of emulating the functional and sensory characteristics of unaltered high-fat food items while not adding to the overall caloric content. This study found that increasing the amount of inulin in muffins decreased their calorie content (Table 5), potentially making them a healthier food option. Fat replacement at 50%, 75%, and 100% significantly reduced calories by 12.37%, 12.63%, and 30.96%, respectively, compared to the control sample (100% oil). Although calorie content was successfully

Table 5
Nutritional composition and calorie content per 100 g muffin at different concentrations of inulin

Inulin content (%)	Fat replacement level (%)	Moisture content (%)	Fat content (%)	Fibre content (%)	Calorie content (kcal)
0	0	24.04 ± 0.30 [c]	17.37 ± 0.60 [a]	0.05 ± 0.03 [b]	388 ± 22 [a]
5	25	25.30 ± 0.48 [c]	12.73 ± 0.55 [b]	0.12 ± 0.05 [b]	386 ± 24 [ab]
10	50	29.08 ± 0.02 [b]	10.52 ± 0.06 [c]	0.17 ± 0.07 [b]	340 ± 20 [bc]
15	75	31.32 ± 0.87 [a]	5.55 ± 0.53 [d]	0.29 ± 0.06 [a]	339 ± 9 [c]
20	100	32.70 ± 0.36 [a]	0.90 ± 0.21 [e]	0.32 ± 0.05 [a]	323 ± 18 [c]

Note. Different superscript letters in the same column represent significant differences ($p < 0.05$)

reduced by 30.96% in the muffin with full-fat replacement (20% inulin), this formulation has affected the texture and texture acceptability of the muffin. Therefore, it is advisable to substitute the fat by using a maximum of only 15% inulin (75% fat replacement) in the muffins.

It is important to note that calorie content is not the only factor to consider when determining the healthfulness of food; other nutrients like fibre, vitamins, minerals, and overall diet should also be considered. Various food products have employed inulin as a sugar or fat replacement, which can assist in lowering the calorie level (Gao et al., 2016; Khramova et al., 2021; Soh et al., 2021). Adding inulin from chicory root effectively replaced dietary fat in sponge cake, reducing total energy and producing a softer texture without affecting consumer acceptance (Rodríguez-García et al., 2012).

Sensory Properties

Sensory evaluation was conducted to determine if muffins containing inulin affected sensory acceptance among panellists. Table 6 represents the sensory acceptability of muffins formulated with different levels of inulin. This investigation reveals that the complete substitution of oil with inulin did not impact the sensory acceptance of the muffins in terms of their aroma, taste, and sweetness features. However, the acceptance levels pertaining to softness and moistness showed a notable decrease in a muffin that underwent a substitution of 20% inulin or a complete replacement of fat. The result also showed that inulin can replace fat for up to 75% without affecting the overall acceptance level. Nevertheless, substituting inulin up to 100% resulted in a significant reduction compared to other muffins. The 100% substitution of fat with inulin had a detrimental impact on the overall acceptability, indicating that inulin cannot fully replace the functional role of fat. In their review on fat replacers, Colla et al. (2018) did not recommend replacing 100% of inulin in baked products because it might cause a significant decrease in consumer acceptance.

Table 6
Sensory acceptability of muffins for different concentrations of inulin

Inulin content (%)	Odour	Moistness	Softness	Sweetness	Taste	Overall acceptability
0	6.87 ± 1.55 [a]	5.60 ± 1.83 [ab]	5.47 ± 1.74 [ab]	6.333 ± 1.47 [a]	5.97 ± 1.56 [a]	6.07 ± 1.66 [ab]
5	6.67 ± 1.58 [a]	5.80 ± 1.61[ab]	5.77 ± 1.72 [ab]	6.03 ± 1.97 [a]	6.13 ± 1.81 [a]	6.27 ± 1.78 [ab]
10	6.37 ± 1.73 [a]	6.23 ± 1.65 [a]	6.30 ± 1.68 [a]	6.50 ± 1.503 [a]	6.40 ± 1.38 [a]	6.70 ± 1.47 [a]
15	6.73 ± 1.80 [a]	5.47 ± 2.26[ab]	5.33 ± 2.41 [ab]	6.10 ± 2.37 [a]	5.70 ± 2.23 [a]	5.87 ± 2.19 [ab]
20	5.80 ± 1.88 [a]	4.83 ± 1.97 [b]	4.80 ± 2.04 [b]	5.37 ± 2.08 [a]	5.43 ± 1.96 [a]	5.23 ± 2.03 [b]

Note. Different superscript letters in the same column represent significant differences ($p < 0.05$). Values are mean ± standard deviation

The impact of using inulin as a substitute for fat in baked goods can exhibit variability contingent upon the specific food item and the quantity of inulin employed. A study by Liu et al. (2016) showed that the inclusion of 6% inulin as a substitute for fat in a prebiotic cake did not significantly impact sensory characteristics compared to a muffin containing 10% inulin. However, a study by Ren et al. (2020) revealed that the incorporation of inulin as a substitute for fat in muffins yielded an improved sensory experience characterised by reduced oiliness in the end product.

CONCLUSION

This study proves that incorporating inulin into muffin recipes yields notable fat and calorie content reductions while enhancing fibre. Importantly, these modifications do not adversely affect the physical and chemical characteristics of the sensory appeal of the end product. The study's results demonstrated that replacing oil with inulin led to a significant decrease in fat and calorie levels compared to the control group. Moreover, the augmentation of inulin content positively impacted the height and texture of muffins, resulting in an enhanced aerated structure. The utilisation of inulin as a substitute for fat also presents a potential avenue for enhancing the dietary fibre composition of the muffin. This study provides evidence that inulin is a promising and effective fat replacer in baked goods, which can help produce low-fat, low-calorie food products with good functional properties and nutritive value for health. Further investigation is needed to examine the prospective utility of inulin as a replacement for fat in various food items and assess its long-term effects on human health.

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