STM JOURNALS

Research & Reviews: Journal of
Food Science & Technology

https://journals.stmjournals.com/rrjofst

ISSN: 2278-2249 (Online)
ISSN: 2321-6468 (Print)
Volume 15, Issue 2, 2026
May–August
DOI (Journal): 10.37591/RRJoFST

Research RRJoFST

Sustainable Production of Halal Butter from Mango Kernel Oil: Extraction, Characterization and Functional Evaluation

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Abstract

Mango kernel oil (MKO) is a mango processing by-product and is increasingly of interest in food use because of its appropriate fat content. The growing demand of the halal and plant-based alternatives of butter points to the necessity of sustainable non-dairy sources of fat. Mango kernel oil butter has good physicochemical properties such as a good balance of fatty acids, good oxidative stability, and the right level of moisture, which is critical to product stability and shelf life. Thermal and textural properties were comparable to commercial dairy butter. Storage stability evaluation over 60 days under refrigerated conditions showed minimal changes in peroxide and free fatty acid values, indicating good shelf-life potential. Sensory analysis shows that MKO based butter has moderate color, texture, spread ability and general consumer acceptability as opposed to the commonly available butter substitutes. Mango kernel oil used in making butter also helps in better utilization of mango by-products of processing and helps in the maintenance of the food systems. In this research, it will be shown that the mango kernel oil can be successfully employed as a raw material in preparing the halal, plant-based butter. The results are informative in developing value added food products and also promote environmental friendly practices in food industry.

Keywords: Mango kernel oil, halal butter, plant-based fat, agro-waste valorization, solvent extraction, fat characterization, sustainable food processing

INTRODUCTION

Mango processing industries generate substantial quantities of by-products, primarily peels and seeds, which are often discarded as waste and contribute to environmental pollution and disposal challenges (Jahurul et al., 2015) [1]. Among these by-products, mango seeds represent a valuable yet underutilized resource. The mango seed kernel, which constitutes a significant portion of the seed, contains considerable amounts of edible fat known as mango kernel oil (MKO). This oil is characterized by a favorable fatty acid composition, being particularly rich in stearic and oleic acids, which impart desirable functional and nutritional properties (Nzikou et al., 2010) [2].

Due to its semi-solid nature, oxidative stability, and similarity to conventional dairy butter and cocoa butter, MKO has attracted increasing interest for use in butter-like products and fat-based food formulations (Abdel-Razik et al., 2012; Gunstone, 2011) [3, 4].

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Received Date: February 1, 2026
Accepted Date: February 26, 2026
Published Date: July 16, 2026

Citation: Jawata Afnan, Kristy Gourab Sinha, Mafrufur Rahman, Noor Zahin, Safkat Islam Safin, Khalid Mahmud and Mokhlesur Rahman. Sustainable Production of Halal Butter from Mango Kernel Oil: Extraction, Characterization and Functional Evaluation. Research & Reviews: Journal of Food Science & Technology. 2026; 15(2): 12–21p.

Figure 1. (a) Dried mango seed kernels; (b) Finely ground mango kernel powder.

The solvent extraction method operates on the principle of selective solubility, where lipid components present in the mango kernel powder dissolve into the organic solvent. Ethanol effectively penetrates the cellular structure of the kernel, dissolving triglycerides and other lipid fractions. Continuous reflux during Soxhlet extraction ensures repeated washing of the sample, leading to improved oil recovery efficiency (Karunanithi et al., 2015; Fellows, 2022) [5, 6].

Furthermore, ensuring the microbiological safety and extended shelf life of fat-based products remains a critical challenge in food processing. Nuclear preservation techniques, such as gamma irradiation, have emerged as effective non-thermal methods for improving food safety by reducing microbial load without significantly altering nutritional and sensory qualities (Gautam et al., 2016) [7].

Previous studies have demonstrated the potential application of mango seed kernel butter in various food products, including bakery items, confectionery, and spreads, where it has been shown to enhance texture, mouthfeel, and shelf stability (Abdel-Razik et al., 2012; Jahurul et al., 2015) [1,8]. Despite these promising findings, most existing research has focused on conventional processing methods, with limited attention given to halal-compliant butter production. This represents a notable research gap, particularly in regions with large Muslim populations where the demand for halal-certified food products continues to grow (Codex Alimentarius Commission, 2019) [9].

Therefore, this study aims to develop a halal butter formulation using mango kernel oil and to evaluate its physicochemical properties, microbiological safety, and overall quality. The findings of this study are expected to contribute to sustainable waste valorization, promote the utilization of agro-industrial by-products, and support the development of innovative halal-compliant food products with enhanced safety and quality attributes (Jahurul et al., 2015; Fellows, 2022) [1, 6].

MATERIALS AND METHODS

Raw Materials

Mango seed kernels were collected from local fruit processing units immediately after pulp removal to minimize microbial deterioration. The collected seeds were manually cleaned to remove adhering pulp and foreign materials, followed by thorough washing with distilled water. The kernels were then separated from the hard seed coats and dried under controlled conditions at 50–55°C until a constant weight was achieved to reduce moisture content and prevent microbial growth. The dried kernels were milled using a laboratory grinder to obtain a fine powder, which was stored in airtight, food-grade containers at ambient temperature until further analysis. Food-grade ethanol was used as the extraction solvent due to its safety, environmental friendliness, and suitability for halal food processing.

Mechanical Grinding of Mango Kernel

After drying, the mango seed kernels were mechanically ground using a laboratory-scale grinder (Figure 1). Grinding was continued until a fine and uniform powder was obtained. This step was essential to increase the surface area of the kernel particles, thereby enhancing solvent penetration during oil extraction. The powdered kernel material was passed through a sieve to remove coarse particles and ensure uniformity. The prepared powder was stored in airtight containers under dry conditions until extraction.

Extraction of Mango Kernel Oil

Mango kernel oil (MKO) was extracted from the powdered kernel material using Solvent extraction with food-grade ethanol as the solvent. Approximately a known weight of the kernel powder was placed in a cellulose extraction thimble and subjected to continuous solvent extraction at a temperature range of 60–70°C for a duration of 3 hours. The ethanol-oil mixture obtained after extraction was concentrated by removing the solvent under reduced pressure using a rotary evaporator. Residual solvent was further eliminated by gentle heating to ensure complete evaporation (Figure-2.a). In addition to solvent extraction, mechanical cold pressing was performed as a comparative extraction method to evaluate differences in oil yield and quality. The oil yield was calculated on a dry weight basis and expressed as a percentage of the initial kernel powder weight. The extraction was performed using a solid-to-solvent ratio of 1:5 (w/v). Each extraction cycle was conducted in triplicate to ensure reproducibility. The rotary evaporator operated at 45 °C under reduced pressure (200 mbar). Oil yield percentage was calculated as:

$$\text{Oil Yield (\%)} = \frac{Weight\ of\ extracted\ oil}{Weight\ of\ dry\ kernel\ powder} \times 100$$

Refining and Purification of Extracted Oil

The crude mango kernel oil obtained after solvent extraction was refined using a simple flux-based refining system to improve its quality and suitability for butter production (Figure 2(b)). The refining flux was added to the crude oil to facilitate the removal of undesirable components such as phospholipids, free fatty acids, pigments, and volatile impurities.

The oil–flux mixture was gently heated and stirred to enhance the interaction between the flux and impurities. During this process, non-lipid components were adsorbed and separated from the oil phase. After treatment, the oil was clarified by filtration to remove the spent refining flux. This simplified refining approach effectively improved the color, odor, and stability of the oil. The refined mango kernel oil obtained was clear, odorless, and appropriate for use in halal butter formulation (Figure 2(b)).

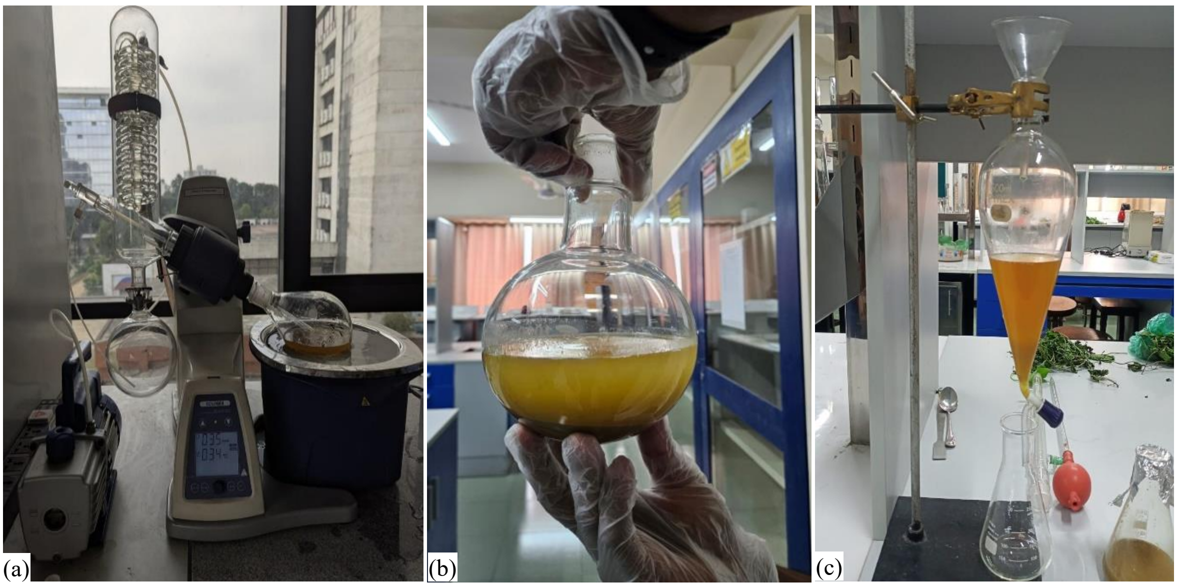

Figure 2. (a) Solvent Extraction Process; (b) Crude oil after Solvent Extraction and (c) Refined mango kernel oil after flux-based purification.

Incorporation of Emulsifying and Structuring Agents

During butter formulation, halal-certified sodium stearate and potassium stearate were used as emulsifying and structuring agents. These compounds were selected to enhance emulsion stability, improve fat crystal network formation, and develop a stable butter-like texture. The agents were incorporated into the refined mango kernel oil under controlled heating and continuous stirring conditions to ensure proper dispersion and prevent agglomeration.

Thermal Treatment and Homogenization

The refined mango kernel oil containing the incorporated emulsifiers was subjected to controlled thermal treatment to obtain a homogeneous mixture. The system was heated gradually under continuous mechanical stirring to ensure uniform mixing and complete dissolution of all components. Temperature was carefully maintained to avoid thermal degradation of the oil.

Following homogenization, the mixture was cooled gradually while stirring was continued. Controlled cooling promoted proper fat crystallization and structural network formation. As temperature decreased, the mixture thickened and developed into a smooth, creamy butter-like consistency. Continuous stirring during cooling minimized phase separation and ensured uniform texture and improved spreadability.

Preparation of Halal Butter

The extracted mango kernel oil was subjected to refining processes, including degumming, neutralization, bleaching, and deodorization, to improve its color, flavor, and overall quality. The refined MKO was then used as the primary fat source for the preparation of halal butter. The butter formulation involved blending the oil with halal-certified emulsifiers and stabilizers to achieve a butter-like consistency, spreadability, and stability. All ingredients used in the formulation were free from animal-derived components and complied with halal food standards. The mixture was homogenized under controlled temperature conditions and allowed to cool to form a uniform butter product.

Halal Compliance and Certification Considerations

All ingredients used in butter formulation were plant-derived and free from animal-based components. Food-grade ethanol used for extraction was completely removed during rotary evaporation to ensure no residual alcohol remained in the final product. Halal-certified sodium stearate and potassium stearate were sourced from certified suppliers providing documentation of halal compliance. The production process avoided cross-contamination with non-halal materials.

The halal compliance framework followed guidelines from the Codex Alimentarius Commission (2019) and general halal food principles for ingredient sourcing, processing, storage, and packaging. For industrial application, certification may be obtained from nationally recognized halal certification authorities following ingredient verification, facility audit, and product testing

Cooling, Textural Development, and Final Stabilization

After the formation of a creamy consistency, the butter mixture was transferred to sterile containers and subjected to further cooling under controlled conditions. The product was then placed in a freezing environment for a specified period to enhance firmness and structural stability. Freezing promoted fat crystal formation, resulting in improved texture and consistency similar to that of commercial butter.

Once stabilized, the butter samples were removed from the freezing condition and allowed to equilibrate at refrigerated temperature prior to analysis. The final product exhibited a uniform appearance, smooth texture, and satisfactory spreadability, making it suitable for further physicochemical, sensory, and microbiological evaluation.

Analytical Methods

The quality and characteristics of the mango kernel oil–based butter were evaluated using a range of physicochemical, structural, and functional analyses. Fatty acid composition of the butter was determined using gas chromatography (GC) after conversion of fatty acids to their methyl esters (FAMEs). This analysis provided detailed information on the relative proportions of saturated and unsaturated fatty acids present in the butter. The analytical procedures were organized into dedicated subsections, as described below.

Gas Chromatography (GC) Analysis of Fatty Acid Composition

The fatty acid composition of mango kernel oil–based butter was determined using gas chromatography (GC) following conversion of fatty acids into fatty acid methyl esters (FAMEs). Methylation was carried out using a standard transesterification procedure prior to analysis. The FAMEs were separated on a capillary GC column under controlled temperature programming, and individual fatty acids were identified by comparing their retention times with known standards. Results were expressed as relative percentage composition of total fatty acids.

Differential Scanning Calorimetry (DSC)

Thermal behavior and melting characteristics of the butter samples were analyzed using differential scanning calorimetry (DSC). Samples were hermetically sealed in aluminum pans and subjected to controlled heating and cooling cycles. Parameters including onset melting temperature, peak melting temperature, final melting temperature, and crystallization temperature were recorded from the DSC thermograms. These thermal parameters were used to evaluate the melting behavior and suitability of the butter for spreadable fat applications.

Texture Profile Analysis (TPA)

Textural properties of the mango kernel oil butter were evaluated using texture profile analysis (TPA) with a texture analyzer. Measurements were conducted at controlled temperature conditions to simulate storage and usage environments. Parameters such as hardness, cohesiveness, springiness, and spreadability were determined using a standardized compression test, providing insight into the mechanical and functional properties of the butter.

Fourier Transform Infrared (FTIR) Spectroscopy

Fourier transform infrared (FTIR) spectroscopy was employed to examine the structural integrity of the butter and to identify characteristic lipid functional groups. Spectra were recorded over a suitable wavenumber range, and characteristic absorption bands corresponding to ester carbonyl and aliphatic C–H stretching vibrations were analyzed to confirm the absence of chemical degradation during processing.

Oxidative and Chemical Stability Analysis

Oxidative stability of the butter was assessed by determining peroxide value and free fatty acid content using standard titrimetric methods. Moisture content was also measured to evaluate its potential influence on oxidative stability and shelf life. These parameters were used as indicators of lipid quality and extent of oxidation.

Sensory Evaluation

Sensory evaluation was conducted by a trained panel using a 9-point hedonic scale. The attributes evaluated included color, aroma, texture, spreadability, taste, and overall acceptability. Samples were coded and presented under controlled conditions to minimize bias, and mean sensory scores were calculated for each attribute. The sensory panel consisted of 15 semi-trained members aged between 22–35 years. Samples (10 g each) were served at 10 ± 2 °C in coded containers under controlled lighting conditions. Drinking water was provided between samples to avoid flavor carry-over effects.

Statistical Analysis

All experiments were performed in triplicate (n = 3), and results were expressed as mean ± standard deviation (SD). Statistical analysis was conducted using one-way analysis of variance (ANOVA) to determine significant differences among measured parameters. Differences were considered statistically significant at $p < 0.05$. Statistical calculations were performed using standard statistical software.

RESULTS AND DISCUSSION

Fatty Acid Composition

In Table 1, Gas chromatography (GC) analysis showed that mango kernel oil butter is predominantly composed of stearic acid (38.5%) and oleic acid (42.1%), with smaller proportions of palmitic acid (9.8%), linoleic acid (6.4%), and other minor fatty acids (3.2%). The high levels of saturated (stearic) and monounsaturated (oleic) fatty acids indicate a lipid profile suitable for solid fat applications. The standard deviation (SD) for fatty acid composition determined by gas chromatography was considered acceptable when values remained within ±0.1–0.5% of the mean, reflecting typical instrumental precision in lipid profile analysis.

Thermal Behavior and Melting Characteristics

In Table 2, Differential scanning calorimetry (DSC) analysis revealed that the mango kernel oil butter exhibited a melting onset at 28.6 °C, a peak melting temperature at 32.4 °C, and an endset melting temperature at 35.8 °C. The crystallization temperature was observed at 24.1 °C. For differential scanning calorimetry (DSC), temperature measurements were considered reproducible when SD values were within ±0.2–0.6 °C, consistent with standard thermal analysis variability.

Textural Properties

In Table 3, Texture profile analysis (TPA) indicated that the butter possessed moderate hardness and good spreadability. The measured hardness was 4.2 N, while cohesiveness and springiness values were 0.61 and 0.74, respectively. Spreadability was recorded as 6.8 N·s. In texture profile analysis, SD values within 2–8% of the corresponding mean were considered acceptable, as commonly reported for mechanical property measurements in fat-based food systems.

Table 1. Fatty acid composition of mango kernel oil butter (GC analysis).

Fatty Acid	**Composition (%)**
Palmitic acid (C16:0)	9.8 ± 0.21
Stearic acid (C18:0)	38.5 ± 0.34
Oleic acid (C18:1)	42.1 ± 0.29
Linoleic acid (C18:2)	6.4 ± 0.18
Others	3.2 ± 0.11

Table 2. Thermal properties of mango kernel oil butter (DSC Analysis).

Parameter	**Value (Mean ± SD)**
Onset melting temperature (°C)	28.6 ± 0.42
Peak melting temperature (°C)	32.4 ± 0.37
Endset melting temperature (°C)	35.8 ± 0.45
Crystallization temperature (°C)	24.1 ± 0.39

Table 3. Texture profile analysis (TPA) of butter sample.

Parameter	**Value** (Mean ± SD)
Hardness (N)	4.2 ± 0.15
Cohesiveness	0.61 ± 0.03
Springiness	0.74 ± 0.04
Spreadability (N·s)	6.8 ± 0.20

Oxidative and Chemical Stability

In Table 4, The butter sample exhibited low free fatty acid and peroxide values, along with low moisture content. The free fatty acid value was 0.72%, the peroxide value was 2.6 meq O_2/kg, and the moisture content was 1.4%. For peroxide value and free fatty acid determinations, SD values within 5–10% of the mean were considered analytically acceptable, in accordance with typical variability observed in edible oil quality assessment.

Structural Integrity and Functional Group Analysis

FTIR spectra of the mango kernel oil butter showed characteristic absorption bands corresponding to ester carbonyl (C=O) stretching and aliphatic C–H stretching vibrations. No abnormal or unexpected peaks were detected.

Sensory Attributes and Consumer Acceptability

In Table 5, Sensory evaluation using a 9-point hedonic scale demonstrated favorable scores for most attributes. Texture and spreadability received the highest ratings, while color, aroma, and taste were also within acceptable ranges. For sensory evaluation using a 9-point hedonic scale, SD values below ±0.5 units were considered indicative of good panel agreement and acceptable reproducibility.

Table 5. Sensory evaluation scores (9-Point hedonic scale).

Comparison with Commercial Dairy Butter

In Table 6, to evaluate market relevance, the developed mango kernel oil butter was compared with commercially available dairy butter values adapted from (O’Brien ,2008) [9].

The developed butter demonstrated comparable melting behavior and texture, with lower moisture content contributing to improved oxidative stability. Unlike dairy butter, the developed product is entirely plant-based and halal-compliant.

Table 4. Oxidative and chemical stability parameters.

Parameter	**Value** (Mean ± SD)
Free fatty acid (%)	0.72± 0.05
Peroxide value (meq O_2/kg)	2.6± 0.18
Moisture content (%)	1.4± 0.07

Attribute	**Values**
Color	7.2± 0.30
Aroma	6.9± 0.25
Texture	7.5± 0.28
Spreadability	7.6± 0.22
Taste	7.1± 0.27
Overall acceptability	7.4± 0.24

Table 6. Comparative analysis of mango kernel oil butter and commercial dairy butter.

Parameter	**MKO butter**	**Commercial dairy butter**
Melting point (°C)	32.4	32–35
Hardness (N)	4.2	3.5–5.0
Peroxide value (m_{eq} O_2/kg)	2.6	1–3
Moisture (%)	1.4	15–18
Animal-derived content	No	Yes

Storage Stability Study

Storage stability was evaluated over 60 days under refrigerated conditions (4 ± 1 °C). Samples were analyzed at 0, 30, and 60 days for peroxide value, free fatty acid content, and sensory acceptability. Results indicated a slight but non-significant ($p > 0.05$) increase in peroxide value from 2.6 to 3.1 m_{eq} O_2/kg after 60 days. Free fatty acid content increased marginally from 0.72% to 0.89%, remaining within acceptable limits. Sensory scores remained above 6.5 throughout storage, indicating good product stability. These findings suggest that mango kernel oil butter possesses satisfactory refrigerated shelf-life potential for industrial application.

DISCUSSION

The fatty acid composition of mango kernel oil butter, characterized by high stearic and oleic acid contents, is consistent with profiles reported for cocoa butter and other solid vegetable fats. Stearic acid contributes to firmness and structural stability at room temperature, while oleic acid enhances smooth melting behavior and mouthfeel. This combination is particularly desirable for butter-like products and supports the suitability of mango kernel oil as a cocoa butter or dairy butter alternative.

The DSC results demonstrated a melting peak close to human body temperature, which is a critical functional property for spreadable fats. The relatively narrow melting range suggests a uniform fat crystal network, which is known to improve texture, spreadability, and sensory perception. Similar melting characteristics have been reported for commercial dairy butter and plant-based butter alternatives, indicating functional comparability.

Textural properties further confirmed the suitability of the product as a butter substitute. Moderate hardness combined with good spreadability suggests that the butter maintains structural integrity while remaining easy to apply, even under refrigerated conditions. These properties can be attributed to controlled thermal processing, emulsifier incorporation, and gradual cooling, all of which promote stable fat crystallization.

The low peroxide and free fatty acid values indicate good oxidative stability and minimal lipid degradation. Effective refining and flux-based purification likely removed pro-oxidant components, contributing to improved shelf-life potential. Oxidative stability is particularly important for plant-based fats intended for storage and commercial distribution.

FTIR analysis confirmed that the fundamental lipid structure remained intact throughout processing, with no evidence of chemical degradation. This suggests that the applied refining, heating, and butter formulation steps were sufficiently mild to preserve lipid integrity.

Finally, sensory evaluation demonstrated good consumer acceptability, especially in terms of texture and spreadability. The favorable overall acceptability score indicates that mango kernel oil butter can achieve sensory qualities comparable to existing plant-based butter products. Collectively, these findings confirm that mango kernel oil can be successfully processed into a stable, halal-compliant, butter-like product with desirable physicochemical, functional, and sensory attributes. Additional studies have reported that mango kernel fat exhibits polymorphic behavior similar to cocoa butter, contributing to desirable crystallization patterns and texture (Jahurul et al., 2015) [1]. The fatty acid distribution observed in this study aligns with findings by Nzikou et al. (2010) [2], confirming the structural suitability of mango kernel oil for solid fat systems.

Compared with commercial plant-based spreads, which often contain hydrogenated fats, the developed butter avoids trans-fat formation while maintaining structural stability. This enhances its nutritional and functional value. Furthermore, previous research has demonstrated that low moisture content significantly improves oxidative resistance in fat-based systems (Shahidi & Zhong, 2010), supporting the observed stability results.

CONCLUSION

This study demonstrates the successful utilization of mango kernel oil, an underexploited agro-industrial by-product, for the development of a halal, plant-based butter alternative. The processing steps, including kernel size reduction, solvent extraction, simplified flux-based refining, controlled thermal treatment, emulsifier incorporation, and cold stabilization, resulted in a stable butter-like product with desirable physicochemical, thermal, textural, and sensory characteristics.

The fatty acid composition, dominated by stearic and oleic acids, contributed to favorable melting behavior and texture comparable to conventional butter. Thermal and texture analyses confirmed appropriate firmness and spreadability, while low peroxide and free fatty acid values indicated good oxidative stability. FTIR analysis verified lipid structural integrity throughout processing, and sensory evaluation showed satisfactory consumer acceptance.

Importantly, all materials and processing steps used in this study were free from animal-derived ingredients and complied with halal food principles. The developed butter therefore represents a suitable alternative for Muslim consumers seeking halal-certified, plant-based fat products. In regions with large Muslim populations, where access to halal dairy alternatives may be limited, mango kernel oil butter offers a culturally acceptable and sustainable solution.

Overall, the findings highlight the potential of mango kernel oil as a value-added halal food ingredient, supporting both sustainable waste utilization and the growing demand for halal and plant-based food products.

Acknowledgments

The authors gratefully acknowledge the Head of the Department of Nuclear Science and Engineering, MIST, for valuable guidance and institutional support throughout this study.

Ethical Approval

This study did not involve human or animal experimentation; therefore, ethical approval was not required.

Funding Information

This research was conducted without any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The work was carried out using available institutional resources and limited project funding.

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