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Characterization of Coconut Oil-Beeswax/Gelatin based Food-Grade Bigel and Its Application in Muffin as Trans-Fat Replacement

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KEYWORDS

Bigel, Oleogel, Hydrogel, Commercial Margarine, Muffins.

ABSTRACT:

Fats play multiple roles in determining variety of desirable characteristics in food. Shortenings are the key components of high quality baked products. Their effects on dough structure formation and desired final product attributes depend on solid fat content and β′ crystalline polymorphs. However, there are health concerns regarding saturated and trans-fats present in the shortening. Thus, alternative plastic fats with little or zero quantity of saturated and trans-fatty acids are now in high demand. In this regard, the bigel (also called hybrid gel) produced from a combination of an oleogel (lipophilic phase) and a hydrogel (hydrophilic phase) have been proposed as a novel fat replacer in food industry. In this research, synthesized bigel (coconut oil/ beeswax oleogel and veg gelatin hydrogel) were used in muffin preparation against commercial margarine (CM) as control, to compare the textural and sensory properties, and fatty acid profile of the muffins. The results showed that in almost all parameters, the bigel muffins resembled CM muffins. However, their fatty acid profile were affected since the CM contains trans-fat but the synthesized bigel contained no amount of trans-fat. Therefore, using bigel as trans-fat replacer, muffins were obtained with a texture similar to those with CM, showing the potential of bigels to be used in the reformulation of healthy food products.

1. Introduction

Fats and oils are important raw materials for variety of food products [1]. Many bakery products are formulated with solid fats, like shortenings and margarines, which contain high amount of saturated fatty acids (SFAs) and trans-fatty acids (TFAs). These fatty acids, which are present in the form of triacylglycerols, cause the assembly of a colloidal or supracolloidal particle network, responsible for structuring the fat into a solid or solid-like material [2]. However, there are serious health concerns about solid fats, that is, SFAs and TFAs. The increased usage of saturated fat and trans-fat intake has negative effects on chronic diseases like obesity, cardiovascular disease, and diabetes etc. TFAs, a form of unsaturated fatty acids, are especially harmful due to the fact that their intake is highly related to raising the level of low-density lipoprotein (LDL) cholesterol, which is known as 'bad cholesterol' and to high-density lipoprotein (HDL) reduction, which is known as 'good cholesterol' [3-5]. It is well known that consumption of unsaturated fatty acid is somewhat beneficial for health. But the presence of higher amount of unsaturated fatty acids in cooking oils prevents the formation of structure in oils at room temperature. Therefore, the replacement of solid fat in food with vegetable oils has adverse effect on food quality and is not easy. For improvement, some of the researchers in their studies, used partially hydrogenated vegetable oil (PHVO) and palm stearin in the solid structured form. However, the advancement of knowledge about the composition of fatty acids in variety of food products and their role in human health have now led to the consumer demand for limiting trans and saturated fatty acid in food products [6-7].

Food manufacturers are therefore facing challenges to replace solid fat in food products without affecting the quality attributes of the products. The replacement of margarines and shortenings in bakery food products is difficult to achieve without altering physical properties, because they play important role in tenderizing the crumb, retaining long-term softness, keeping good quality, and extending the shelf life of the food. However, bakery goods seem like suitable products for saturated and trans-fat replacements or reduction, because of their high demand and consumption, and these changes would confer significant health benefits [8-9].

In this regard, the bigel (or hybrid gel) is a novel solid-like formulation produced from a combination of an oleogel (lipophilic phase) and a hydrogel (hydrophilic phase). One phase is dispersed and the other one is continuous, and the bigel structure is obtained by mixing both phases at high shear rate

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in optimum temperature. The lipid phase is converted into oleogel, structured by using an oleogelator. The aqueous phase forms a hydrogel by using appropriate hydrophilic gelling agent which is capable of absorbing large amount of water. Oleogels are soft matter structures that can trap oils in a thermo-reversible gel network, producing products with properties similar to solids [10-13]. Oleogels produced with beeswax (BW) have been studied previously with good results; the properties of BW oleogels can be tailored to specific food applications by operating with suitable process conditions. The functionality of food products containing BW oleogels has been positively evaluated as a total or partial fat replacer in food [14]. In recent years, oleogels have begun to be applied in various processed food items such as chocolate and spreads, muffins and cookies, ice cream, and frankfurters etc [15-17]. It is important to expand the utilization of oleogels in a wider range of food products with the current demand of low or no saturated and trans-fat and high unsaturated fats in diets. On the other hand, hydrogels are another three-dimensional solid networks formed by physically or chemically cross-linked hydrophilic polymeric structures that can trap water or any other biological liquid inside their network. Hydrogels pose interesting properties like easy spreadability and miscibility, and their compatibility with a wide range of excipients (i.e., solvents) results in a wide range of applications. As a thermoreversible gel, gelatin gels tend to melt above a certain temperature which depends on the concentration and source and is normally below human body temperature. This “melt-in-mouth” property of gelatin is a highly desirable textural characteristic for good human consumption perception, showing the potential to improve the quality of low-fat foods [18-19].

Currently, bigels are mainly used in the field of pharmaceutical and cosmetic, but their applications have already started getting found in the food area too. Some food-grade bigels have been studied posing that it is possible to tailor their rheology, thermal stability, and mechanical properties, directing their characteristics to allow for their potential use in food products as a saturated/ trans-fat or total fat replacer [20-22]. The potential of bigels in food as a fat replacer was introduced for the first time by Ghiasi et al. [23], who found that low-fat beef burgers made by using bigels shown better cooking properties as compared to animal fat burgers. Moreover, there were no significant differences detected by sensory panelists between control and low-fat burgers in terms of overall acceptability.

Muffins are traditionally composed of wheat flour, solid fat, sugar, baking powder, and other minor ingredients. An appropriate combination of these basic ingredients can result in muffin with high-quality attributes. Especially, solid fat plays a significant role in generating the viscous foam structure of muffin by entrapping air bubbles into the fat phase of the batters. Therefore, the use of solid fat is necessary for the aeration of baked muffin for their maximum volume and soft texture quality [24]. However, as mentioned earlier, the solid fat (usually shortening or margarine) used in making muffin is generally high in trans-fatty acids and also contain saturated fatty acids. Therefore, the solid fat replacement in muffins could result in a healthier product (trans-fat free) with prolonged shelf life but with greater brittleness and hardness, and lower crumbliness, than the muffins made with shortening or margarine. For this reason, in this study, the authors decided to prepare trans-fat free muffins using bigel. The aim of this research was to evaluate the role of the type of oleogel and hydrogel used in the development of bigel to be used as low SFAs and TFAs replacers in muffins. Bigel was prepared with coconut oil/beeswax oleogel, and veg gelatin was used as gelling agent to prepare the hydrogel. The characterizations of bigel were done using various technique.

2. Materials and Methods

2.1 Materials

Cold pressed coconut oil (VAMA oil, Coimbatore, India) was purchased from a local supermarket and stored at 4℃ until use. Veg-gelatin powder (Carrageenan E407) and beeswax (BW) which is a yellowish solid pellet with a mild odor and melting point of 63-65℃ were provided from Loba Chemie, Mumbai, India. All other chemicals and reagents used in this investigation were of analytical grade and purchased from SRL Pvt. Ltd. Mumbai (India).

2.2 Bigel formulation

Initially, the oleogel and hydrogel were prepared separately. After that, the two gels were mixed together at room temperature to obtain a homogenized bigel (Fig.1). Oleogel (BW-O) was prepared by mixing BW (7% w/w) with cold pressed coconut oil. The mixture was heated until 70℃ and stirred for 30 min at 300 rpm. Then, the resulting solution was immediately kept at room temperature for at least 2 h. After that, the oleogel was stored in refrigerator (6℃). Hydrogel was prepared by mixing veg-gelatin powder (7% w/w) with distilled water. The mixture was stirred at room temperature until complete dissolution was achieved (for about 2 h). Then, the resulting hydrogel was stored in refrigerator (6℃). Bigel was prepared by mixing the oleogel with the hydrogel in proportions of 50/50 (w/w) in batches of 100 g. Each mixture was conditioned at 30℃ in an oven for at least 1 h. Then, the oleogel and hydrogel were mixed together using a homogenizer (Model No. GIh850, Omni General Laboratory, USA) at mixing rates of 25,000 rpm for 2-3 min in total. The synthesized bigel was stored in a glass container in refrigerator for 24 h before being analyzed. These conditions to prepare the bigel got from previous experiment that looked for bigels with solid-like texture for food application [25-26].

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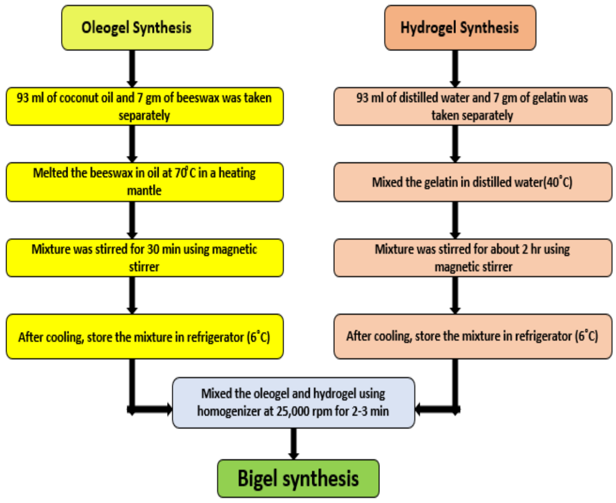

Figure 1: Method of the development of bigel.

2.3 Bigel characterization

Once bigel is synthesized, the formulation is usually confirmed by the tube inversion test (TIT). This is the most common and easy method for proving gelation which involves turning a test tube or vial with the sample in it and checking whether it flows under its own weight. If the sample does not flow, a correct bigel is considered to have formed [27].

2.3.1 Fatty acid profile

The fatty acid composition was determined according to the AOCS Official Method Ce 1f-96, using gas chromatography (7820A, Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector [28].

2.3.2 Microstructural analysis

The internal phase distribution in synthesized bigel was analyzed by Confocal scanning laser microscopy (Olympus, Tokyo, Japan). A fresh bigel sample was spread on a glass bottom slide of the microscope. The cover was sealed on the slide with soybean wax after preparation to prevent the moisture evaporation before imaging. The analysis was done by using fluorescent dyes which were used to stain each phase of bigel separately. A 0.2% solution of Nile red in ethanol was used to dye the hydrophobic (oil) phase while a 0.2% solution of Nile blue A in distilled water was used to color the hydrogel (aqueous) phase. Two different excitation laser sources were used in the experiment: an argon laser with excitation of 514 nm (Nile red) and a helium-neon laser (He-Ne) with excitation at 633 nm (Nile blue). Multiple images were obtained, but a representative one is depicted in the result section [29].

2.3.3 Molecular studies

X-ray diffraction analysis was done to study the crystalline polymorphism of the bigel. The sample was analyzed using X-ray diffractometer (D8 Advance, Bruker, Karlsruhe, Germany) equipped with a $CuK_{\alpha}1,2$; a K_{β} X-ray tube was set to 40 kV and 40 mA. The bigel sample was mounted on a Lucita sample plate and gently compressed by hand. Scans were collected from $2\theta = 2^{\circ}$–50° with step sizes of 0.02° at 1 s per step. The EVA (Bruker Corp., Billerica, MA, USA) software was used to identify and analyze the different peaks [30].
The prepared bigel formulation was also analyzed using an FTIR spectrometer (AlphaE ATR-FTIR, Bruker, Bremen, Germany). The spectra of the formulation was recorded in the ATR (attenuated total reflectance) mode. The spectra was measured in solutions of 2 cm^{-1} with 32 scans in the wave number ranging from 4000–500 cm^{-1} [31].

2.3.4 Antioxidant analysis

The radical scavenging activity was studied using DPPH assay as described by [32] with some modifications. 20 µL of various dilutions of bigel sample was mixed with a 0.2 mM methanolic DPPH solution. After 30 min of incubation at 25±2°C, the absorbance was recorded as A (sample) at 524 nm. For the A (blank), same experimentation was applied for a solution devoid of the test material, and then we recorded the absorbance. For each solution, the calculation of free-radical-scavenging activity was done as percent inhibition (%) following this equation: $\% \text{ Inhibition} = 100 \times [(A_{(blank)} - A_{(sample)}) / A_{(blank)}]$. The IC50 is the concentration required for the test formulation to cause a 50% decrease in DPPH concentration. Ascorbic acid was used as reference. All the measurements were performed in triplicate.

2.4 Preparation of muffins

The development of the bigel based muffins and commercial margarine based muffins (as control) consisted of 120 g refined flour, 100 g sugar, 180 ml milk, 2.5 g baking powder, 2.5 ml vinegar, and 5 ml vanilla essence. All purchased from the local shop of Lucknow city. For control, 45 g commercial margarine (Baked Mart) was used, while for experiment 45 g of formulated bigel was used to replace commercial margarine in muffins. The flow chart of the recipe is given in Fig 2. Portions of 45 g ± 0.5 of batter were added to paper muffin cases and then placed into metallic muffin trays. Muffins were baked in a pre-heated oven for 30 min at 190 °C. After baking, the muffins were allowed to cool at room temperature for 1 h and then stored in plastic bags until further analysis.

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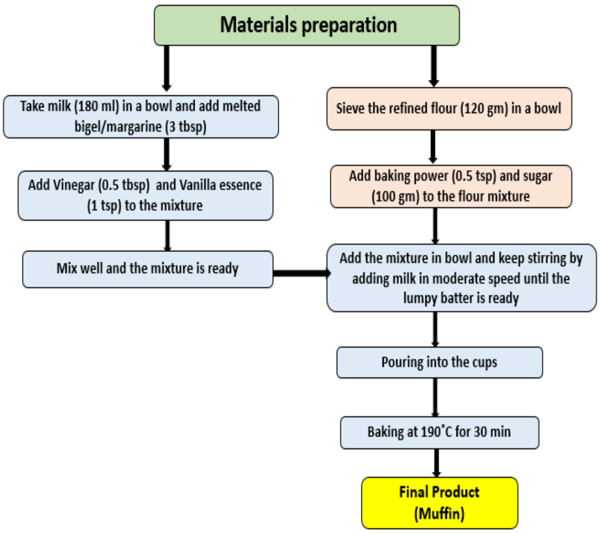

Figure 2: Flow chart of the muffin recipe.

2.5 Characterization of Muffins

2.5.1 Textural profile analysis

Texture profile analysis of the prepared muffins was carried out using a texture analyzer (TMSPro, Food Technology Co., VA, U.S.A.). Muffin crumbs were cut into a cylindrical shape (23 mm in height × 40 mm in diameter) and a cylindrical probe (50 mm diameter) was lowered at a speed of 60 mm/min to compress the muffin samples to 50% of the original height. From the forcetime plots, hardness, cohesiveness, chewiness and springiness of the muffins were determined [33].

2.5.2 Sensory Evaluation

Sensory evaluation of the muffins were carried out by following the method reported by Meilgaard et al. [34]. Evaluation was done using hedonic scale by the sensory panel consisting of 5 judges. The panelists were naive to this research. Samples were coded by giving random numbers. Panelists were given a glass of water in order to rinse and swallow water between muffins testing. They were given written instructions and asked to evaluate the products for different attributes i.e. appearance, taste/flavor, aroma, texture, and overall acceptability**,** and to mark on the sheet of Hedonic Rating Test (where, 1 stands for "dislike extremely", 9 stands for "Like extremely" and 5 stands for "Neither like nor dislike") in accordance with their opinion as shown in Table.1.

Table 1: Point hedonic scale used for sensory evaluation

Score	***Likeness***
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

2.5.3 Fatty acid composition

The fatty acid composition of the muffins prepared with bigel and CM were analyzed according to the official method, using a gas chromatograph (Hewlett-Packard 6890, Agilent Technologies, Santa Clara, CA, USA) with flame ionization detector [33]. Lipids in the muffins were extracted with ethyl ether, and triundecanoin (Sigma-Aldrich, St Louis, MO, USA) in isooctane was added as an internal standard at a concentration of 1 g L^{-1}. Fatty acids were derivatized (using 140 g kg^{-1} boron trifluoride in methanol) to fatty acid methyl esters, which were injected into an SP-2560 column (100 m × 0.25 mm i.d., 0.2 μm thickness; Supelco, Bellefonte, PA, USA). Helium was used as the carrier gas at a flow rate of 0.75 mL min^{-1}. The oven temperature was set at 100°C for 4 min, then increased to 225°C and for 20 min. The injector and detector temperatures were 225°C and 285°C respectively. Each fatty acid peak was quantified as an equivalent of the concentration of the internal standard (Sigma-Aldrich)**.**

2.5.4 Microstructure analysis

A SEM (scanning electron microscope) is used to study the morphology of particle of the sample and is a type of electron microscope that creates images of nano-particles by scanning the surface of particle with a focused beam of electrons. The electrons interact with atoms in particles, producing various signals containing information about the morphology and composition of the particles. EDX (Energy Dispersive X-Ray Analyze) was used to provide elemental identification and quantitative compositional information of the prepared muffins [35].

2.5.5 Proximate analysis

Muffins were assessed for proximate composition i.e. carbohydrate, crude protein, total fat, ash and moisture content, and water activity according to their respective methods as given in AACC 2000 [36].

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2.6 Statistical analysis

All the required analysis were performed in three replications and the obtained data were subjected to Mean and Standard Deviation (SD) values using Microsoft Excel 2007.

3. Results and Discussion

3.1 Characterization of Bigel

It is depicted from Fig. 3 that the synthesized bigel was highly viscous and did not show any flow under gravity, therefore confirming the formation of a gelled structure. A careful observation of the confocal images (CLSM) at different focal planes revealed the co-existent of two separate phases. Thus it was concluded that the hydrogel and oleogel phases create a bi-continuous gel network in bigel (Fig 3). Such bi-continuous gel networks were previously reported for combinations of different biopolymer gels, for example; gelatin and whey proteins with various polysaccharides such as maltodextrin, xanthan, and gellan [37]. The ratio between the two phases (oleogel and hydrogel) and the composition used for each phase control the formation of a bi-continuous phase, while above and below this regime, two separate phases were confirmed.

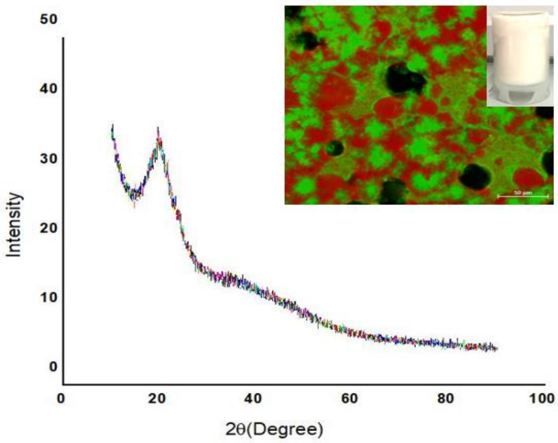

Figure 3: The XRD pattern, CLSM image and tube inversion test of the resulting bigel.

The diffraction pattern obtained from X-ray analysis showed in Fig.3 that the resulting synthesized bigel was a semi-crystalline solid that presented both, a crystalline and an amorphous component. The crystalline component shown a low degree of crystallinity, while the amorphous component contributed largely to the diffraction pattern. The strong diffraction peaks at 19◦, 21◦, and 23◦ of the bigel were due to the presence of beeswax in oleogel preparation. Beeswax is a semi-crystalline solid with a high degree of crystallinity [38] showing strong diffraction peaks, corresponding to d spacing of 4.5, 4.1, and 3.7 Å, respectively. These peaks are characteristics of beeswax and show the presence of β, α, and β' crystals in the structure. This confirms that the crystalline structure of the bigel is due to the oleogel made with beeswax; however, the presence of hydrogel particles led to the prevalence of the amorphous characteristic of bigel similar to those found in previous studies. Overall, the X-ray diffraction patterns of the bigel suggests that the crystal structure is not very much dependent on the type of polymer used in the formulation of hydrogel, suggesting that the homogenization process using high shear rates could destroy the crystal structure formed in the original oleogel, which might cause the synthesized bigel matrix to have lesser oil-retention capacity.

Table 2: Fatty Acid Compositions (%) of the Coconut Oil & Coconut Oil based Bigel

Fatty Acids	*Coconut Oil*	*Coconut Oil based Bigel*
SATURATED FATTY ACIDS		
Capric acid (C10:0)	7.01	6.1
Lauric acid (C12:0)	44.62	44.78
Tridecanoic acid (C13:0)	2.21	2.14
Myristic acid (C14:0)	20.42	20.41
Palmitic acid (C16:0)	11.21	12.7
Stearic acid (C18:0)	2.66	2.23
Arachidic acid (C20:0)	1.43	1.47
Total SFAs	89.56	89.83
MONO UNSATURATED FATTY ACIDS		
Cis-9 oleic acid (C18:1)	5.52	5.89
Total MUFAs	5.52	5.84
POLY UNSATURATED FATTY ACIDS		
Linoleic acid (C18:2)	1.82	1.94
Linolenic acid (C18:3)	1.12	1.13
Total PUFAs	2.94	3.07

Most of the fatty acids found in the cold pressed coconut oil were maintained in synthesized bigel (Table 2). Moreover, trans-fatty acids were not detected in the bigel formation. The main fatty acids identified in cold pressed coconut oil were lauric acid (C12:0), myristic acid (C14:0), palmitic acid (C16:0) and cis-9 oleic acid (C18:1), which are consistent with reports by other authors for coconut oil [39-40]. It can be observed that in the oleogel, the palmitic acid and other fatty acids (present in minor amounts) slightly increased their amount, compared to coconut oil. This could be due to the BW being mainly a heterogeneous mixture of long-chain esters, n-alkanes, and fatty acids, where the amount of free fatty acids can be 9–11%, as suggested by some authors. Thus, BW can contribute to the fatty acid content of oleogels. Coconut oil is recognized for its high content of SFAs (which is good quality for oil structuring), low content of MUFA, and very low content of PUFA, which is in accordance with what was found in our research. The oil had approximately 89.56% of SFAs, 5.52% of MUFAs, and 2.94% of PUFAs, while bigel contained 89.83%

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SFAs, 5.84% of MUFAs, and 3.07% of PUFAs, which was not very different from the fatty acid profile of cold pressed coconut oil. The result indicates that the structuration of coconut oil in bigel matrices containing beeswax and veg gelatin as gelling agents allows for the maintenance of the healthy fatty acid profile of the original oil.

FTIR analysis was performed to obtain information on possible intermolecular interactions between components of both phases in bigel. The spectra of bigel formulated with 7% (w/w) gelatin and the oleogel, are shown in Fig.4. The bigel shows intense peaks at 2916 and 2848 cm^{-1}. These two peaks correspond to C–H stretching from cooking oil. Peaks at 1172 cm^{-1} and 1463 cm^{-1} correspond to C–H bending, while 1735 cm^{-1} corresponds to C= O stretching. In the gelatin spectra, the broad peak in 3200–3400 cm^{-1} range is associated with O–H and N–H stretching and bending from water and gelatin, respectively. The peak at 1636 cm^{-1} corresponds to C=O stretching in gelatin. The bigel shows a combination of the peaks identifed in the pure gel samples. The sample shows clear characteristic peaks from gelatin. Overall, the spectra did not show any major shifts or the presence of new peaks from interactions between the components of both phases, suggesting that the resulting formulation is a “true” bigel.

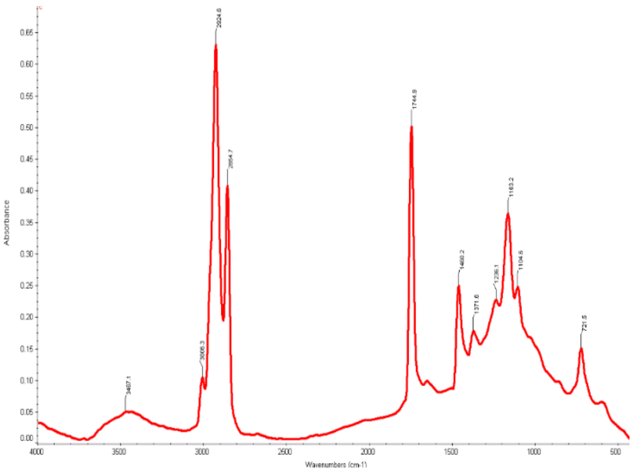

Figure 4: FTIR spectra of the resulting bigel.

The antioxidant analysis of the synthesized bigel was done by using DPPH Assay method. Since coconut oil contain a good amount of antioxidant activity**,** the bigel made from the oil possessed good amount of antioxidant activity too. According to Phongpaichit [41] IC_{50} value (µg/ml) of 10-50 shows strong antioxidant activity, followed by 50-100 having intermediate antioxidant activity while more than 100 indicates weak antioxidant activity. Here, from the Table 3 and Fig 5 we observe the strong antioxidant activity of the coconut oil based bigel due to the capacity of coconut oil being a good source of antioxidant.

Table 3: Radical Scavenging Activity (%) and IC_{50} value (µg/ml) of the resulting bigel.

S.No.	*Concentration*	*OD at 517nm*		*% Scavenging*	*IC_{50} value (µg/ml)*
	(µg/ml)	Control	Sample		
1	50	0.441	0.214	51.4739	
2	100	0.441	0.185	58.0499	
3	150	0.441	0.167	62.1315	**26.132**
4	200	0.441	0.135	69.3878	
5	250	0.441	0.129	70.7483	

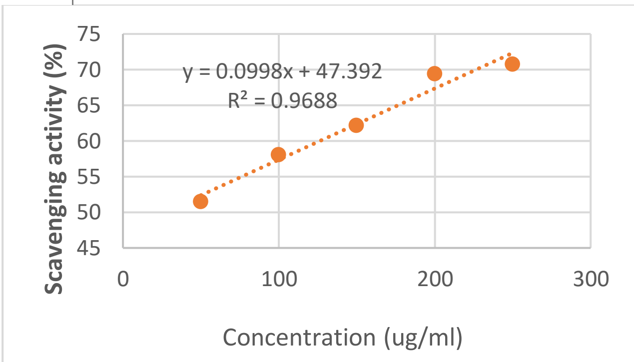

Figure 5: Graph showing the bigel’s Radical Scavenging Activity (%) at different concentration (µg/ml) of the sample.

3.2 Characterization of Muffins

Figure 6: Muffins made from synthesized bigel and commercial margarine (control).

Muffins made from synthesized bigel and commercial margarine (control) are presented in Fig 6. The effects of margarine replacement with bigel on the muffin texture were investigated. As presented in Table 4, there were almost no differences in the cohesiveness and springiness of the muffins. However, the hardness and chewiness were slightly increased

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in bigel based muffins due to the low volume and dense structure.

Table 4: Effect of margarine replacement with bigel on the textural properties of muffin crumbs.

Texture	*Control*	*Bigel*
Hardness	5.34 ± 0.16	8.26 ± 0.39
Cohesiveness	0.81 ± 0.02	0.79 ± 0.03
Chewiness	4.17 ± 0.09	6.74 ± 0.28
Springiness	0.78 ± 0.05	0.80 ± 0.02

Sensory analysis of muffin samples made from bigel along with commercial margarine (control) was done by panelists and its mean is shown in Fig.7. The data revealed that there is no significant differences in overall acceptability of both muffins. Statistical analysis of both treatments were done and the pooled data showed that all treatments were significant to control in maintaining the overall acceptability of both the samples. Based on the results, sensory panelists could not detect much difference in the appearance, aroma, texture and overall acceptability of the bigel based muffins; however, they preferred the taste of control muffins (commercial margarine) over the muffins made from bigel.

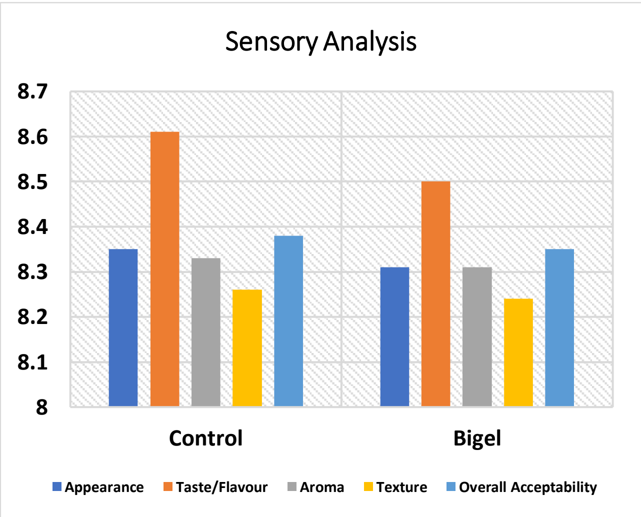


Figure 7: Result of sensory analysis of the muffins made from commercial margarine (control) and synthesized bigel.

Morphology of muffins developed by using commercial margarine (control) and formulated bigel has been studied by SEM technique taken at x550 magnifications shown in Fig. 8 which were spherical in shape and having slightly smooth surface. Hydrogel/ oleogel concentration used during synthesis process plays an important role on morphology of bigels. The EDX analysis was done to know the elements present in developed muffins. Results are given in the Fig 9.

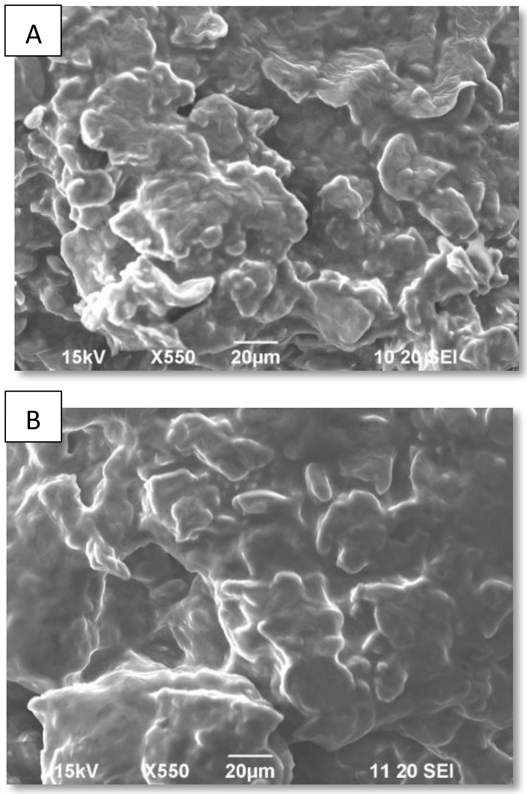
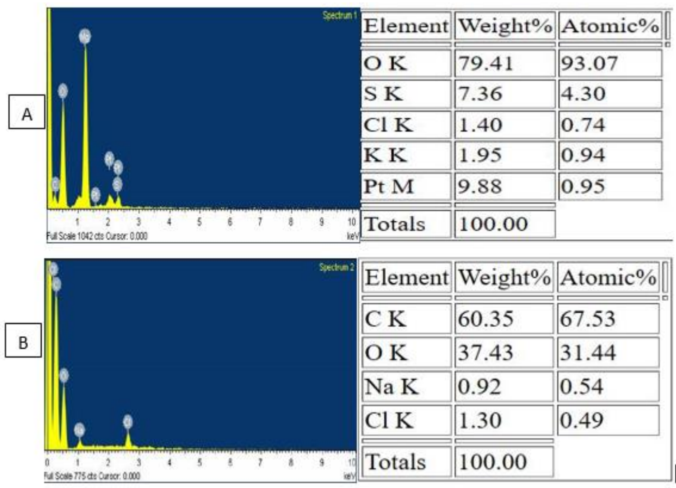


Figure 8: Image of the SEM analysis; A. represents the morphology of muffins made from resulting bigel, and B. represents the morphology structure of muffins made from margarine (control).



Element	Weight%	Atomic%
O K	79.41	93.07
S K	7.36	4.30
Cl K	1.40	0.74
K K	1.95	0.94
Pt M	9.88	0.95
Totals	100.00	

Element	Weight%	Atomic%
C K	60.35	67.53
O K	37.43	31.44
Na K	0.92	0.54
Cl K	1.30	0.49
Totals	100.00	

Figure 9: Shows the elements present in the muffins made from synthesized bigel (A); and muffins made from control (B).

The data obtained from the nutritional/proximate analysis are presented in Table 5. The parameters of nutritional analysis of treatments were carbohydrate, total fat, crude protein, ash and

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moisture content, and water activity. The result revealed that the nutritional value of all muffins was not much differentiating from each other except total fat. Total fat content in muffin made from control was lil bit higher than muffin made from bigel. Thus it can be concluded that not only trans-fat but bigel also helps to decrease the total fat content in food product.

Table 5: Proximate analysis of the muffins.

Control	
Carbohydrates	64.60±0.51
Protein	5.95±0.03
Total Fat	7.56±0.24
Ash	1.17±0.28
Moisture	19.97±0.07
Water Activity	0.75±0.08
Bigel	
Carbohydrates	66.14±0.05
Protein	5.13±0.03
Total Fat	7.21±0.11
Ash	1.45±0.02
Moisture	19.33±0.08
Water Activity	0.746±0.008

Fig.10 presents the effect of margarine replacement with bigel on the fatty acid composition of the muffins. Result shows that the muffins prepared with commercial margarine contained trans-fat. On the other hand, the proportions of trans-fat in muffins made by using bigel had almost negligible.

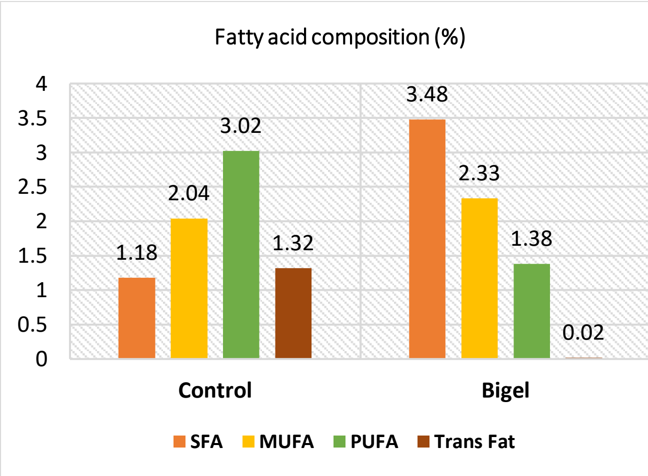

Figure 10: Fatty Acid Composition (%) of the muffins made from control and synthesized bigel.

4. Conclusion

In conclusion, the synthesized bigel was a semi-solid structure with a crystalline and an amorphous component, having firmness lesser than the pure oleogel but higher than the pure hydrogel. The replacement of commercial margarine, a plastic fat traditionally used in manufacturing baked goods, with bigel (coconut oil/beeswax oleogel structured with gelatin hydrogel), was effective in providing similar physical and textural characteristics in reformulating muffins. However, the muffins made with bigel found to have no trans-fatty acid in their fatty acid profile as compared to muffins formulated with commercial margarine which had higher amount of trans-fat. At the sensory level, no major differences were observed between the margarine based muffins and bigel based muffins. This demonstrated the potential use of bigel as a trans-fat replacer in bakery products. Therefore, the results suggest that the reformulation of muffins with bigel as trans-fat replacer could help the food industry prepare healthy bakery products. However, more research is needed to find the conditions to use bigel in a variety of food products, studying other types of gelators or gelling agents; and other variables such as homogenization temperature, time and the proportion of replacement etc.

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