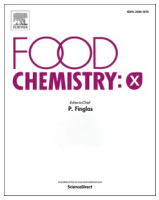
Food Chemistry: X 23 (2024) 101539

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x



Exploring pectin from ripe and unripe Banana Peel: A novel functional fat replacers in muffins

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ARTICLE INFO

Keywords:
Banana peel
FTIR
Fat replacer
Muffin
Pectin
SEM

ABSTRACT

The study addresses global fruit waste concerns in the food industry by extracting pectin from both ripe and unripe banana peels at varying pH levels and time intervals using hydrochloric acid. The best results were observed for unripe banana peel pectin at pH 1.5 and 250 min exhibiting a yield of 16.46% and favorable characteristics. In muffin development, seven treatments (M_0, M_1, M_2, M_3, M_4, M_5 and M_6) are prepared and analyzed for morphology, nutritional content, and sensory parameters. The M4 treatment, utilizing pectin from unripe banana peel at pH 1.5 and 250 min, displays superior qualities with reduced peroxide value, free fatty acids, percent moisture loss, and hardness. Sensory evaluations indicate high acceptability due to lower fat content. In conclusion, the extraction of pectin from unripe banana peels proves promising as a fat replacer in bakery items, maintaining muffin quality while addressing fruit waste challenges in the food industry.

1. Introduction

A growing global population leads to an increasing demand for food production. To cope up this scenario, processing industries has significantly enhanced processing of food however; it resulted in the generation of large amount of food waste (Ravindran & Jaiswal, 2016). One-third of the total produce for human consumption is wasted globally, resulting in a revenue loss of 1.6 billion tons per year (FAO, 2018). Food waste can be utilized in isolating useful functional compounds and value-added products thereby; appropriate application will not only be beneficial economically but also helpful for reducing global pollution. Although a large amount of food waste accounting about 50% of food material is being generated by food-oriented establishments yet it encompasses an array of components such as pectin, phenolics, fiber and carotenoids that may make their re-utilization in food formulation very special (Siddiqui, Azhar, Ali, & Mahmood, 2018).

The banana, a member of the *Musaceae* family and genus Musa, is regarded as one of the most significant tropical fruits. It is widely farmed in >135 countries (Ploetz & Evans, 2015). Worldwide, there are >100 varieties. Among various countries, India and China are leading in banana production following Indonesia, Brazil, Philippine etc. Every year, around 105 million tonnes of bananas are produced worldwide, making the current study extremely valuable (Siddiqui et al., 2018). After harvesting, about 60% of banana biomass remains as waste. The fruit peel may be employed in pectin extraction (Bisht, Sharma, Rawat, Chakraborty, & Yadav, 2020). Bananas constitute 60% pulp with 40% leaf, nearly 7.25 kg of peel is produced from 18.14 kg bananas. However, the peel encompasses carbon-rich organic compound for example cellulose (10–21%), pectin (7.6–9.6%), hemicelluloses (6.4–9.4%), lignin (6–12%) and other chlorophyll pigments (Sulong, Hamid, Sivam, Abdullah, & Wee, 2021).

Pectin is extracted primarily on an industrial scale from the apple pomace (14%), the beet root (1%) and the citrus peel (85%). Various researches indicated how pectin may be recovered from a wide range of by-products generated from food organizations, allowing agro-industrial

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https://doi.org/10.1016/j.fochx.2024.101539
Received 28 February 2024; Received in revised form 30 May 2024; Accepted 5 June 2024
Available online 6 June 2024

Nomenclature and abbreviations section

AACC	American Association of Cereal Chemists
ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
AUA	Anhydrouronic acid
CRD	Completely Randomized Design
DE	Degree of esterification
DES	Deep Eutectic Solvents
FAO	Food Agriculture Organization
FFA	Free Fatty Acids
FTIR	Fourier-Transform Infrared Spectrometer
HM	High Methoxyl
LM	Low Methoxyl
MAE	Microwave Assisted Extraction
MeC	Methoxyl content
NADES	Natural Deep Eutectic Solvents
NFE	Nitrogen Free Extract
PEF	Pulsed Electric Field
PV	Peroxide value
RBP	Ripe Banana Peel
UAE	Ultrasound-Assisted Extraction
UBP	Unripe Banana Peel

waste to be valued (Freitas, Coimbra, Souza, & Sousa, 2021). Different methods are being used worldwide for utilizing banana peel waste by extracting valuable ingredients such as fiber and pectin. Despite the high energy and solvent costs, acid extraction and alcoholic precipitation are being employed to synthesize pectin (Badaró, Garcia-Martin, del Carmen López-Barrera, Barbin, & Alvarez-Mateos, 2020). Many studies have been conducted to estimate the effects of extraction conditions (time, solid: liquid ratios, pH, and temperature) and different variety of acid solvents on the structure, physicochemical characteristics, and the extraction yield of pectin. Citric acids, hydrochloric, or sulfuric were typically utilized for extended periods of time (1–6 h), at higher temperatures (60–90 °C) followed by the alcoholic precipitation. In recent years, many advanced methods are also used for isolation of pectin such as Subcritical Water Extraction (SWE), Microwave Assisted Extraction (MAE), Pulsed Electric Field (PEF), Ultrasound-Assisted Extraction (UAE), extraction with Deep Eutectic Solvents (DES), isolation with Natural Deep Eutectic Solvents (NADES), and the combination of these modes (Freitas et al., 2021).

Pectin belongs to polysaccharide family, contains 300–1000 galacturonic acid units having α 1–4 linkages between two galacturonic acid units that plays major role in the formation of cell wall of plants and also abundantly found in apple pomace (Kamble, Gawande, & Patil, 2017). Pectin has lot of applications in pharmaceutical as well as food industries. It is not only used in confectionary industry for the production of jam and jellies but also acknowledged as main ingredient in dairy, beverages and baking (Munarin, Tanzi, & Petrini, 2012). Another important application of pectin is in low caloric food products as it involves in the formation of hydrogels with proteins (López-Mata et al., 2018).

Currently in Pakistan, there is no pectin production plant, hence all market need is met by imports. Certain well-known pectin-producing businesses have raised the costs of their pectin brands. Pectin costs may become competitive when new low-cost sources are discovered. It is expected that research on pectin extraction and additional sources would bring enhanced knowledge to producer and markets.

Dietary fat, which is commonly over consumed in developed countries, is one of the most important risk factors for a variety of chronic illnesses, including cardiovascular disease, type-2 diabetes, obesity, and cancer (Mozaffarian, 2016). Reduced-fat foods are a realistic and practical choice when considering the negative health effects and economic consequences linked with dietary fat over consumption (Gutiérrez-Luna, Astiasarán, & Ansorena, 2022). Fat replacers are on high demands and used in various products such as bakery items, dairy and frozen products. Functions of fat replacers are same as fat however; they provide nutrients with less calorific value. Among carbohydrates-based fat replacers, pectin, gums, maltodextrin, fiber, modified starches and cellulose are mostly used (Othman, Abdul Manaf, Harith, & Wan Ishak, 2018). There is need to replace a part of fat using fat replacer that would decrease caloric value of muffins. Considering aforementioned information, the present study was designed to utilize banana peel waste as a raw material to extract pectin and its utilization in bakery product with special reference as fat replacer in muffin. This study has focused on acceptability of low-fat muffins using pectin as fat replacer.

2. Materials and methods

2.1. Procurement of raw materials

Study was conducted in Department of Food Science and Technology at Jinnah University for Women. Ripe and unripe banana (*Musa spp*) was purchased from a local market for the study. Analytical grade chemicals used for the study were purchased from Nawaid Scientific Traders. Ingredients used for the preparation of muffins (all-purpose flour, granulated sugar, low fat milk, egg, salt, butter etc.) were also purchased from local market.

2.2. Preparation of sample

Peel obtained from ripe and unripe banana was soaked for an hour in sodium metabisulphite (0.05%) to inhibit color variations then dried in dehydrator for 6 h at 55 °C and cooled at environmental temperature. The dried peels were converted into powder using grinder and stored in polythene bags for further analysis (Castillo-Israel et al., 2015).

2.3. Physicochemical analysis of banana peel

The moisture content, crude- protein, −fat, and ash content of ripe and unripe banana peel powder were analyzed by using Method No. 44–15, 46–30, 30–25, and 08–01 given in AACC (2010), accordingly. Crude fiber content of ripe and unripe banana peel powder was determined by Mamiru and Gonfa (2023). The total percentage of nitrogen free extract was determined by the following formula (Khamsaw et al., 2024). The value obtained is the percentage carbohydrate constituent of the sample.

$$\%NFE = 100 - (\%moisture + \%crude\ fiber + \%protein + \%lipid + \%ash) \quad (1)$$

2.4. Extraction of pectin

Pectin was extracted from powder of ripe banana peel (RBP) and unripe banana peel (UBP) by trailing protocol (Kamble et al., 2017) as per the treatment plan enclosed in Table S1 and Table S2 in supplementary material. Accordingly, 40 g banana peel powder was mixed with 500 mL distilled water and acidified with hydrochloric acid (0.5 N) to achieve desired pH of 1.5 and 2.5. Afterwards, the mixture was agitated with a stirrer unless all of the banana peel powder was wetted evenly in homogeneous form by acidified water. The pectin isolation was continued by heating the acidified samples to 90 ± 5 °C for 50, 100, 150, 200, 250, 300 min on a swirling hot plate. After cooling, the

solution was filtered through a standard screen of 1-mm mesh size with two layers of cheese cloth. After collecting the filtrate, it was mixed with two times of its volume with pure ethanol. Afterwards, precipitated pectin was centrifuged at 5000 rpm for 10 min to recover the pectin. Then obtained pectin was oven dried at 65 °C until the weight remains consistent.

Pectin extraction yield (%) was calculated by using following formula;

$$\text{Pectin yield}\ (\%) = \frac{\text{Weight of extracted pectin}}{\text{Bi}} \times 100 \quad (2)$$

Where,
Bi = Weight of alcohol insoluble residues (g).

2.5. Characterization of pectin

Isolated pectin from ripe and unripe banana peel was characterized for the following parameters:

2.5.1. Moisture content

The pectin moisture content from both samples was analyzed according to the procedure described by Mamiru and Gonfa (2023). One gram of pectin was weighed in metal dish and dried at 100 °C for 5 h in an oven. Then, cooled in desiccator and weighed. The moisture content was calculated using the following equation:

$$\textit{Moisture content}(\%) = \frac{\textit{Weight of dried pectin}}{\textit{Weight of sample}} \times 100 \quad (3)$$

2.5.2. Ash

Ash content of the pectin sample was measured by following the protocol of Mamiru and Gonfa (2023). Accordingly, 1-2 g of pectic material was weighed. The sample was gently ignited, then heated at 600 °C for 3–4 h in muffle furnace. The crucible was then cooled to room temperature in desiccator and correctly re-weighted. The process was continued until a constant weight is reached, and the final weight was noted.

$$\textit{Ash}\ (\%) = \frac{\text{Weight of Ash}}{\text{Weight of Sample}} \times 100 \quad (4)$$

2.5.3. Equivalent weight

The equivalent weight of each sample was calculated to determine anhydrouronic acid content and degree of esterification. For the purpose, titration was done with NaOH till 7.5 pH using phenol red as an indicator (Titration A) (Castillo-Israel et al., 2015).

Following expression was employed for equivalent weight:

$$\textit{Equivalent weight} = \frac{\text{Weight of sample} \times 1000}{(\text{mL of alkali} \times \text{normality of alkali})} \quad (5)$$

2.5.4. Methoxyl content

Methoxyl content was determined by using neutralized solution obtained from equivalent weight according to guidelines of Petkowicz, Vriesmann, and Williams (2017). Methoxyl content is important in terms of controlling setting time of pectin. For the purpose, 25 mL of 0.25 N NaOH was added to the neutral solution (titration A) following the agitation and left to stay for 30 min at ambient temperature in a cork fixed flask. Afterwards, 25 mL aliquot of 0.25 N HCl was added and titrated with 0.1 N NaOH to the same endpoint as the previous one (Titration B).

The equation was used to compute the methoxyl content is as follow:

$$\text{Methoxyl content}\ (\text{MeC}) = \frac{\text{mL of alkali} \times \text{normality of alkali} \times 3.1}{\text{Weight of the sample}} \quad (6)$$

2.5.5. Anhydrouronic acid (AUA)

The determination of anhydrouronic acid content is important to identify degree of esterification and purity of pectin. Pectin was esterified with polygalacturonide and organic materials (10%) like arabinose & other sugars. The anhydrouronic acid content was calculated by following expression according to the methodology of Mada, Duraisamy, and Guesh (2022).

$$AUA(\%) = \frac{176 \times 0.1z \times 100}{w \times 1000} + \frac{176 \times 0.1y \times 100}{w \times 1000} \quad (7)$$

where,
z = mL of NaOH used for determination of equivalent weight.
y = mL of NaOH used in methoxyl content determination.
w = weight of sample (g).

2.5.6. Degree of esterification

The degree of esterification of all pectin samples was measured by mathematical expression as mentioned by Kamal, Abo Omirah, Hussein, and Saeed (2021) on the basis of anhydrouronic acid and methoxyl contents.

$$\text{Degree of esterification} = \frac{176 \times \text{MeC}\ (\%) \times 100}{31 \times \text{AUA}(\%)} \quad (8)$$

where,
MeC = Methoxy content.
AUA = Anhydrouronic Acid.

2.5.7. Selections of best treatments

Two best treatments from each pectin source; ripe or un-ripe banana peels was selected depending on pectin characterization analyses.

2.5.8. Pectin characterization using FTIR

The best selected treatments were further analyzed by using FTIR for the confirmation ofstructure of pectin. It was performed at PCSIR laboratory by following the method of Kozioł-Nadolna (2020). Accordingly, functional groups detection in the sample was conducted by absorption spectroscopy in the infrared region (4000–650 cm^{-1}) with a resolution of 4 cm^{-1} and 16 scans. An Infrared Fourier-Transform Spectrometer (FTIR), Perkin Elmer Spectrum One, equipped with a UATR (Universal Attenuator Overall Reflectance) accessory. The obtained spectrum was analyzed for the presence of functional group in pectin.

2.6. Product development

For the development of muffins, seven treatments were prepared as elaborated in Table S3 in supplementary material. The treatment M_0 was used as control whereas; M_1 and M_2 contained peel powder of ripe and unripe bananas. In M_3 and M_4 muffins, pectin isolated at pH 1.5 from ripe and unripe was incorporated, correspondingly. Similarly, muffins containing pectin separated from ripe and un-ripe banana peels at 2.5 pH was named as M_5 and M_6, respectively.

Firstly, the conventional oven was preheated at 175 °C for 20–30 min. Butter and sugar were beaten using a stand mixer for 3–4 min at top speed until a creamy texture was achieved. A small proportion of egg yolk, half milk and egg white were added and mixed it at low speed for 1 min and then poured the remaining portion of egg white and yolk and whisked it again for 3 min at maximum speed. The remaining dry ingredients (ripe or unripe banana peel powder or pectin extracted from ripe or unripe banana peel powder, sodium bicarbonate, salt, and citric acid) were added according to treatments and the batter was mixed for an additional minute at medium speed. Finally, the rest of the milk, essence and yogurt were added, and the batter was beaten for 3 min at medium speed until smooth. A known quantity of batter was poured into a paper mould having 60 mm diameter & 36 mm height and arranged in a baking tray and then baked for 20 min at 175 °C in an electric oven.

After baking, the muffins were left to cool at room temperature for 1 h to prevent moisture condensing on the upper surface. The muffins were prepared according to the method described by Martínez-Cervera, Sanz, Salvador, and Fiszman (2012).

2.6.1. Viscosity of muffin batter

Prior to muffin formation, viscosity of batter was determined by B-One Plus viscometer SN:19.05.PB080, France using spindle no 5 at 120 rpm (Ren, Song, & Kim, 2020).

2.6.2. Water holding capacity (WHC) of muffin batter

Water holding capacity of batter was determined by method described by (Kim & Shin, 2022). Purposely 3 g of batter was combined with 30 mL of distilled water. It was then centrifuged at 3500 rpm for 15 min. The tube was inverted for about 10 min after removing supernatant. Then, the precipitate was weighed. The WHC was computed by dividing the precipitate weight by the starting sample weight as expressed below:

$$\textit{Water holding capacity} = \frac{\text{Weight of precipitate}}{\text{Weight of sample}} \tag{9}$$

2.7. Physio-chemical analysis of muffins

2.7.1. Proximate analysis of muffins

Proximate analysis for muffins including moisture, crude- protein, −fat, −fiber, ash and NFE was accomplished by using AACC (2010) methods specified for each parameter.

2.7.2. Bulk density

The bulk density of muffin was measured as the ratio between weight of sample and its volume (AACC, 2010).

$$\textit{Bulk density} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \tag{10}$$

2.7.3. Specific volume of muffins

Muffin volume was determined by using the protocol of AACC by rapeseed displacement method 44–15.02. Accordingly, the volume of container filled with rapeseed was recorded. Afterwards, the muffin was positioned in container following refilling container with rapeseed. The volume of re-filled rapeseed was determined. The volume of rapeseed displaced was corresponding to muffin volume.

2.7.4. Morphology analysis of muffins by scanning Electron microscope (SEM)

For evaluation of microstructure of muffins after addition of pectin as fat replacer, SEM technique was used. Sample preparation was done according to the method of Bhatt, Kumari, Abhishek, and Gupta (2021) with a little bit modification. Firstly, muffins were thinly sliced followed by freeze-drying for 5–6 h. Dried sample was packed & then sealed in polyethylene bags and kept in desiccator till further used. A JEOL Scanning Electron Microscope (Model JSM-6380 A) was used that is placed at centralized Science laboratories, University of Karachi. Freeze dried samples were placed on specimen holder and sputter coated up to 300 A with gold. Afterward, samples were observed at 15 kV at vacuum of 9.75×10^{-5}Torr.

2.7.5. Storage behavior

The prepared muffins were analyzed for physical and sensory parameters at 0, 24, 48, 72 and 96 h storage intervals.

2.7.6. Peroxide value (PV)

Peroxide value of muffin was determined by Mariana, Susanti, Hidayati, and Wahab (2020). Approximately 5.04 g of sample was weighed. About 30 mL of acetic acid and chloroform at a ratio of 3:2 was added. The solution was further treated with 1 mL of potassium iodide solution and placed in the dark for 1 min. Few drops of 1% starch were added after mixing with 30 mL distilled water. Then, the sample was titrated against 0.01 N sodium thiosulphate.

$$\text{Peroxide value (PV)} = \frac{\text{S} \times \text{N} \times 1000}{\text{Sample weight}} \tag{11}$$

N = normality of sodium thiosulphate.
S = mL of sodium thiosulphate used.

2.7.7. Free fatty acid

Free Fatty acids was determined by Mariana et al. (2020). In this procedure, approximately 2.0 g of oil was dissolved in a 25 mL ether-alcohol solution (2:1), along with two drops of 1% phenolphthalein indicator in ethanol. Titration was conducted using a 0.1 M sodium hydroxide solution in deionized water until the appearance of a persistent pink color, with a minimum duration of 30 s. The free fatty acid (FFA) content was then calculated using following equation.

$$\text{Free fatty acid} = \frac{\text{Solvent volume (mL)} \times \text{NaOH solution molarity} \times 28.2}{\text{weight of oil (g)}} \tag{12}$$

2.7.8. Percent moisture loss

Percent moisture loss was analyzed by subtracting initial weight (g) from final weight (g) of muffin after baking (Ren et al., 2020).

$$\textit{Percent moisture loss}\ (\%) = \frac{\text{Initial weight–Final weight}}{\text{Initial weight}} \times 100 \tag{13}$$

2.7.9. Color

The surface color of the muffins was evaluated using a CIE-Lab Color Meter (CIELAB SPACE, Color Tech-PCM, USA), measuring the L* (lightness), a* (−a greenness; +a redness), and b* (−b blueness; +b yellowness) values. These parameters were selected to assess the visual appearance and color attributes of the muffins.

2.7.10. Texture

Hardness of the muffin during storage was analyzed by texture analyzer (Model CT3 1000, Brookfield, USA). Using an aluminum cylinder probe with a 75 mm diameter (P/75), a double compression cycle test was run at up to 50% compression on a muffin (55 mm in diameter and 10 mm in height). Test speed of 5 mm/s was used (Martínez-Cervera et al., 2012).

2.7.11. Sensory evaluation

The study was approved by Board of Advanced Studies and Research, Jinnah University for Women, Karachi, Pakistan (Ref. No.: BASR/82nd Proc./Sept/2021 dated 30-10-2021). The sensory response for muffins was evaluated by a semi-trained panel using 9-point hedonic scale system as pronounced. Panelists were selected randomly to evaluate the sensory properties. Evaluation for various parameters; texture, color, appearance, and overall acceptability was executed by giving scores from 1 to 9 point using 9-point hedonic scale where 1 epitomizes the “extremely dislike” while 9 signifies the “extremely like”. All the participants were provided with free will to participate in the study. The participants signed the consent form prior to participation in the sensory evaluation of the trial and briefed about the protocols. Separate cabins with fluorescent white light were provided for each participant during the sensory evaluation of the product.

2.8. Statistical analysis

The resultant data was statistically compiled using completely randomized design (CRD) through Statistix 8.1. Moreover, Analysis of Variance (ANOVA) under 2 factor-factorial was performed to compare

the level of significance (Mason, Gunst, & Hess, 2003).

3. Result

3.1. Proximate analysis of unripe and ripe banana peel powder

To assess the quality and nutritional value of the food commodities, proximate analysis is carried out. The moisture, protein, fat, ash, and crude fiber of unripe banana peel was found to be less as compared to ripe banana peel powder except Nitrogen Free Extract (NFE) as depicted in Table 1.

3.2. Characterization of pectin

3.2.1. Yield of pectin

Pectin isolation was conducted at various time duration (50, 100, 150, 200 and 250 min), maintaining a peel to extractant ratio of 1:12.5 (*w/v*), and pH of 1.5 & 2.5 for the extractant. The impact of extraction time duration on pectin yield is summarized in Table 2 & Table 3. The findings indicated a significant ($p < 0.05$) increase in pectin yield as the time rose from 50 to 250 min (Table 2).

The higher yields for pectin were observed from unripe and ripe banana peel at time interval of 250 min and pH 1.5 (16.46 ± 2.27 and 8.76 ± 1.34%) for T_{11URBP} and T_{11RBP}, respectively. Results showed that yield of pectin increased as the extraction time increased but due to prolonged extraction, pectin started to decrease from 13.32 ± 1.17 to 12.66 ± 2.86% for T_{5URBP} and $T_{6URBP,}$ respectively at pH 2.5 while at pH 1.5 pectin decreased in T_{11URBP} and T_{12URBP} from 16.46 ± 2.27 to 15.18 ± 1.45% by increasing time duration from 250 to 300 min correspondingly, for the unripe banana peel. Similarly, for the ripe banana pectin yield decreased at pH 2.5 from 8.65 ± 0.33 to 8.11 ± 1.87% for $T_{5\ RBP}$ and $T_{6\ RBP}$, correspondingly likewise at pH 1.5, pectin content lowered from 8.76 ± 1.34 to 8.02 ± 2.87% for T_{11RBP} and T_{12RBP} when extraction time was increased from 250 to 300 min, accordingly. Significant effect of pH was observed on extraction rate of pectin. At pH 1.5 extraction rate is higher (16.46 ± 2.27% for unripe and 8.76 ± 1.34% for ripe banana) than pH 2.5 (13.32 ± 1.17% for unripe and 8.65 ± 0.33% for ripe banana).

3.2.2. Moisture content

Time and pH effect on pectin moisture content is calculated in Table 2 & Table 3. It is analyzed that the moisture level of unripe and ripe banana peel pectin was found to increase from 7 to 12% and 7–13%, respectively. The maximum moisture value (12.3 ± 1.21%) was exhibited by pectin isolated from ripe banana peel at 2.5 pH for time length of 50 min while minimum content (7.01 ± 1.53%) at similar condition for unripe banana peel. However, $T_{6\ RBP}$ was found to hold the maximum moisture as 12.56 ± 1.47% while $T_{7\ RBP}$ has the least content 8.71 ± 1.84%.

3.2.3. Ash content

The pooled data regarding ash content significantly vary ($p < 0.05$) owing to changes in extraction variables. The ash content manipulated in Table 2 and Table 3 for unripe and ripe banana peel pectin are recorded from 6 to 10% and 6–9%, correspondingly. The ash content for $T_{1URBP,}$ $T_{2URBP,}$ $T_{3URBP,}$ $T_{4URBP,}$ $T_{5URBP,}$ $T_{6URBP,}$ $T_{7URBP,}$ $T_{8URBP,}$ $T_{9URBP,}$ $T_{10URBP,}$ T_{11URBP} and T_{12URBP} was recorded as 7.64 ± 2.83, 7.64 ± 2.83, 8.73 ± 1.27, 9.02 ± 0.05, 9.64 ± 0.61, 10.52 ± 1.11, 7.21 ± 2.75, 7.96 ± 1.89, 8.31 ± 1.34, 8.88 ± 2.49, 9.57 ± 1.87 and 10.03 ± 1.42%, correspondingly. For ripe banana peel, 6.11 ± 1.67, 6.98 ± 1.92, 7.16 ± 0.51, 7.63 ± 2.36, 8.25 ± 2.82, 8.74 ± 2.79, 6.53 ± 1.67, 6.25 ± 1.83, 7.51 ± 2.18, 7.93 ± 2.25, 8.32 ± 2.82 and 9.22 ± 1.16% for $T_{1RBP,}$ $T_{2RBP,}$ $T_{3RBP,}$ $T_{4RBP,}$ $T_{5RBP,}$ $T_{6RBP,}$ $T_{7RBP,}$ $T_{8RBP,}$ $T_{9RBP,}$ $T_{10RBP,}$ T_{11RBP} and $T_{12RBP,}$ accordingly.

Table 1
Proximate analysis of unripe and ripen banana peel powder.

Parameters	Unripe banana peel (%)	Ripe banana peel (%)
Moisture	12.67 ± 2.5[b]	15.32 ± 2.78[a]
Protein	2.53 ± 1.04[a]	3.46 ± 1.73[a]
Fat	5.21 ± 1.68[a]	5.89 ± 2.69[a]
Ash	13.02 ± 2.36[a]	14.33 ± 2.75[a]
Crude fiber	14.20 ± 1.57[a]	15.57 ± 0.85[a]
Nitrogen free extract	52.37 ± 4.58 [a]	45.43 ± 2.76 [b]

Values having different alphabetical letters across the column are significantly ($p \leq 0.05$) different from each other.

3.2.4. Equivalent weight

Gel formation ability is also determined by equivalent weight of pectin as higher molecular weight pectin has better ability to form strong gel (Castillo-Israel et al., 2015). Equivalent weight of pectin obtained from unripe (T_{11URBP}) and ripe banana (T_{11RBP}) was the highest at 250 min and pH 1.5. Nonetheless, it was the lowest 1219.51 ± 2.71 & 521.49 ± 4.53 for T_{1URBP} & $T_{1RBP,}$ correspondingly. Observed results showed that equivalent weight increased as the extraction time increased but at 300 min it started to decrease. Results also showed that pectin obtained from unripe banana peel has higher equivalent weight as comparable to ripe banana peel.

3.2.5. Methoxy content

Table 2 & Table 3 illustrates the variations in methoxyl group content, ranging from 5.25 to 6.58% for ripe banana peel and 6.98 to 7.86% for unripe banana peel. It was observed that the methoxyl group content exhibited non-significant increase ($p < 0.05$) with the rise in extraction time.

Methoxy content of pectin isolated from unripe banana peel elucidated the highest score (7.86 ± 1.94%) for $T_{11\ URBP}$ at 250 min, pH 1.5 trailed by T_{5URBP} (7.75 ± 0.83%) at 250 min and 2.5 pH. However, the lowest methoxy content was measured in $T_{1\ URBP}$ accounting 7.16 ± 0.15% at 50 min and 2.5 pH. Among treatments for ripe banana peel, the maximum methoxy content was detected in $T_{11\ RBP}$ as 6.58 ± 1.94% at 250 min and pH 1.5 that is lower than unripe banana peel pectin.

3.2.6. Anhydrouronic acid (AUA)

Pectin; a partially esterified polygalacturonide, comprises approximately 10% organic components made up of galactose, arabinose, and various sugars. Anhydrouronic acid is required to assess the amount of esterification, and physical attributes. Table 2 highlighted a notable increase in anhydrouronic acid, which was found to be significantly elevated ($p < 0.05$) with the rise in extraction pH and time. Conversely, it demonstrated a significant increase ($p < 0.05$) with decreasing temperature and increasing pH (Table 3). AUA in pectin obtained from ripe banana peel depicted 54.67 ± 4.12 to 63.57 ± 3.12% purity while 53.39 ± 1.18 to 56.39 ± 2.47% purity from unripe banana peel.

3.2.7. Degree of esterification (DE)

As the methoxy level and anhydrouronic acid changes, esterification levels also varied significantly for all treatments. The typical range for degree of esterification should be 60–90% (Shaha, Punichelvana, & Afandi, 2013). Table 2 & Table 3 indicates a significant variation in the degree of esterification across different extraction time, ranging from 73.86 ± 1.27 to 79.99 ± 2.69% for T_{1URBP} & T_{11URBP} and 46.89 ± 2.36 to 65.04 ± 1.32% for T_{1RBP} &T_{11RBP}. Additionally, the impact of pH on the degree of esterification was explored using a hydrochloric acid extraction method. As depicted in Table 2 & Table 3, the lowest degree of esterification value (73.86 & 46.89%) was observed at high pH (2.5), while it reached its maximum at low pH (1.5).

3.2.8. Pectin characterization using FTIR

Infrared (FTIR) spectrophotometer was used to illustrate the chemical structure of commercial pectin and pectin extracted from the four

Table 2
Characterization of pectin extracted from unripe banana peel (URBP).

Treatments	pH	Time	Yield (%)	Moisture Content (%)	Ash (%)	Equivalent Weight	Methoxy Content (%)	Anhydrouronic Acid (%)	Degree of Esterification (%)
T_{1URBP}	2.5	50	8.94 ± 1.46^{e}	12.3 ± 1.21^{a}	7.64 ± 2.83^{c}	1219.51 ± 2.71^{e}	7.16 ± 0.15^{a}	55.03 ± 2.36^{bc}	73.86 ± 1.27^{de}
T_{2URBP}	2.5	100	9.02 ± 2.31^{d}	10.85 ± 0.93^{b}	8.21 ± 1.95^{bc}	1270.78 ± 2.93^{de}	7.38 ± 1.46^{a}	55.61 ± 1.97^{c}	75.34 ± 0.34^{c}
T_{3URBP}	2.5	150	10.51 ± 1.96^{c}	9.72 ± 0.75^{c}	8.73 ± 1.27^{bc}	1315.73 ± 3.10^{c}	7.46 ± 2.79^{a}	55.72 ± 3.21^{a}	76.01 ± 0.19^{c}
T_{4URBP}	2.5	200	12.25 ± 4.6^{bc}	8.53 ± 2.28^{cd}	9.02 ± 0.05^{b}	1387.25 ± 2.78^{b}	7.68 ± 1.67^{a}	56.39 ± 2.47^{c}	76.92 ± 1.34^{c}
T_{5URBP}	2.5	250	13.32 ± 1.17^{b}	7.77 ± 2.91^{de}	9.64 ± 0.61^{ab}	1429.76 ± 1.92^{ab}	7.75 ± 0.83^{a}	56.31 ± 1.34^{a}	78.15 ± 2.56^{b}
T_{6URBP}	2.5	300	12.66 ± 2.86^{bc}	7.01 ± 1.53^{e}	10.52 ± 1.11^{a}	1278.32 ± 3.57^{d}	6.98 ± 0.12^{a}	53.39 ± 1.18^{d}	74.22 ± 1.28^{d}
T_{7URBP}	1.5	50	10.21 ± 1.73^{c}	11.26 ± 4.12^{b}	7.21 ± 2.75^{c}	1349.37 ± 3.29^{bc}	7.23 ± 1.59^{a}	54.17 ± 2.29^{cd}	75.87 ± 2.92^{cd}
T_{8URBP}	1.5	100	10.77 ± 2.72^{c}	10.78 ± 2.89^{b}	7.96 ± 1.89^{c}	1382.18 ± 2.81^{b}	7.48 ± 0.67^{a}	55.21 ± 0.86^{b}	76.32 ± 1.64^{c}
T_{9URBP}	1.5	150	15.03 ± 1.63^{ab}	10.11 ± 1.74^{bc}	8.31 ± 1.34^{bc}	1406.72 ± 1.77^{b}	7.51 ± 0.61^{a}	$55.12 \pm 1.96a$	77.35 ± 2.48^{bc}
T_{10URBP}	1.5	200	15.87 ± 1.19^{ab}	9.62 ± 2.56^{c}	8.88 ± 2.49^{b}	1495.31 ± 3.73^{ab}	7.63 ± 1.28^{a}	55.09 ± 1.67^{c}	78.63 ± 1.77^{a}
T_{11URBP}	1.5	250	16.46 ± 2.27^{a}	8.93 ± 1.43^{cd}	9.57 ± 1.87^{ab}	1578.27 ± 2.25^{a}	7.86 ± 1.94^{a}	55.79 ± 2.48^{b}	79.99 ± 2.69^{b}
T_{12URBP}	1.5	300	15.18 ± 1.45^{ab}	8.12 ± 2.92^{d}	10.03 ± 1.42^{a}	1377.48 ± 2.86^{bc}	7.25 ± 1.37^{a}	53.89 ± 2.34^{a}	76.37 ± 1.47^{e}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.

Table 3
Characterization of pectin from ripe banana peel (RBP) powder.

Treatments	pH	Time	Yield (%)	Moisture Content (%)	Ash (%)	Equivalent Weight	Methoxy Content (%)	Anhydrouronic Acid (%)	Degree of Esterification (%)
T_{1RBP}	2.5	50	5.52 ± 2.14^{e}	8.92 ± 1.32^{ef}	6.11 ± 1.67^{d}	521.49 ± 4.53^{e}	5.25 ± 1.97^{a}	63.57 ± 3.12^{a}	46.89 ± 2.36^{f}
T_{2RBP}	2.5	100	6.11 ± 1.86^{d}	9.11 ± 2.81^{d}	6.98 ± 1.92^{c}	598.64 ± 3.14^{d}	5.86 ± 2.34^{a}	62.69 ± 2.94^{ab}	53.07 ± 1.17^{e}
$T_{3\ RBP}$	2.5	150	7.02 ± 0.25^{c}	9.89 ± 1.19^{c}	7.16 ± 0.51^{c}	624.37 ± 1.96^{cd}	6.18 ± 0.36^{a}	61.25 ± 3.38^{b}	55.47 ± 2.63^{de}
$T_{4\ RBP}$	2.5	200	7.83 ± 1.52^{b}	10.23 ± 0.53^{bc}	7.63 ± 2.36^{bc}	672.55 ± 4.15^{c}	5.78 ± 1.58^{a}	58.99 ± 2.52^{c}	55.63 ± 3.67^{de}
$T_{5\ RBP}$	2.5	250	8.65 ± 0.33^{a}	11.01 ± 2.78^{b}	8.25 ± 2.82^{ab}	749.26 ± 3.23^{b}	6.34 ± 2.43^{a}	59.52 ± 2.67^{bc}	60.52 ± 3.81^{c}
$T_{6\ RBP}$	2.5	300	8.11 ± 1.87^{ab}	12.56 ± 1.47^{a}	8.74 ± 2.79^{ab}	554.71 ± 2.88^{de}	5.14 ± 1.69^{a}	60.97 ± 1.64^{b}	47.86 ± 1.58^{f}
$T_{7\ RBP}$	1.5	50	4.73 ± 0.29^{f}	8.71 ± 1.84^{f}	6.53 ± 1.67^{c}	694.48 ± 3.71^{c}	5.78 ± 2.37^{a}	58.11 ± 2.37^{c}	56.47 ± 4.13^{d}
$T_{8\ RBP}$	1.5	100	5.97 ± 1.83^{de}	8.83 ± 2.63^{ef}	6.25 ± 1.83^{cd}	767.12 ± 2.48^{b}	6.11 ± 0.31^{a}	57.55 ± 1.17^{cd}	60.27 ± 3.34^{c}
$T_{9\ RBP}$	1.5	150	6.21 ± 1.37^{d}	9.21 ± 0.76^{cd}	7.51 ± 2.18^{bc}	803.33 ± 1.87^{ab}	6.04 ± 2.17^{a}	56.17 ± 3.78^{f}	61.04 ± 1.26^{d}
$T_{10\ RBP}$	1.5	200	7.53 ± 2.48^{bc}	$9.66 \pm 0.07c^{d}$	7.93 ± 2.25^{b}	848.38 ± 3.27^{a}	6.37 ± 1.66^{a}	56.88 ± 2.95^{d}	63.58 ± 2.58^{b}
$T_{11\ RBP}$	1.5	250	8.76 ± 1.34^{a}	10.06 ± 1.34^{c}	8.32 ± 2.82^{ab}	875.47 ± 2.59^{a}	6.58 ± 1.94^{a}	57.44 ± 3.60^{cd}	65.04 ± 1.32^{a}
$T_{12\ RBP}$	1.5	300	8.02 ± 2.87^{ab}	10.57 ± 1.81^{bc}	9.22 ± 1.16^{a}	721.27 ± 3.62^{bc}	5.32 ± 2.35^{a}	54.67 ± 4.12^{e}	55.32 ± 3.93^{de}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.

best-selected treatments, two each from unripe and ripe banana peels (M_3, M_4, M_5, M_6). The obtained spectra are shown in Fig. S1 to Fig. S5 with infrared range from 500 to 4000 cm^{-1}(mid infrared region) in supplementary material. It can be seen that the commercial pectin and samples taken from banana ripe and unripe peels contain spectra in the "fingerprint" region that resemble the pectin spectra previously reported by (Oliveira et al., 2016). It also confirms that the extracted polysaccharides obtained in this study is pectin. Results of current study represent peaks at 1054.3 cm^{-1} for C-O-C and 1233.7 $cm^{-1}$for C—O for commercial pectin peaks at 1000 cm^{-1} for C-O-C vibration and 1235.1, 1235.1, 1229, 1229.6 cm^{-1} for C—O vibrations confirm the presence of pectin in four best selected treatments from unripe and ripe banana peel. The stronger absorption of ester carbonyl groups and carboxyl groups indicates that commercial and pectin obtained from banana peel were high methoxy pectin as mentioned in Fig. S1 to Fig. S5 in supplementary material. Furthermore, the peak at 3322.5 cm^{-1} and 2937 cm^{-1} for the commercial pectin while 3313.7 cm^{-1}& 2922.7 cm^{-1}, 3309.1 cm^{-1} & 2923.1 cm^{-1}, 3306.5 cm^{-1} & 2923.1 cm^{-1} and 3309.7 cm^{-1} & 2922.6 cm^{-1} for the four best treatments of ripe and unripe banana peel, respectively represents the presence of -OH and -CH functional groups of pectin. Conclusively, FTIR spectrum of current study shows that pectin contains C—H, C-O-C, C—O, COOH, C═O, COO- and -OH functional groups. Similarities between commercial and banana peel pectin were observed.

3.3. Product development

3.3.1. Viscosity and water holding capacity of batter

Viscosity is a ratio of stress to strain. The results of viscosity of muffins batter are shown in Table 4. The control sample and other samples had significant difference ($p < 0.05$) in batter viscosity and water holding capacity. The viscosity increased with the incorporation of ripe and unripe banana peel powder from 3983 ± 10.34 (M_0) to 5231 ± 9.18 (M_1) and 5447 ± 12.57(M_2) m.Pa.s, respectively while the viscosity of batter by the addition of extracted pectin from ripe and unripe banana peel at pH 1.5 and 2.5 increased from 4325 ± 9.49 to 4731 ± 11.65 m.Pa.s and 4276 ± 10.28 to 4655 ± 9.47,correspondingly. Likewise, the water holding capacity of muffins batter increased momentously from $44.61 \pm 1.95\%$ (M_5) to $52.19 \pm 2.26\%$ (M_1) with the incorporation of ripe and unripe banana peel powder and pectin

Table 4
Physical properties of muffin batter.

Treatments	Viscosity (m.Pa.s)	Water Holding Capacity (%)
M_0	3983 ± 10.34^{c}	43.78 ± 0.12^{c}
M_1	5231 ± 9.18^{ab}	50.43 ± 1.37^{a}
M_2	5447 ± 12.57^{a}	52.19 ± 2.26^{a}
M_3	4325 ± 9.49^{bc}	45.57 ± 1.68^{b}
M_4	4731 ± 11.65^{b}	49.29 ± 2.67^{ab}
M_5	4276 ± 10.28^{bc}	44.61 ± 1.95^{b}
M_6	4655 ± 9.47^{b}	47.01 ± 0.69^{ab}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.
M_0 = Control; M_1 = Muffins containing ripe banana peel powder.
M_2 = Muffins containing unripe banana peel powder.
M_3 = Muffins containing pectin extracted from ripe banana peel powder at pH 1.5.
M_4 = Muffins containing pectin extracted from unripe banana peel powder at pH 1.5.
M_5 = Muffins containing pectin extracted from ripe banana peel powder at pH 2.5.
M_6 = Muffins containing pectin extracted from un-ripe banana peel powder at pH 2.5.

extracted from them.

3.3.2. Proximate analysis of muffin

The muffins prepared from pectin obtained from ripe and unripe banana peels are shown in Fig. 1. As evident in Table 5, moisture content of muffins prepared by 30% replacement using ripe and unripe banana peel powder and pectin derived from banana peel was found to be in range from 24.02 ± 2.17 to 29.32 ± 1.29%. The moisture content in muffins showed a significant increase ($p < 0.05$) with the addition of ripe and unripe banana peel flour and pectin. Similarly, the ash content of samples incorporated by ripe and unripe banana peel powder increased to 5.96 ± 2.12 and 4.71 ± 0.78%, respectively as compared to control sample which had 3.91 ± 1.36% ash content. Muffins prepared by using pectin extracted from ripe and unripe banana peel have ash content from 3.95 ± 0.38 to 4.12 ± 1.66%. As depicted in Table 5, the incorporation of pectin and powders of both ripe and unripe banana peel did not significantly change the protein content of muffins. Moreover, fat content of control muffin (12.43 ± 2.21%) decreased with the addition of both banana peel powder and pectin. Minimum fat (6.36 ± 1.25%) was observed in M4 (pectin extracted from unripe banana peel power at 1.5 pH) treatment. The crude fiber showed insignificant increase with the incorporation of pectin, ranging from 0.08 ± 0.02 to 0.25 ± 0.09% while significant difference was observed by the addition of ripe and unripe banana peel powder 3.89 ± 1.21% and 3.35 ± 0.93%, respectively.

As shown in Table 5, nitrogen free extract of treatments was observed in range of 59.04 ± 2.7 to 60.64 ± 1.66% by the 30% replacement with pectin. Observed values showed significant variation in nitrogen free extract as compared to control (56.91 ± 3.91%) but nitrogen free extract decreased to 48.21 ± 1.22% and 47.63 ± 2.85% by substitution of ripe and unripe banana peel powder, respectively.

3.3.3. Physical properties of muffins

3.3.3.1. Specific volume and bulk density of muffins. As depicted in Fig. 2, specific volume of muffins decreased from 2.94 ± 0.63 to 2.85 ± 1.92 cm^3/g while bulk density changed non-significantly from 3.02 ± 1.36to 3.25 ± 0.42 $g/cm^3$by the addition of ripe (M_1) and unripe banana peel powder (M_2), correspondingly. Nonetheless, the specific volume and bulk density of muffins increased from 4.06 ± 1.47 to 4.23 ± 1.79 cm^3/g and 1.64 ± 0.27–1.81 ± 0.53 g/cm^3 as compared to control (3.69 ± 1.36 cm^3/g and 0.69 ± 0.28 g/cm^3) by the addition of pectin from unripe and ripe banana peel.

3.3.4. Storage behavior of muffins

The prepared muffins were analyzed for physical parameters throughout the storage period of 0, 24, 48, 72 and 96 h. Muffins were kept in polyethylene plastic bags at room temperature. Peroxide oxide value, free fatty acids, percent moisture loss and hardness were also observed in freshly baked muffins to analyze the changes from zero to four days old muffins.

3.3.4.1. Peroxide value (PV). According to some researches (Pearson, 1970), the PV range of oil lies between 10 and 20 meq/Kg. Exceeding the range from 20 meq/Kg declared that the oil is rancid and not preferable for consumption. In current study, all samples lie under the range as shown in Table 6 and it was found that peroxide value increased significantly ($p < 0.05$) from 6.21 ± 1.84 to 7.30 ± 1.57 meq/Kg during 0 to 96 h storage duration. The S3 table is showing that PV is increasing during storage but at slower pace in muffins prepared from powder and especially pectin extracted from banana peel as compared to control.

3.3.4.2. Free fatty acids (FFA). The maximum free fatty acid was observed in control as banana peel as well as pectin obtained from banana peel powder contain antioxidants that prevent and delay fat oxidation. However, with passage of time from 0 to 96 h, free fatty acids slightly increased from 0.01 ± 0.007 to 0.04 ± 0.01% (Table 6). Ayoub et al. (2022) also found reduction in fat content during storage as activity of the lipase enzyme, which converts fat into glycerol and free fatty acids in the presence of catalysts such light, heat and moisture reduced.

3.3.4.3. Moisture loss. As depicted in Table 6, all the reduced fat muffins prepared by powder and pectin of ripe and unripe banana peel had lower moisture loss and it varied from 25.23 ± 2.18 to 24.71 ± 2.27, 24.13 ± 2.28, 23.62 ± 2.32 and 22.08 ± 2.11% at 0, 24, 48, 72 and 96 h, respectively (Table 6).

3.3.4.4. Hardness. The muffins hardness was assessed using a texture analyzer. As shown in Table 6, during 4 days storage period, the hardness of muffins increased significantly ($p < 0.05$) especially muffins prepared with banana peel powder with maximum hardness 3.66 ± 0.82 Kg/cm^2 for ripe and 3.33 ± 0.71 Kg/cm^2 for unripe banana peel powder than control (3.01 ± 0.84 Kg/cm^2) however, the least change in hardness was observed in pectin substituted muffins (2.84 ± 0.62, 2.76 ± 1.23, 2.78 ± 0.91 and 2.79 ± 0.74 Kg/cm^2).

3.3.4.5. Color. Means regarding L* values of muffins are presented in Table 7. It was observed that addition of ripe and unripe banana peel powder decreased the lightness of product from 69.23 ± 3.83 to 62.01 ± 2.75 and 60.58 ± 2.64 however, the color did not significantly change due to addition of pectin isolated at pH 1.5. A significant variation was recorded for muffins prepared with pectin isolated at 2.5 pH. It showed that increasing pH enhanced the isolation of sugars along with pectin that facilitate the browning reaction in M_5 and M_6. Regarding a* values, ripe and unripe banana peel powder darkens the color of muffins as did pectin addition isolated at pH 2.5 nonetheless the a* value slightly changed from 3.34 ± 0.97 to 4.57 ± 1.78 and 3.79 ± 1.32 for M_3 and M_4, accordingly. Considering b* muffins get yellower by incorporation of peel powder from both sources. The same situation was noted for pectin addition in muffin extracted at pH 2.5 owing to millard reaction and caramelization of sugars. Nevertheless, b* did not change for M_3 and M_4 at greater rate as compared to M_0.

3.3.5. Sensory evaluation of muffins

It was revealed from Fig. S6 in supplementary material that sensory scores for different parameters of muffins significantly changed ($p < 0.05$) as function of treatments. These substantial differences are found among the mean hedonic scores regarding muffin sample's aroma, taste,

Fig. 1. Developed Muffins. (M_0) control muffins, (M_1) muffins containing unripe banana peel powder, (M_2) muffins containing ripe banana peel powder, (M_3) muffins containing pectin extracted from unripe banana peel powder at pH 1.5, (M_4) muffins containing pectin extracted from ripe banana peel powder at pH 1.5, (M_5) muffins containing pectin extracted from ripe banana peel powder at pH 2.5, (M_6) muffins containing pectin unripe banana peel powder at pH 2.5.

texture, color, and overall acceptability.

It was analyzed that muffin fat replacement with banana peel pectin (M_4) improved aroma (8.35 ± 1.57) nevertheless the least score (6.53 ± 1.22) was noted for M_1 containing banana peel powder. Likewise, the taste (8.55 ± 1.67) of muffins having pectin was also good as compared to counterparts containing peel powder. The texture of muffins with pectin feels fresh owing to good water holding capacity of pectin however, the addition of banana peel powder makes the muffins dry and crumbly. The crust color of pectin containing muffins was uniform and attractive that fetch more scores as compared to other muffin treatments. Lastly, the scores of the overall acceptability showed significant diversity among the treatments.

3.3.6. *Morphology analysis of muffins*

Scanning electron microscopy was used to analyze the external morphology of the various treatments of muffins (Fig. 3). Significantly, noticeable differences are observed in the SEM scans of various treatments. Fig. 3 (A) representing the microstructure of control muffin revealed that majority of the starch granules have gelled. A few deformed starch granules are also visible with partial outlines trapped in the gluten protein matrix.

Moreover, Fig. 3 (B & C) illustrates the uneven structure of the samples made with ripe and unripe banana peel powder at the magnification levels of × 400. This could be attributed to the banana peel powder that has replaced the gluten protein. However, structure of the control was compact and consistent. The reduced gluten content prevents the optimal gluten networking when the dough is baked (Heo, Kim, Lee, & Moon, 2019). Fig. 3 (D to G) depicts micrographs of muffins prepared by the substitution of pectin. The incorporation of pectin led to the development of a dense layer covering the gas bubble surfaces,

Table 5
Proximate analysis of muffins.

Treatments	Moisture (%)	Ash (%)	Crude Protein (%)	Crude Fat (%)	Crude Fiber (%)	Nitrogen Free Extract (%)
M_0	23.62 ± 1.15^{c}	3.91 ± 1.36^{c}	3.08 ± 0.78^{a}	12.43 ± 2.21^{a}	0.05 ± 0.02^{c}	56.91 ± 3.91^{b}
M_1	28.45 ± 0.34^{a}	5.96 ± 2.12^{a}	4.88 ± 0.63^{a}	9.15 ± 0.19^{bc}	3.35 ± 0.93^{a}	48.21 ± 1.22^{d}
M_2	29.32 ± 1.29^{a}	4.71 ± 0.78^{ab}	4.24 ± 1.57^{a}	10.21 ± 1.48^{b}	3.89 ± 1.21^{a}	47.63 ± 2.85^{c}
M_3	24.97 ± 0.78^{a}	3.95 ± 0.38^{c}	3.27 ± 1.14^{a}	8.52 ± 0.37^{c}	0.25 ± 0.09^{b}	59.04 ± 2.74^{a}
M_4	26.84 ± 1.63^{ab}	4.12 ± 1.66^{b}	3.22 ± 0.04^{a}	6.36 ± 1.25^{d}	0.12 ± 0.01^{b}	59.34 ± 1.78^{a}
M_5	24.02 ± 2.17^{b}	3.93 ± 1.47^{c}	3.03 ± 0.45^{a}	8.94 ± 0.53^{c}	0.17 ± 0.06^{b}	59.91 ± 3.39^{a}
M_6	25.02 ± 2.26^{ab}	4.03 ± 0.82^{b}	3.15 ± 0.96^{a}	7.07 ± 0.41^{cd}	0.08 ± 0.02^{bc}	60.65 ± 1.66^{a}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.
M_0 = Control; M_1 = Muffins containing ripe banana peel powder.
M_2 = Muffins containing unripe banana peel powder.
M_3 = Muffins containing pectin extracted from ripe banana peel powder at pH 1.5.
M_4 = Muffins containing pectin extracted from unripe banana peel powder at pH 1.5.
M_5 = Muffins containing pectin extracted from ripe banana peel powder at pH 2.5.
M_6 = Muffins containing pectin extracted from un-ripe banana peel powder at pH 2.5.

thereby reducing the probability of individual gas cells merging.

4. Discussion

Utilizing designer foods in one's diet is a practical approach to enhance health and wellness. The repurposing of food waste to extract valuable functional chemicals and high-value products contributes to economic value and aids in global pollution reduction. In this study, we focused on extracting pectin from banana peels to substitute fat in muffins. While fat contributes to certain desirable physical and sensory characteristics, such as softness and juiciness, however, intentionally removing, and characterizing pectin from banana peels has allowed its use as a fat alternative without compromising nutritional value. The study comprehensively examined the physical, chemical, and microstructural aspects of the muffins.

Moisture content in food samples influences the flow characteristics and stability of peel powder, with higher moisture levels often leading to increased microbial growth (Adepoju, Onasanya, Ogunfuwa, & Ayoade, 2006). The moisture content observed in this study exceeded values reported in previous research (11.11 & 13.53% and 9.21 & 10.88% for unripe and ripe banana peel, correspondingly) (Ramli, Ismail, Alkarkhi, & Easa, 2010) indicating potential implications for freshness and shelf life (Zaini, Sintang, & Pindi, 2020). The correlation between the moisture content and maturity of bananas is evident, attributed to the osmotic movement of water and breakdown of starch into sugars. This correlation is further influenced by variations in moisture content based on storage temperature. The quality, freshness, and shelf life of food items and their processed derivatives are intricately linked to their moisture content, as emphasized by Adepoju et al. (2006). The pH of the extraction medium can affect the degree of extraction efficiency and the

Table 6
Effect of storage intervals on peroxide value, fatty acid, hardness and color of muffin.

Storage Interval (hours)	Peroxide value (meq/Kg)	Fatty acid (%)	Moisture loss (%)	Hardness (Kg/cm^2)
0	6.21 ± 1.84^{c}	0.01 ± 0.007^{a}	25.23 ± 2.18^{a}	2.75 ± 0.55^{b}
24	6.37 ± 2.21b^{c}	0.01 ± 0.005^{a}	24.71 ± 2.27^{ab}	2.85 ± 0.35^{ab}
48	6.80 ± 1.62^{b}	0.02 ± 0.01^{a}	24.13 ± 2.28^{bc}	3.00 ± 0.48^{ab}
72	7.04 ± 2.15^{ab}	0.03 ± 0.01^{a}	23.62 ± 2.32^{cd}	3.15 ± 0.92^{a}
96	7.30 ± 1.57^{a}	0.04 ± 0.01^{a}	22.08 ± 2.11^{d}	3.36 ± 1.24^{a}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.

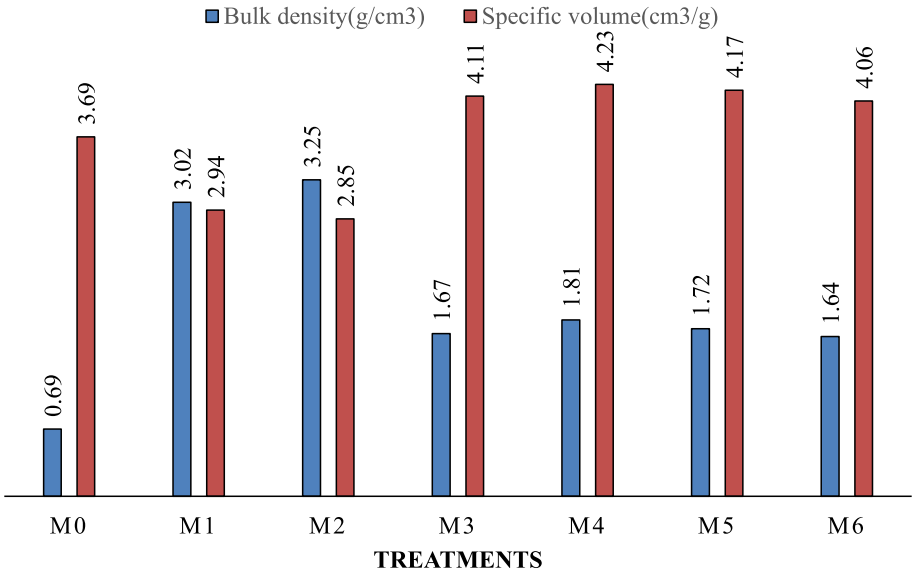

Fig. 2. Effect of treatments on specific volume (cm^3/g) and bulk density (g/cm^3) of muffins.

Table 7
Color tonality of various muffins formulation.

Treatments	L	a*	b*
M_0	69.23 ± 3.83^{a}	3.34 ± 0.97^{d}	21.37 ± 1.73^{cd}
M_1	62.01 ± 2.75^{b}	$5.49 \pm 1.35b^{c}$	37.29 ± 1.86^{a}
M_2	60.58 ± 2.64^{b}	6.32 ± 0.85^{a}	35.77 ± 0.57^{a}
M_3	65.34 ± 3.89^{ab}	4.57 ± 1.78^{c}	23.68 ± 0.89^{c}
M_4	68.89 ± 1.76^{a}	3.79 ± 1.32^{cd}	19.45 ± 1.52^{d}
M_5	63.53 ± 2.21^{ab}	5.14 ± 1.64^{bc}	32.56 ± 1.59^{b}
M_6	62.71 ± 1.87^{b}	5.89 ± 0.78^{b}	30.41 ± 1.42^{b}

Values having different alphabetical letters within the same column are significantly ($p \leq 0.05$) different from each other.
M_0 = Control; M_1 = Muffins containing ripe banana peel powder.
M_2 = Muffins containing unripe banana peel powder.
M_3 = Muffins containing pectin extracted from ripe banana peel powder at pH 1.5.
M_4 = Muffins containing pectin extracted from unripe banana peel powder at pH 1.5.
M_5 = Muffins containing pectin extracted from ripe banana peel powder at pH 2.5.
M_6 = Muffins containing pectin extracted from un-ripe banana peel powder at pH 2.5.

quality of the extracted pectin. As the pH can enhance the yield and purity of the extracted pectin by promoting the dissolution of pectinaceous materials and minimizing the co-extraction of unwanted compounds. Moreover, under acidic conditions, pectin molecules may undergo partial hydrolysis or protonation, leading to changes in their structure and hydration properties (Mada et al., 2022). Although banana peel is not a significant source of protein, it contains unsaturated fat, making it a potential aid in weight reduction. The fallouts of the present study were found to be similar with the outcomes of (Morais et al., 2017) recorded fat as 5.9% and 6.1% in ripe and unripe banana peel powder, correspondingly.

Utilizing banana peel as a source of dietary fiber has the potential to contribute to the prevention of various diseases, as highlighted in the study by Rodriguez-Sandoval, Prasca-Sierra, and Hernandez (2017). Research suggests that the accumulation of dietary fiber increases the crude fiber level in banana peels during the ripening process. A previous study also revealed that bananas boast a notably high carbohydrate content, predominantly consisting of indigestible carbohydrates. In contrast, simple carbohydrates like sucrose are present at much lower levels, as reported by (Lau et al., 2020).

The study also explored the extraction of pectin from banana peels, with findings aligned with existing literature on factors affecting pectin yield, such as extraction time, pH, and temperature (Kamble et al., 2017). Furthermore, Torres-Sciancalepore et al. (2023) optimized pectin

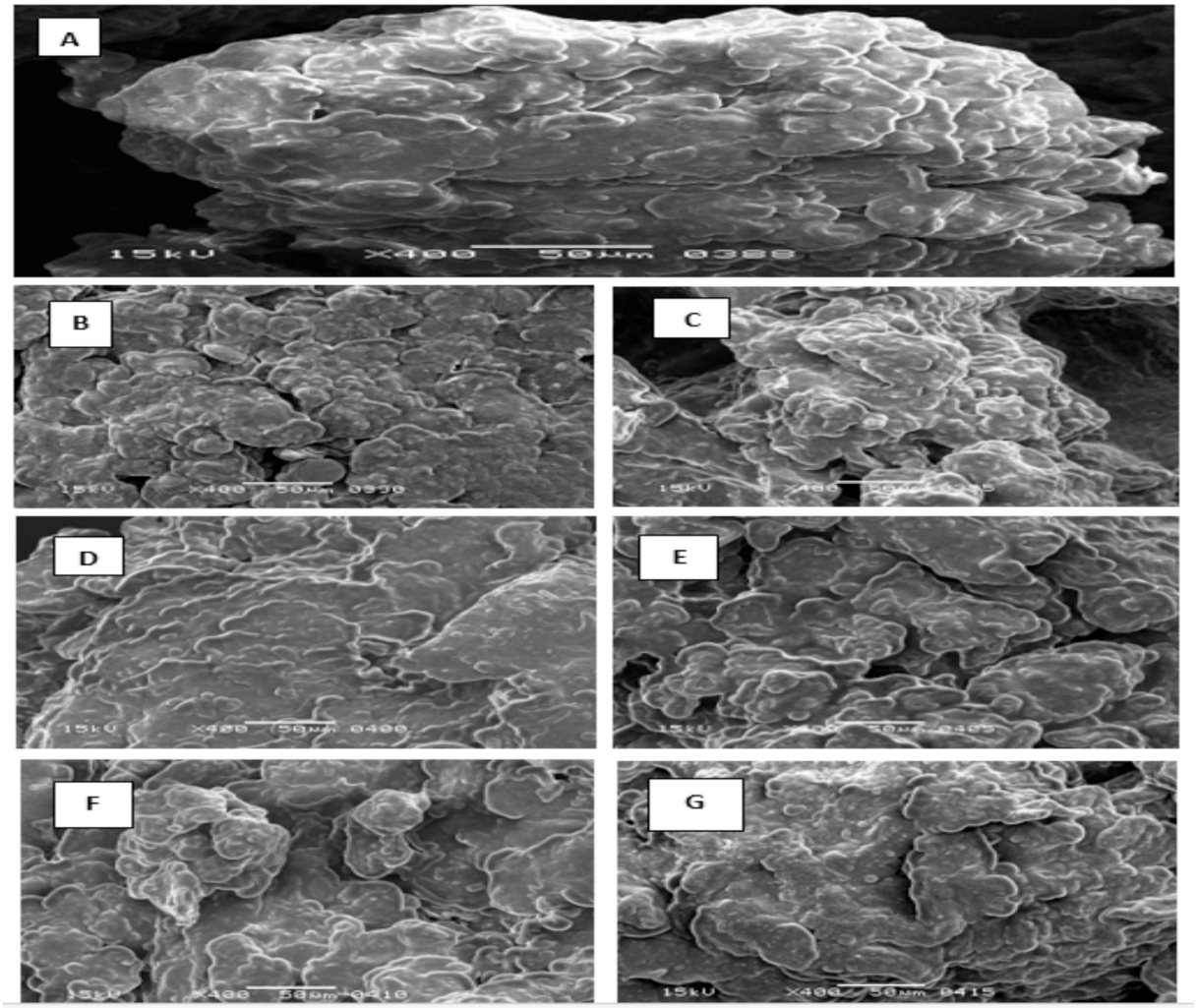

Fig. 3. Micro-structure of (A) control muffins, (B) muffins containing unripe banana peel powder, (C) muffins containing ripe banana peel powder, (D) muffins containing pectin extracted from unripe banana peel powder at pH 1.5, (E) muffins containing pectin extracted from ripe banana peel powder at pH 1.5, (F) muffins containing pectin extracted from ripe banana peel powder at pH 2.5, (G) muffins containing pectin unripe banana peel powder at pH 2.5.

extraction conditions for pectin isolation by pyrolysis of rosehip husk (pectin yield; 17.83%). It was observed that increasing pH improves pectin yield (31.89%) as it facilitates extraction by breaking linkages as recorded by Podetti et al. (2023).

Differences in yield were observed between ripe and unripe banana peels, attributed to variations in celluloses, hemicelluloses, and lignin during fruit maturity. Moreover, the effects of pH and temperature align with those documented by Emaga, Robert, Ronkart, Wathelet, and Paquot (2008). Further, Kliemann et al. (2009) highlighted the influence of pH on pectin recovery, emphasizing the efficacy of a strong acid, such as HCl at a low pH ranging from 1.0 to 1.5. This acidic environment enhances the yield by improving the removal of sugars, including galactose, rhamnose, arabinose, and D-galacturonic acid, from the food matrix. Additionally, a noteworthy disparity in pectin yield was observed based on the ripening stage, with unripe bananas yielding more pectin compared to ripe bananas. This discrepancy is attributed to variations in celluloses, hemicelluloses, and lignin associated with fruit maturity. As the fruit peel softens, the dissolution of connections between pectin and certain cellular components occurs, rendering the pectin more accessible for extraction and causing an initial rise in pectin levels. Conversely, the breakdown of pectin by enzymes like pectin methyl esterase, polygalacturonase, or pectatelyase in over-ripe banana peel may lead to a decline in yield, as outlined by Castillo-Israel et al. (2015).

Furthermore, maintaining minimal moisture levels is crucial for both secure storage and preventing the proliferation of microorganisms, which could compromise quality due to the activation of the pectinase enzyme. Pectin exhibits high hygroscopicity, necessitating storage in a sealed, dry environment (Kamble et al., 2017). In contrast to banana peel pectin, commercial pectin tends to have a lower ash concentration (1.76%), potentially influencing its gel quality. This distinction may be further pronounced during extraction, particularly when employing an appropriate acid extraction to chelate excess Ca2+, a significant contributor to the ash content (Castillo-Israel et al., 2015).

Additionally, Sharma et al. (2023) explored variations in extraction methods, source species, and acidic environments, highlighting the higher equivalent weight of *citrus limetta* pectin compared to commercial pectin. Methoxyl content also plays a role in pectin solubility, with higher methoxyl levels exhibiting greater solubility in water than pectin with lower methoxyl content. Our findings align with Aina et al. (2012), illustrating extracted pectin with methoxyl percentages ranging from 0.22 to 12.0%, dependent on the source and extraction method. Kamble et al. (2017) reported similar methoxy content ranges (7.4 to 8.4%) for unripe banana peel pectin at different temperatures and pH levels.

Commercial pectin typically possesses a methoxyl concentration between 8 and 11%, capable of forming high sugar gels (exceeding 65% sugar). Conversely, low methoxyl pectin (<7%) enables the development of gels with lower sugar contents. Pectin purity is influenced by higher galacturonic acid and lower ash content (Hwang, Roshdy, Kontominas, & Kokini, 1992). An anhydrouronic acid level exceeding 65% signifies the quality of extracted pectin, while levels below 65% AUA may indicate contaminants, as precipitating pectin contains sugars and proteins (Ismail, Ramli, Hani, & Meon, 2012). The obtained AUA value for pectin in our study (53%) closely corresponds to the findings of Apsara and Pushpalatha (2002).

Pectin can be categorized as either rapid-set (DE >72%) or slow-set (DE 58–65%), based on the speed of gel formation (Shaha et al., 2013). Pectin from ripe peel tends to be slow-setting, while that extracted from unripe banana peel exhibits rapid-setting properties. Tiwari et al. (2017) emphasized the impact of pH on the degree of esterification, concluding that Low Methoxyl (LM) pectin forms at low pH (2.0), whereas High Methoxyl (HM) pectin forms at high pH (>2.0). LM pectin produces a thermo-irreversible gel, maintaining its gelled state even when exposed to high temperatures that would typically cause it to melt (Yapo & Koffi, 2013). Studies indicate that the esterification strength of pectin isolated from unripe banana peel may range from 75 to 80%. Low methoxyl pectin is commonly employed in the food industry to create jams with reduced sugar content and has gained popularity in pastries and other low-calorie recipes that are not overly sweet (Pan, Qu, Ma, Atungulu, & McHugh, 2011).

The banana peel boasts a wealth of pectin, phytochemicals such as flavonoids, tannins, alkaloids, glycosides, and phenols, along with various carbohydrate components, primarily cellulose, hemicellulose, and lignin (Kamble et al., 2017). In FTIR spectra, the "fingerprint" region for carbohydrates, spanning 800 to 1300 cm-1, facilitates the identification of specific chemical groups inherent to a polysaccharide (Muhammad, Zahari, Gannasin, Adzahan, & Bakar, 2014). Another group of researchers similarly emphasized that the C—H vibrations of carbohydrates contribute to peaks within the 560 to 920 cm-1 range (Kairyte, Kadys, & Luksiene, 2013). It was stated that C-O-C vibrations is associated with the band at 1055 cm-1, and C—O vibrations with the band at 1253 cm-1(M. A. Alam & Al Riyami, 2018). Additionally, It was reported the presence of a C-O-C stretching band at 1009.48 cm-1 (Tanaid & Lauzon, 2018). Our findings align with previous studies; observed a similar band for the ester carbonyl group but a weak band for the carboxyl group, categorizing them as high methoxy pectin in citrus peel and apple pomace (Khamsucharit, Laohaphatanalert, Gavinlertvatana, Sriroth, & Sangseethong, 2018). Furthermore, the peak at 3419 cm-1 is linked to -OH groups in the pectin structure or from water adsorption (Dasa, Chandra, Phukonc, Kalitaa, & Doluia, 2013), while the peak at 2933 cm-1 corresponds to -CH vibrations in aliphatic hydrocarbons (da Silva, Caetano, Chiari-Andréo, Pietro, & Chiavacci, 2019).

To create muffins, seven distinct treatments were devised. The control sample, denoted as M0, represented the baseline, while M1 and M2 incorporated peel powder from ripe and unripe bananas, respectively. In M3 and M4 muffins, pectin isolated at pH 1.5 from ripe and unripe bananas was integrated, respectively. Likewise, muffins containing pectin derived from ripe and unripe banana peels at 2.5 pH were designated as M5 and M6, respectively. The impact of integrating powder from both unripe and ripe banana peels, as well as banana peel pectin, on the proximate composition, physico-chemical properties, sensory attributes, storage behavior, and microscopic structure of the muffins was systematically analyzed using standard procedures. The assessment of functional characteristics was imperative in elucidating the composition, structural confirmation, and physicochemical attributes of proteins and other food components.

Viscosity plays a crucial role in determining the final volume of a product, as it is linked to both air incorporation and batter stability. An increase in batter viscosity has been associated with enhanced stability and a lighter final product (Baixauli, Salvador, Hough, & Fiszman, 2008). Conversely, a less viscous batter may fail to trap carbon dioxide and water vapors in air cells during the baking process (Rajiv, Soumya, Indrani, & Venkateswara Rao, 2011). The incorporation of pectin extracted from yuja pomace as a fat replacer in baked goods has been shown to elevate viscosity, contributing to greater batter stability, as observed by Lim and colleagues in 2014. Similarly, previous findings demonstrated increased batter viscosity with the addition of pectin in cakes (Psimouli & Oreopoulou, 2013).

Water Holding Capacity (WHC) is a critical parameter providing insights about product's water retention capability, influencing various physical characteristics such as cooking loss, texture, and mouthfeel (Zaini et al., 2020). Moisture loss is a prevalent issue in the industry, leading to both weight reduction and surface liquid accumulation. A higher water holding capacity helps prevent moisture evaporation during baking, minimizing weight loss. The elevated water holding capacity associated with banana peel powder can be attributed to its dietary fiber content, where water molecules occupy the inter-spaces between fiber strands (Ali, El-Anany, & Gaafar, 2011). As the control sample had lower water holding capacity due to the absence of dietary fiber, the hydrated nature of dietary fiber contributes significantly to this parameter. Water holding capacity (WHC) is a property influenced

by factors such as porosity, ionic strength, hydration capacity, calcium content, pH, temperature, free hydroxyl groups in pectin, and ultrasound-assisted cavitation in the pectin structure (Bayar et al., 2017).

The proximate analysis of muffins was conducted, and our findings align with those of Eshak (2016), who noted an increase in bread moisture content when using banana peel powder. Another study highlighted that the addition of banana fiber to bread, known for its excellent water-binding properties, led to increased water absorption and higher bread moisture content. Additionally, it was demonstrated that replacing fat with pectin gel in cookies increased moisture content (6.79–7.33%) compared to control cookies (6.79–7.33%), as pectin gel retained more water than butter (16–18%) (Sharma et al., 2023). This rise in moisture content contributed to a positively perceived moist mouthfeel, distinguishing pectin from other fat replacers that impart a dry and hard mouthfeel. The water retention properties of pectin were associated with this increased moisture content (Zhou et al., 2020).

It was also reported an elevation in the ash content of banana peel bread with an increasing amount of banana peel flour (Eshak, 2016). Protein is vital for maintaining physiological functions and reducing protein-energy deficiency (WHO, 2024). It exhibited an increase, ranging from 13.53% to 17.80%, compared to the control (13.03%) when powdered banana peel was incorporated into cake formulation (Ahmed, El-Sharnouby, & El-Waseif, 2021). Similar outcomes were observed by (Ndife, Abdulraheem, & Zakari, 2011) in soy flour bread and banana peel flour bread. Our study's results resemble those of Sharma et al. (2023), who noted a reduction in cookie fat content from 14% in the control to 4.63% with the addition of pectin from *citrus limetta* peel. Furthermore, our findings align with M. J. Alam, Akter, Afroze, Islam, and Sayeem (2020), reporting an increasing trend in crude fiber with the addition of banana and banana peel flour in cookies, which is consistent with the observations of Nassar, AbdEl-Hamied, and El-Naggar (2008), who investigated an increase in crude fiber with the incorporation of citrus fruit peel in wheat flour. Another group of researchers observed significant increment in nutritional profiling of muffin by the addition of grape pomace powder at 15 & 25% (Baldan, Riveros, Fabani, & Rodriguez, 2023).

Dough should have optimum viscosity to hold the air bubbles created by baking powder and mixing. Therefore, adding small amounts of fiber to increase viscosity facilitate to hold air bubbles thus increasing cake volume. On the other hand, very high fiber content inhibited expansion and reduced cake volume (Gómez, Moraleja, Oliete, Ruiz, & Caballero, 2010). The former results are consistent with Ahmed et al. (2021), who mentioned that by increasing substitution of banana peel powder (BPP), the specific volume of the cake significantly decreased (2.44–1.69 cm^3/g) while the density of the cake was increased. Similarly, Psimouli and Oreopoulou (2013) also reported that increasing the amount of pectin as fat replacer from 65 to 100% led to a great consistency coefficient which made it easier for many air bubbles to develop, giving it specific volume that was similar to the control although the specific gravity of the relevant batters was lower. According to Liu et al. (2017), the addition of hydrocolloids significantly increased the specific volume of bread. Furthermore, Gao et al. (2018) categorized pectin as hydrocolloid. According to Rai, Kaur, and Chopra (2018), they can improve viscoelastic properties, flocculation, coalescence, foam stability, and gas holding capacity in dough systems. Additionally, they can reduce moisture loss, maintain the bread overall quality, including texture, specific volume, crumb structure; sensory qualities etc. and extend the bread shelf life (Jnawali, Kumar, & Tanwar, 2016).

During storage period peroxide oxide value, free fatty acids, percent moisture loss and hardness were also observed in freshly baked muffins. In a study, Zou, Tan, Zhang, Wu, and Shang (2022) elaborated that banana peels have larger amounts of phenols, an important secondary metabolite with antioxidant properties, than other fruits. Several phenolic substances, including gallic acid, catechin, epicatechin, gallocatechin, and anthocyanins are found in banana peel. Banana peel is a considerable source of antioxidants as evidenced by the fact that its gallo-catechin level is five times higher than that of banana pulp. It is noteworthy that incorporation of banana peel powder increased antioxidant properties in whole meal bread thus reduced peroxide value. Further, Aly, Tahoon, and Faid (2017) also concluded in their study that adding extracts of banana, orange, and mango peel to soybean and olive oils enhanced their quality while being stored. Similarly, Jouki, Shakouri, and Khazaei (2021) evidenced reduction in oxidation by the addition of pectin in sausages formulation. Likewise, Smirnov et al. (2017) also reported antioxidant property of pectin in their study. In the current study, peroxide value increased during storage but at slower pace in muffins prepared with banana peel powder and pectin.

According to Noorlaila, Hasanah, Yusoff, Sarijo, and Asmeda (2017), the retrogradation process involves the formation of stable interactions between water molecules and the amylopectin found in starch. As a result, there was less free water available, which eventually resulted in a decrease in moisture content. Numerous mechanisms connected to the retro gradation of starch molecules could be used to explain moisture loss in baked goods during an extended period of storage. An increase in a product's hardness results from moisture loss. Results are accordance to Ng, Chiang, Ng, Lee, and Henry (2021), reported that continuous loss of moisture in low fat muffins prepared with inulin-konjac had higher moisture content than control for 5 days storage duration due to high fiber content that enable the binding of the water in the batter to the free hydroxyl group. Similarly, TÜrKEr, Savlak, and Kaşıkcı (2016) found that after the addition of banana peel flour decreased cooking loss because of high water holding capacity of banana peel flour. Likewise, Ozkoc and Seyhun (2015) mentioned in their study that hydrocolloids facilitate mixing and extend the shelf life of bakery products by retaining moisture and preventing syneresis. Fat lubricates and softens the dough's gluten networks. Decrease in fat content in the formulation may be responsible for the increase in hardness. Our findings are in line with Gómez et al. (2010), who reported hardness of bread increase by the 20% substitution of banana peel flour. Further, Ayoub et al. (2022) also observed hardness of biscuits increased from 5.3 to 9.5% as compared to control (5.2%) significantly due to substitution of different ratio of banana peel flour because of soluble dietary fiber content increased which has higher capacity to hold water, leads to increase viscosity of dough and breaking strength. Additionally, all gums could minimize moisture loss during bread storage, lowering the rate at which the crumb dehydrates. By the addition of 1% xanthan gum decrease in the loss of moisture and hardening of bread crumb (Fakhreddin Salehi, 2020). Similarly, Škara, Novotni, Čukelj, Smerdel, and Ćurić (2013) also observed that as hydrocolloids are hygroscopic in nature was responsible to prevent moisture loss in hydrocolloid (pectin, inulin, and guar gum) enriched bread as compared to control during storage. Moreover, It was observed in current study that pectin isolated at higher pH levels may contain more sugars due to the alkaline conditions during extraction. When incorporated into muffin batter, these sugars can participate in maillard browning reactions during baking, contributing to a darker color in the crust of the muffins that increases its a* and b*.

Most crucial aspects influencing consumer acceptance is the sensory attributes of food products (Mehder, 2013). Our findings are accordance with Eshak (2016) who also reported the highest score 8.8, 7.13, 8.2, 8.7 and 8.6 for the aroma, taste, texture, color and overall acceptability of control sample of balady flat bread as compare to samples supplemented with banana peel flour and concluded that bread's increased fiber content causes the gluten structure to deteriorate, and this altered gluten structure has an impact on the bread's crumb structure. According to Kurhade, Patil, Sonawane, Waghmare, and Arya (2016), chapatti was brown in color as compared to control by substituting 5–20% peel powder of banana in chapatti formulation because of presence of phenolic substances, carotenoids, and other xanthophylls, which are linked to fruit's color features. They also reported decreased in score of taste from 4.15 to 3 by adding banana peel flour and concluded that difference was due to astringency of banana peel containing flavonoids

phenol higher than control sample. Recently, Ayoub et al. (2022) also reported decrease trend in taste and texture from 3.0 to 1.0% and 3.5 to 1.5%, correspondingly as compared to control (3.1% for taste and 2.5% for texture) as the substitution level of banana peel flour increased from 5 to 30% in biscuit formulation and further elaborated the cause of decline trend in taste and texture due to tannins compounds and high fiber content presents in banana peel. The volatile components of the source material determine how the products taste and smell (M. J. Alam, Huq, Prodhan, & Talukder, 2013). According to Galanakis (2019), the color characteristic is one crucial element that has a considerable impact on the quality of baked goods. Non-enzymatic browning processes (Maillard reactions) may cause a significant shift in color from light brown to dark shades of brown with greater fiber addition. Through this non-enzymatic mechanism, high-molecular-weight macromolecule compounds known as melanoidins were produced during baking. Earlier, F Salehi and Kashaninejad (2017) reported that the bakery products produced by the addition of hydrocolloids significantly enhanced the color, flavor, texture and overall acceptability. Bakery goods made with wheat and hydrocolloids revealed high levels of weight, thickness, diameter, moisture content, and decreased fracture strength in comparison to those made only from flour. The sensory properties of flour were greatly enhanced by the addition of different gums (Fakhreddin Salehi, 2020).

In current work, scanning electron microscope was used to analyze the surface topography. In this connection, Ashraf et al. (2020) observed that control bread, which had good porosity and bigger pore size, had starch granules that were quite prominent and visibly embedded within the gluten network. According to Lee et al. (2015), when some of the flour was replaced with other components, volume and height of muffins were correspondingly reduced. In the view of Upadhyay, Ghosal, and Mehra (2012), the addition of hydrocolloids resulted in the formation of a thick layer on the surface of gas bubbles, which decreased the likelihood of individual gas cells coalescing. Our finding is similar to Ashraf et al. (2020) who observed that the microstructure of xanthan gum-containing bread was continuous, with starch molecules covered with xanthan gum that had good porosity. However, its texture was stiffer than control, which is explained by xanthan gum's higher affinity for water molecules, which causes the gluten network to stiffen and shatter.

5. Conclusion

The utilization of pectin from banana peel as a partial fat replacement in muffins presents a viable alternative for reducing the fat content in baked goods. The inclusion of pectin not only contributes to improved health profiles by lowering fat content but also offers potential health benefits associated with dietary fiber. Moreover, it demonstrates the feasibility of utilizing food by-products to enhance the nutritional value of food products, aligning with sustainable food practices. Nonetheless, future studies should focus on optimizing the level of pectin added to muffins to achieve the best balance between fat reduction and sensory qualities. Additionally, evaluating the impact of pectin from banana peel on the shelf life of muffins would provide valuable insights into its suitability for commercial production. Furthermore, consumer perception studies could shed light on the acceptance of muffins with pectin as a fat replacer, informing market potential and preferences. Finally, a cost-effectiveness analysis comparing pectin from banana peel to traditional fat sources would be beneficial for commercial viability assessment and wider adoption in the food industry.

Funding

This project was supported by Researchers Supporting Project Number (RSP2024R7) King Saud University, Riyadh, Saudi Arabia and National Research, Development, and Innovation Office of Hungary (OTKA, contract No FK 137577).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This project was supported by Researchers Supporting Project Number (RSP2024R7) King Saud University, Riyadh, Saudi Arabia and National Research, Development, and Innovation Office of Hungary (OTKA, contract No FK 137577).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.101539.

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