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Research Article

EFFECTS OF FATTY ACID COMPOSITION AND TEMPERATURE ON TEXTURE AND SPREADABILITY: A COMPARATIVE STUDY OF BUTTER AND LARD

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ABSTRACT

Animal fats play a crucial role in enhancing food production and improving the emulsion qualities, texture, acceptability, and palatability of products. Therefore, the current research focused on analyzing butter and lard's chemical composition and fatty acid profiles, investigating their impact on textural properties and spreadability under varying temperature conditions. The predominant fatty acids identified in the butter samples were palmitic, oleic, stearic, and myristic. Arachidic fatty acid was only quantified in the lard samples. Among the monounsaturated fatty acids, lard samples exhibited the highest concentration at 39.67%, with oleic acid being the most prominent at 38.99%. The lard samples showed a lower hardness compared to the butter samples. The lard samples have the highest spread capacity at 10±2 °C (55.9 N·mm) between the analyzed samples and also at 20±2 °C (7.7 N·mm). The higher hardness and lower spread capacity of butter compared to lard at both temperatures (10±2 °C and 20±2 °C) are due to its high proportion of saturated fatty acids. The unpaired Student-T test between butter and lard hardness (Hs) and spreadability (S) highlighted a significant difference at a level of $p < 0.001$. The textural characteristics of analyzed fats are influenced not only by temperature but also by their fatty acid composition.

1. Introduction

Animal fats are essential in the production of foods, greatly enhancing emulsion qualities, textural characteristics, acceptability, and also product palatability. Annually, the European Union's meat industry produces roughly 17 million tons of slaughter by-products, of which 4% are intended for edible fat processing (Woodgate and der Veen 2004). By 2030, the market size for animal and marine fats and oils is forecasted to double, reflecting significant growth in this sector with a CAGR (Compound Annual Growth Rate) of 7.6%. The growing production of animal fats is accompanied by a troubling escalation in the volume of waste generated from these fats, potentially resulting in environmental pollution (Dhanavel and Nandakrishnan 2024). The organ fats and adipose tissue (depot fats) found in domestic animals like cattle and swine, along with milk fat serve as essential raw materials for fat production while sheep fat plays a minor role. Animal fat extraction differs from plant oil extraction due to the absence of rigid cell walls or supporting tissue (sclerenchyma) in animals. Heating, either through dry or wet rendering with steam or hot water, is sufficient to free fat from adipose tissue. Upon heating, the fat expands, breaking the cell membrane and flowing freely. Further separation of fat is straightforward and doesn't present technical difficulties (Belitz, Grosch, and Schieberle 2009). The edible animal fats, sourced from tallow (beef), lard (swine), butter, and poultry, are utilized in baking and cooking (Dhanavel and Nandakrishnan 2024). Sheep tallow's strong odor makes it unsuitable for edible fat, while its harder and more brittle texture, compared to beef tallow, further limits its culinary use (Belitz, Grosch, and Schieberle 2009). Lard has been recommended as a good replacement for cow milk fat in infant formulae due to its fatty acid profile, which closely resembles that of breast milk. Additionally, lard is also readily digested and absorbed (Woodgate and der Veen 2004). The lipid phase of cow's milk mainly consists of triacylglycerols, along with small amounts of other compounds such as monoacylglycerols, glycolipids, free fatty acids, sterols, and phospholipids. Approximately one-third of the global milk production is dedicated to butter manufacturing. Butter is distinctive in texture and flavor, playing a crucial role in enhancing sensory properties like mouthfeel, color, and textural, and rheological properties in various food products. The physical characteristics, stability, and nutritional value of butter are determined by the composition of fatty acids (Pădureţ 2021). In contrast to lard, which contains approximately 40% saturated fats, butter contains more saturated fatty acids, about 70%, while coconut oil has a significantly higher proportion at around 90% saturated fats. In Romania, the consumption of animal fats, particularly butter, has significantly increased over time reaching an average of 3.9 kg per capita in 2020, whereas lard consumption is stable showing an average between 2 and 2.5 kg per capita (Popescu et al. 2022). The animal fats are solid or semi-solid at room temperature due to their higher fraction of saturated fatty acids. Fats in the pastry industry play a critical role, being an important raw material in dough production, influencing its structural and mechanical properties as well as the texture of the final products. Fats are selected for baked goods based on their physical and chemical properties, spoilage resistance, nutritional value, organoleptic characteristics, and safety, particularly concerning saturated and trans fatty acids (Renzyaeva 2013). Globally, palm oil is the most widely used fat in the food industry, primarily because of its low cost, high oxidative stability, and neutral taste and odor (Baldassarre et al. 2023). In 2021 world palm oil production exceeded 80 million tonnes (occupying approximately 30 million hectares), with over two-thirds of it utilized across various food products, including margarine, chocolate, pizzas, bread, cooking oils, and animal feed (Ritchie and Roser 2024). However, the environmental impacts of oil palm cultivation on natural ecosystems are predominantly negative. Expanding oil palm plantations will have significant and varied effects on biodiversity, food security, climate change, land degradation, and livelihoods (Meijaard et al. 2020). Fat has a distinctive role in the human diet, serving as the most concentrated source of dietary energy. Fat not only enhances the texture, flavor, and aroma of numerous foods, making them more palatable, but it also plays a crucial role in adjusting the texture of cooked or processed foods. Specifically, it contributes to the crispiness or crunchiness found in cakes, pastries, and cookies (Drewnowski and Almiron-Roig 2010). Consumers and industry alike value spreadability and hardness as crucial textural qualities of fats. The textural properties of solid or semi-solid edible fats are influenced primarily by their constituents, especially by solid fat content (Pădureţ 2022). The mouthfeel of fat is also influenced by the physical form that fat takes at different temperatures (Drewnowski and Almiron-Roig 2010). Thus, the main idea of the current research was to study the chemical composition and fatty acid content of butter, and lard focusing on their impact on key textural properties, such as hardness, plasticity, adhesiveness, viscosity, and spreadability under varying temperature conditions. Furthermore, FTIR (Fourier-Transform Infrared Spectroscopy) spectral analysis and the color properties were evaluated.

2. Materials and methods

2.1. Materials

The experimental materials in this research included butter and lard. The butter samples were prepared from cream at 10–12 °C (35% fat from cow's milk) through the churning process (Pădureţ 2021), while the lard samples were obtained from a local producer (Suceava, Romania). Both types of samples were stored in sealed plastic containers under refrigeration until they were analyzed.

2.2. Methods

2.2.1.Physico-chemical analysis.

The moisture content of fat samples was assessed following the ISO 3727-1:2003 standard (ISO 3727-1:2003). For this procedure, 5 grams of the sample were heated in an oven at 103 ± 2°C until a constant weight was achieved. The fat content of the analyzed samples was measured according to the ISO 3727-3:2003 standard (ISO 3727-3:2003), while the refractive index was measured with a Leica Mark II Plus refractometer at 40°C (ISO 1739:2006). The physicochemical analysis results were expressed as mass percentages.

2.2.2.Color evaluation.

The color characteristics including brightness (L*), red-green color parameter (a*), and yellow–blue color parameter (b*) were evaluated using the Konica Minolta CR-400 ChromaMeter (Konica Minolta, Tokyo, Japan), with C illuminant, 2° observer, and 8 mm aperture size, applying the CIE Lab* (Commission Internationale de l'Eclairage) uniform color space method. The tone or hue angle (h^o), whiteness index (WI), color intensity or chroma (C*), yellowness index (YI), and total color differences (ΔE*) were calculated based on the measured color parameters (Zimbru, Pădureţ, and Amariei 2020).

2.2.3.Fatty acid analysis.

The analyzed samples stored in refrigeration conditions were used for lipids phase extraction at 50°C, following the guidelines of ISO 14156:2001 (ISO 14156:2001). The fatty acids methyl esters (FAMEs) were obtained with n-hexane as a lipids solubilization reagent while 200 µL of KOH 2 mol/L methanolic solution was used as a transesterification reagent (ISO 12966-2:2017; Pădureţ 2021). The samples' FAMEs were analyzed using a GC-MS QP 2010 Plus (Shimadzu, Kyoto, Japan) equipped with an AOC-01 auto-injector and a SUPELCOWAXTM[10] capillary column (60 m length, 0.25 mm diameter, and 0.25 µm film thickness from Supelco Inc. Bellefonte, PA, USA). Samples' fatty acid methyl esters were identified by evaluating their retention times with those of a 37-component FAME Mix standard (Restek, Bellefonte, PA, USA, 35077), (Pădureţ 2022). All reagents utilized for the analysis were sourced from Sigma Aldrich (Darmstadt, Germany).

2.2.4.FTIR analysis.

For the Fourier-Transform Infrared Spectroscopy (FTIR) analysis, a Nicolet iS-20 spectrometer (Thermo Scientific, Germany) was utilized. The fat samples were examined in Attenuated Total Reflectance (ATR) mode, covering a wavenumber range of 4000 to 650 cm^{-1} with a resolution of 4 cm^{-1}. The spectra were recorded at room temperature after 32 scans using OMNIC software. The reference spectrum was measured against air using a spectrometer equipped with a deuterated triglycine sulfate (DTGS) detector. (Nurrulhidayah et al. 2015).

***2.2.5. Textural properties analysis*.**

The textural properties of edible fat samples placed in cylindrical plastic containers were assessed using three different probes: a 120° conical probe (PC_{120}), a spherical probe with a 5 mm diameter (PS_5), and a spherical probe with a 10 mm diameter (PS_{10}). These measurements were conducted with the Mark 10 ESM 301 texture meter (Mark 10 Corporation, Copiague, NY, USA). The penetration depth was set at 4 mm for PC_{120} and PS_{10} while for PS_5 probe the depth was set at 2 mm. The testing speed was maintained at 10 mm/min, and the MESUREgauge software was utilized for data collection. The texture parameters assessed from the force versus penetration depth curves were hardness (Hr), plasticity (Pl), adhesiveness (Ah), and viscosity (Vs) (Bourne 2002; Pădureţ 2022).

The fat samples' spreadability was determined using a Spreadability Rig attachment with a 500 N load cell (Mark 10 Corporation, Copiague, NY, USA), whereas the fat samples were placed within a female cone (90° angle). The testing was conducted with an appropriate male cone until a gap of 2 millimeters was obtained between the two elements. From the resulting curves the firmness/hardness (Hs), spreadability (S), and adhesiveness (As) were assessed. The spreadability of the fat samples was assessed as the area under the loading force deformation curve (Ziarno et al. 2023). The edible animal fat samples were kept at 20±2 °C for more than 10 hours before being placed into cylindrical plastic containers measuring 35 mm in both height and diameter or plastic female cones (Figure 1), ensuring no bubbles formed in the fat structure. Half of these containers were analyzed after 4 hours at 20±2 °C, while the remaining half was refrigerated at 10±2 °C for 24 hours before undergoing textural analysis.

Figure 1. Edible fat sample: lard (left), butter (right)

2.3. Statistical Analysis

The results are expressed as the mean of three measurements. To differentiate the samples, an Unpaired Student's T-test and one-way ANOVA (α=0.05) were conducted using Statgraphics Centurion XVI. Multiple comparisons of means were subsequently performed using Fisher's Least Significant Difference (LSD) test at a 95% confidence level. The SPSS 16 software was used for Pearson correlation analysis.

3. Results and discussions

3.1. Physico-chemical analysis.

Figure 2 presents the average physico-chemical results of analyzed edible fat samples. Lard samples showed the highest fat content (98.63%) while the moisture content presented low values (0.86%). Similar results were also observed in other studies using both official assays and low-field nuclear magnetic resonance (LF-NMR) techniques (Tang et al. 2022).

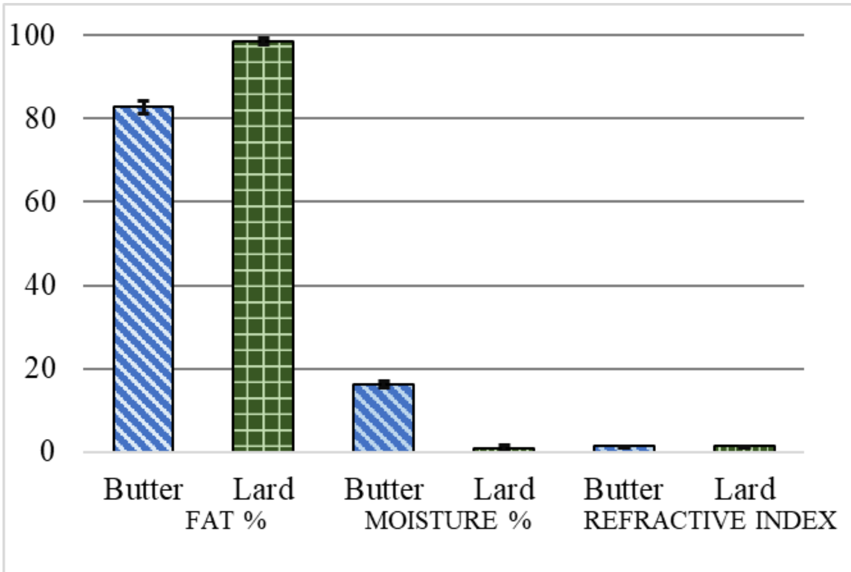

Figure 2. Physico-chemical results of animal edible fat.

Table 1. Unpaired Student-T test of animal edible fat color parameters

Sample	Butter	Lard	T-value	p-value
	Mean ± SD			
L*	89.02 ±0.35	73.46 ±0.13	72.21	<0.001
a *	-2.26 ±0.02	-0.79 ±0.01	110.0	<0.001
b*	34.07 ±0.22	8.63 ±0.21	144.6	<0.001
C*	34.1 ±0.22	8.67 ±0.21	145.6	<0.001
h^0	93.79 ±0.06	95.23 ±0.14	16.31	<0.001
YI	54.68 ±0.14	16.78 ±0.41	151.3	<0.001
WI	64.13 ±0.11	72.08 ±0.15	76.1	<0.001
ΔE*	29.86±0.31			

L* - brightness, a* - red/green, b* - yellow/blue, C* - color intensity, h^0 - tone, YI - yellowness index, WI - whiteness index, ΔE*- total color differences. SD - standard deviation

The butter samples presented higher values for moisture content of 15.83%, whereas the average fat content was 82.76%. According to, Codex Alimentarius (Codex Alimentarius, 2022) butter is a water-in-oil emulsion with a minimum of 80% milkfat concentration and a maximum of 16% water. Moisture content is a crucial factor in assessing the quality of fats. Keeping moisture content low is beneficial as it extends shelf life by preventing oxidation and rancidity (Fathima Sajeetha, Abdul Majeed, and Mohamed Asmath 2021). The average refractive index of butter samples was 1.4563 whereas the lard samples presented an average of 1.4540 complying with the standards set by the Codex Alimentarius (Codex Alimentarius 2021). The difference between the analyzed edible fat samples was assessed using an unpaired Student's T-test. The results demonstrated a notable distinction in fat and moisture content at a level of $p < 0.001$, while the refractive index showed a smaller difference at a level of $p < 0.01$. Table 1 displays the measured (brightness, red/green, and yellow/blue) and calculated (color intensity, tone, yellowness index, whiteness index, and total color differences) color parameters of butter and lard samples and the Unpaired Student-T results. It can be observed that the difference between butter and lard mean color parameters is significant at a level of $p < 0.001$. The brightness (L*) in the CIELab assay ranges from 100 (white) to 0 (black). The analyzed animal fat samples exhibited values between 89.02 and 73.46. Butter samples displayed higher brightness values compared to lard samples, consistent with findings reported by Ziarno et al. (2023), but slightly smaller than those reported in other butter research (Pădureţ 2021). According to Krause et al. (2008) the butter samples color lightened over time when stored in both refrigerated and frozen conditions. The a* color parameters (+a* = red; -a* = green) showed negative values, indicating a greenish hue in the analyzed animal fat samples; the red/green color parameter of lard samples (-0.79) was greater than that of butter (-2.26). In contrast, the b* color parameter (+b* = yellow; -b* = blue) showed positive values for both butter (34.07) and lard samples (8.63), indicating a yellowish hue. A high positive b* value signifies a strong yellow color, whereas a low positive b* value denotes a lighter yellow color. The highest b* color parameter was registered by butter samples due to the presence of carotenes, vitamin A, and other pigments (Kontkanen et al. 2011). Chroma (C*) indicates the intensity or saturation of color and therefore the butter samples presented a more intense color. The tone (h^0) combines a* and b* color parameters, is expressed in sexagesimal degree, represents the main spectral component, and ranges from 0 to 360 degrees (red at 0 or 360 degrees, yellow at 90 degrees, green at 180 degrees, and blue at 270 degrees) (Pădureţ 2023). The average tone results for butter (93.79) and lard (95.23) samples were in the second quadrant between yellow (90°) and green (180°), leaning more toward yellow, which supports the above statement. Furthermore, the yellowness index (YI) and whiteness index (WI) were also calculated, and as can be seen, the lard samples showed a higher WI of 72.08 while the butter samples presented higher YI values. The total color differences quantify the magnitude of color disparity between any two samples and the obtained results were greater than 3, implying that the color differences may be perceivable by the human eye (Milovanovic et al. 2020).

3.2. Fatty Acid Composition

The fatty acids composition, as percentages, of the animal fat fraction is given in Table 2. Of the 37 fatty acids analyzed, only 21 were quantified. It is well known that milk fat contains over 400 different fatty acids with distinctive physicochemical and biological properties (Djordjevic et al. 2019), and among the analyzed animal fats, the butter samples exhibited the highest count of fatty acids, totaling 18 fatty acids of 37, followed by lard samples with 14 fatty acids. Additionally, lard derived from pig fatty tissues is a highly nutritive food that plays a role in human nutrition and is one of the most widely used animal-based raw materials, containing about

40% saturated and 59% unsaturated fats, including a good balance of omega-3 and omega-6.

Table 2. The mean composition of fatty acids (%) of the analyzed edible fat samples

Name	Abbreviation	RT ± 0.50 min	Mean values	
			Butter	**Lard**
Butyric	C4:0	6.05	1.44	-
Caproic	C6:0	7.84	0.72	-
Caprylic	C8:0	10.73	0.37	-
Capric	C10:0	14.14	0.82	-
Lauric	C12:0	17.52	0.98	0.02
Short and middle-chain saturated			4.33	0.02
Myristic	C14:0	20.67	5.42	0.34
Pentadecanoic	C15:0	22.18	0.44	-
Palmitic	C16:0	23.81	36.50	27.04
Heptadecanoic	C17:0	25.60	0.37	0.13
Stearic	C18:0	27.70	15.13	20.76
Arachidic	C20:0	30.54	-	0.02
Heneicosylic	C21:0	36.25	-	0.03
Behenic	C22:0	37.60	0.38	0.07
Long-chain saturated			58.24	48.39
Tetradecenoic (Myristoleic)	C14:1	21.30	0.28	-
Pentadecenoic	C15:1 (cis-10)	22.86	0.14	-
Palmitoleic	C16:1	24.36	0.55	0.61
Heptadecanoic	C17:1 (cis-10)	26.25	-	0.05
Oleic	C18:1 cis (n9)	28.33	35.11	38.99
11-Eicosenoic	C20:1 cis (n9)	33.32	0.03	0.02
Monounsaturated			36.11	39.67
Linoleic	C18:2 cis (n6)	29.60	0.88	11.64
γ-Linolenic	C18:3 (n3)	31.54	0.38	0.22
Polyunsaturated			1.26	11.86
Unsaturated/saturated fatty acids			0.60	1.06
Atherogenicity index			1.58	0.55

It provides tocopherol and vitamin D, aiding in nutrient and calcium absorption (Mrázová et al. 2018). The measured fatty acids were grouped into different categories based on their chain length and unsaturation degree as short- and medium-chain saturated, long-chain saturated, monounsaturated, and polyunsaturated. From the mentioned categories the long-chain saturated one exhibited substantial levels in both lard and butter samples (lard-48.39%, butter-58.24%) followed by the monounsaturated category (lard-39.67%, butter-36.11). The palmitic content of lard samples was higher than that reported by Nevrkla et al. (2017) for pork back fat, the oleic content was very close to the stated values, whereas the stearic acid was similar. The stearic acid content or the stearic to linoleic acids ratio has been found to provide the most accurate prediction of lard firmness (Gläser, Wenk, and Scheeder 2004). The arachidic fatty acid was quantified only in the lard samples, arachidonic acid is exclusively found in animal tissues and does not occur in vegetable fats, similar findings were also reported by Sinclair (1961). Furthermore, the butter samples were distinguished by the presence of butyric acid, a distinctive constituent of the milk fat found in ruminant animals with benefits on human health (Parodi 1997). In the monounsaturated fatty acids group lard samples showed the highest concentration of 39.67%, the oleic fatty acid stands out as the most representative (38.99%). In the case of butter samples, the most abundant fatty acids were palmitic, oleic, stearic, and myristic, similar results were reported for conventional, organic, and grass butter and also for American, Irish, and Polish butter (Pustjens et al. 2017). Furthermore, lard samples presented substantial amounts of polyunsaturated fatty acids like linoleic and γ-linolenic acids, whereas the butter samples presented lower values. According to Pustjens et al. (2017) organic butter has a linolenic fatty content of over 0.50% and based on the results obtained (0.88%) from the analysis of the butter samples, it can be concluded that they fall within the organic category.

The atherogenicity index (IA) of animal fat samples was calculated using the fatty acid composition according to the Ulbritcht and Southgate formula: IA = [lauric acid + 4·myristic acid + palmitic acid]/unsaturated fatty acids (Khalili Tilami and Kouřimská 2022). This index is commonly used to evaluate the nutritional value of foods. Generally, a lower atherogenic index signifies that the food is less likely to contribute to atherosclerosis, making it healthier (Bermingham et al. 2020). The atherogenicity index of lard samples was smaller (0.55) than that of butter (1.58). Moreover, the atherogenic index of butter is approximately 3 to 5 times higher than that of other animal-derived foods because of its high saturated fatty acid content (Naydenova 2021). Table 2 also includes the ratios of unsaturated to saturated fatty acids; the highest ratio was shown by lard samples, while the butter samples presented smaller values. The World Health Organization recommends that the ratio of unsaturated to saturated fatty acids should be higher than 1.6 (WHO and Consultation 2003), consequently, lard samples are closer to the recommended values. According to some studies, (Vu et al. 2022; Fang et al. 2021; Suriaini et al. 2023) solid fats provide several technological benefits over oils in the food industry because of their superior oxidative stability. This stability enhances the texture, spreadability, shelf life, and flavor of food products. In baking, most fats must be solid or semisolid at room temperature to facilitate batter handling, necessitating a higher content of saturated fatty acids. Lard is valued in baking, due to its large fat crystals that contribute to a flaky texture and rich flavor. It is commonly used alongside butter in pastries for its shortening properties and can also be used as a spread. With its high smoke point, lard is also suitable for quick frying (Sanders 2015).

3.3. FTIR Spectra analysis.

The FTIR spectra of the butter and lard samples in the 4000 - 600 cm^{-1} region are presented in Figure 3.

The majority of the spectral bands and their respective wave number ranges are linked to different chemical compounds. According to Nurrulhidayah et al. (2015), FTIR spectra serve as unique fingerprint patterns for each type of fat and oil. In fats and oils, the majority of the peaks correspond to specific functional groups, highlighting their distinctive chemical characteristics. The FTIR spectra of butter and lard show a comparable spectrum region for each sample, indicating similarity in their chemical composition. The noticeable differences between the butter and lard spectra were attributed to variations in intensity at specific wavenumbers, similar to those reported in another study (Nurrulhidayah et al. 2015).

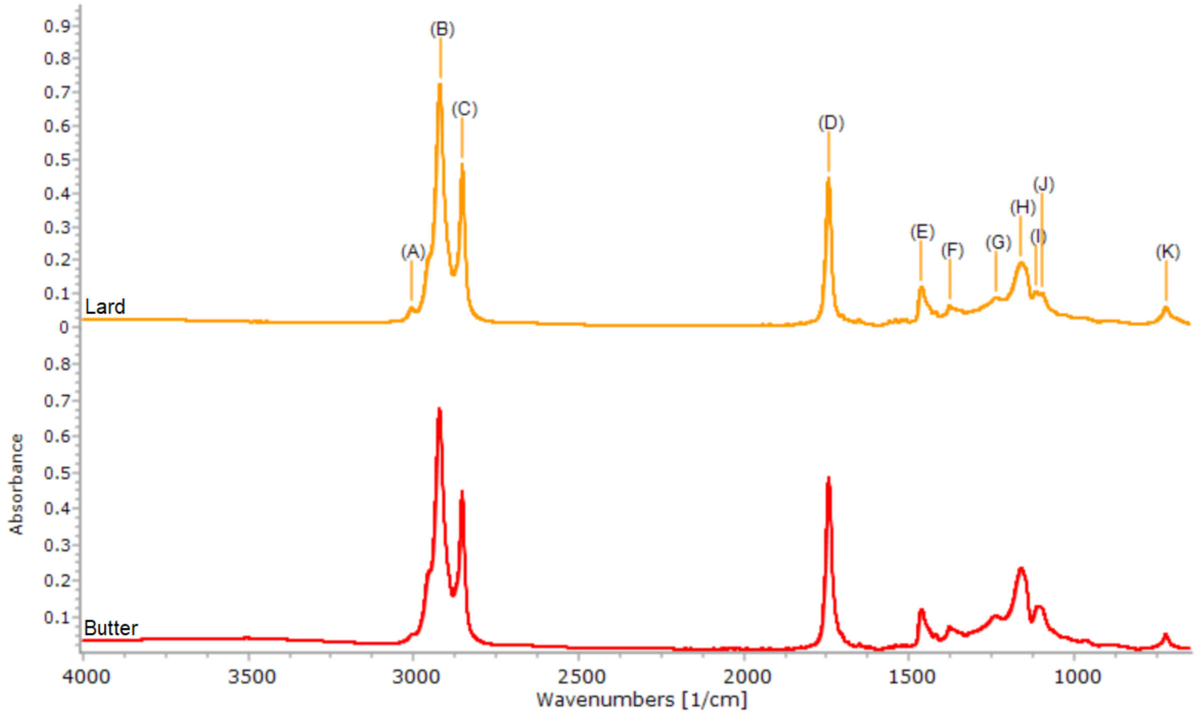

Figure 3. The ATR-FTIR spectra of lard and butter samples in the 4000-600 cm^{-1} region: A-3005 cm^{-1}, B-2920 cm^{-1}; C-2852 cm^{-1}; D-1743 cm^{-1}; E-1462 cm^{-1}; F-1376 cm^{-1}; G-1236 cm^{-1}; H-1160 cm^{-1}; I-1116 cm^{-1}; J-1098 cm^{-1}; K-721 cm^{-1}

The peak at 3005 cm^{-1} (A peak) corresponds to the olefinic double bond oscillatory movements (Guillen and Cabo 1997), with lard samples showing a higher intensity, indicating that lard contains a higher proportion of oleic and linoleic acyl groups compared to butter. Both samples clearly exhibited the methylene (-CH_2-) asymmetrical stretching absorption bands (Li et al. 2019), with peaks observed at 2920 cm^{-1} (B peak) and 2852 cm^{-1} (C peak). However, these bands differed in intensity between the two samples, with lard showing higher absorption values than butter. Furthermore, between the (A) and (B) peaks at approximately 2953 cm−1 in both sample categories, a shoulder is observed due to the methyl asymmetrical stretching vibration, while the vibration band is not detected. The carbonyl (C=O; ester group) (Oroian 2024) absorption of triacylglycerol ester exhibits a stretching vibration band with D peaks at 1743 cm^{-1}. The butter samples showed greater absorbance values at this peak compared to the lard samples. Additionally, the small shoulder at approximately 1701 cm^{-1} is attributed to free fatty acids. Correspondingly to Nurrulhidayah et al. (2015) the peaks at 1462 cm^{-1} (E) in both lard and butter samples were attributed to C–O stretching and -C-H (-CH_2, –CH_3) bending/scissoring. Additionally, the peaks at 1376 cm^{-1} (F), attributed to C–O stretching, are more pronounced in butter than lard. The bands between 1400 and 1000 cm^{-1} present challenges in assignment. These bands typically correspond to vibrations of CH_2 groups, such as twisting and wagging, which generally show weaker intensity compared to methylene scissoring bands (Guillen and Cabo 1997). The peaks observed at 1236 cm^{-1} (G), 1160 cm^{-1} (H), 1116 cm^{-1} (I), 1098 cm^{-1} (J), and 721 cm^{-1} (K) in both lard and butter spectra result from the overlapping of methylene rocking vibrations and the out-of-plane bending vibration of cis-disubstituted olefins (Man et al. 2005). Apart from the band at 721 cm^{-1}, the absorption intensities of the other bands were notably higher in butter compared to lard.

3.4.Textural and spreadability measurement.

The primary characteristics of spreadable fats are texture, appearance, and flavor. Spreadable fats' textural characteristics encompass physical properties perceived through touch and are defined by how they deform, disintegrate, and flow under applied force (Kolanowski, Jaworska, and Weissbrodt 2007). These properties are typically evaluated using sensory or instrumental methods that measure responses to stress, time, and distance. Sensory evaluations are typically time-consuming, costly, and often yield inconsistent results. In contrast, instrumental measurements of texture are faster, more reliable, and widely adopted in practical applications (Bourne 2002). From the obtained force-penetration depth curves, textural parameters like hardness (H), plasticity (P), adhesiveness (A), and viscosity (V) were calculated.

Table 3. The textural properties of the analyzed fat samples.

Probe	Sample	10±2 °C - refrigeration				20±2 °C- room temperature			
		Hr (N)	**Vs** (N)	**Pl** (mJ)	**Ah** (mJ)	**Hr** (N)	**Vs** (N)	**Pl** (mJ)	**Ah** (mJ)
PS_5	Butter	3.35c (0.12)	1.14c (0.05)	3.07c (0.10)	0.33e (0.03)	0.24c (0.02)	0.10b (0.01)	0.25c (0.01)	0.09b (0.01)
	Lard	0.14e (0.02)	0.03e (0.01)	0.11d (0.02)	0.05f (0.01)	0.02d (0.01)	0.02b (0.01)	0.01c (0.01)	0.01b (0.01)
PS_{10}	Butter	16.02b (0.71)	3.7a (0.45)	24.18b (2.88)	1.51b (0.06)	1.16b (0.03)	0.34a (0.05)	1.55b (0.70)	0.62a (0.25)
	Lard	1.86d (0.58)	0.52d (0.15)	3.43c (0.92)	0.73d (0.11)	0.15cd (0.01)	0.06b (0.01)	0.31c (0.01)	0.46a (0.08)
PC	Butter	31.38a (1.34)	2.96b (0.06)	38.3a (2.23)	1.15c (0.05)	2.42a (0.21)	0.38a (0.15)	2.92a (0.41)	0.61a (0.15)
	Lard	3.16c (0.30)	1.53c (0.25)	4.42c (0.61)	2.09a (0.23)	0.19c (0.01)	0.07b (0.01)	0.19c (0.01)	0.17b (0.02)
F-Ratio		978.5	123.7	295.9	144.3	347.1	17.3	35.8	14.2
p-value		p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001

Distinct lowercase letters within a column indicate statistically significant differences between the groups ($p < 0.05$). PS_5 - spherical probe with 5 mm diameter, PS_{10} - spherical probe with 10 mm diameter, PC -conical probe. Hr - hardness, Vs- viscosity, Pl - plasticity, Ah - adhesiveness. (SD) - standard deviation.

Table 3 presents the one-way ANOVA results for the textural parameters of edible animal fat samples, assessed using three different probes at two temperatures. The differences between the textural results evaluated with three different probes were highlighted by the ANOVA statistical analysis at a level of p<0.001, and divided into different statistical groups (a-f). The hardness values of refrigerated samples (10±2 °C) varied from 31.38 N to 0.14 N, the cone probe presented the highest results. The lard samples exhibited the lowest hardness, while the butter samples showed the highest hardness. According to Woodgate and der Veen (2004), the soft texture and crystalline structure of lard make it the optimal shortening for pastry-making. Unlike other fats that may become too hard at typically lower processing temperatures, lard retains its plastic properties. The utilization of lard in the bakery industry brings benefits in terms of color, flakiness, flavor, and tenderness in baked goods. The highest viscosity was registered for both refrigerated and room temperature butter samples and evaluated with the 10 mm spherical probe (*a* statistical group). Regarding the probes used, it can be observed that for the analyzed butter samples stored at two different temperatures the hardness and plasticity values measured with the cone probe were higher than those obtained with the 10 mm spherical probe, whereas the 10 mm spherical probe results were higher than those obtained with the 5 mm spherical probe. The cone probe and even the 10 mm spherical one are essential techniques for evaluating the hardness and plasticity of fats. The cone probe measures resistance by penetrating the fat. Similarly, the spherical probe compresses the fat samples, indicating how well it deforms under stress. Using both the cone and spherical probes provides a comprehensive profile of the fat's textural properties, ensuring that both hardness and plasticity are accurately and precisely evaluated. This dual approach is essential for quality control and product development in the food industry, where the texture of fats can significantly affect product development and consumer preference. The same results were also registered for the lard hardness. The plasticity values of the lard samples measured at 20±2 °C were distributed by the ANOVA in the same statistical group (c). The hardness and plasticity of lard stored at 20±2 °C and measured with the 5 mm spherical probe exhibited the smallest results, close to zero. The registration of the testing curves in force versus displacement allowed the calculation of adhesiveness as energy (mJ) and the highest value was measured with the cone probe for the refrigerated lard samples. The spreadability parameters are presented in Table 4.

Table 4. Spreadability properties of analyzed fat samples.

Sample	10±2 °C - refrigeration			20±2 °C- room temperature		
	H_S (N)	**S** (N·mm)	**A_S** (mJ)	**H_S** (N)	**S** (N·mm)	**A_S** (mJ)
Butter	97.1 (2.2)	472.9 (5.5)	18.5 (1.2)	20.6 (0.8)	51.9 (2.8)	15.5 (1.3)
Lard	17.9 (1.8)	55.9 (3.7)	12.1 (0.7)	2.9 (0.3)	7.7 (0.8)	4.7 (0.2)
T -value	48.2	108.9	7.9	35.8	26.2	14.2
p-value	$p < 0.001$	$p < 0.001$	$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$

H_S – hardness, S – Spreadability, A_S - Adhesiveness. (SD) - standard deviation.

According to Glibowski, Zarzycki, and Krzepkowska (2008) in addition to hardness, the spreadability of butter, margarine, and other spreadable fats represents also an important parameter that is the key feature that consumers perceive as most important. The fat samples that required smaller forces to be displaced from the female cone indicated smoother spreadability. Therefore lard samples have the highest spread capacity at 10±2 °C (55.9 N·mm) between the analyzed samples and also at 20±2 °C (7.7 N·mm). Similar to texture parameters evaluated with three different probes, the spreadability parameters of both butter and lard samples were influenced by the storage temperature; refrigerated samples exhibited greater values compared to those kept at room temperature. Another study (Glibowski, Zarzycki, and Krzepkowska 2008) indicates significant differences in the spreadability of butter and mixed fat products stored at refrigeration temperatures, while Bobe et al. (2003) stated that the spreadability of butter was positively influenced by the unsaturated fatty acids of milk fats. Adhesiveness represents the work needed to separate a product from the surface it is being tested (Ziarno et al. 2023); the butter samples presented statistically ($p<0.01$) significantly higher values and were dependent on the samples' storage temperature. The unpaired Student-T test between butter and lard hardness (H_s) and spreadability (S) highlited a significant difference at a level of $p < 0.001$. The textural characteristics of fats are influenced not only by temperature but also by their fatty acid composition. The higher hardness and a lower spread capacity of butter compared to lard at both temperatures (10±2 °C and 20±2 °C) are due to its high proportion of saturated fatty acids; Pearson correlation analysis revealed a strong positive relationship between the content of saturated fatty acids (palmitic, stearic fatty acids) and both the hardness and plasticity of the samples, with a significance level of $p<0.01$. Furthermore, the unsaturated fatty acids (linoleic, palmitoleic, and oleic fatty acids) were positively correlated with the spreadability of fat samples ($p<0.05$).

4. Conclusions

The Student's T-test indicated significant differences in fat and moisture content and also in refractive index which complied with the Codex Alimentarius standards. Butter samples exhibited higher brightness values compared to lard samples. Conversely, the b* color parameters were positive for both butter and lard, indicating a yellowish color. Lard samples had higher concentrations of monounsaturated fatty acids, primarily oleic acid, while butter samples contained significant levels of palmitic, oleic, stearic, and myristic acids. Consequently, lard samples showed a lower atherogenicity index than butter, alongside a higher ratio of unsaturated to saturated fatty acids. The hardness and plasticity of fat samples stored at two temperatures varied based on the probe used for measurement, with the cone probe yielding higher results compared to both the 10 mm and 5 mm spherical probes. Using the cone probe and even the 10 mm spherical probe is essential for accurately assessing the hardness and plasticity of fats. This dual approach ensures a comprehensive evaluation of textural properties, crucial for quality control and product development in the food industry. Both butter and lard samples showed temperature-dependent changes in spreadability parameters, with refrigerated samples displaying higher values than those stored at room temperature. The textural properties of fats are affected by both temperature and their fatty acid composition. Butter's higher hardness and lower spreadability compared to lard at both temperatures can be attributed to its higher content of saturated fatty acids. Given the substantial global consumption of vegetable fats and their associated negative impacts, coupled with the increasing production of fats from the meat industry, lard, and potential lard-butter blends appear to offer a viable alternative for the pastry or bakery industry.

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