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Assessment of fatty acid content and lipid nutritional quality indicators for some cheese kinds using gas chromatography-mass spectrometry

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ABSTRACT

This study aimed to compare the fatty acid composition and determine the lipid quality indices of some hard and semihard cheese varieties sold in Egyptian markets, namely, Ras, Cheddar, and Gouda cheeses. The fatty acid profile of fifteen cheese samples was analyzed using gas chromatography–mass spectrometry (GC–MS). Moreover, the atherogenic index (AI), thrombogenic index (TI), and nutritional value index (NVI) were calculated. The analysis revealed the presence of 22 fatty acids in the cheese samples, with palmitic and myristic acids being the dominant saturated fatty acids (SFAs), while oleic and linoleic acids were the main unsaturated fatty acids (UFAs). Regarding the presence of trans fatty acids, the oleic acid trans isomer (C18:1n9, t) was detected in some samples, with the highest mean value in the Ras cheese (0.23). Cheddar cheese recorded the lowest AI and TI and the highest NVI, suggesting that it has greater nutritive value than the other two cheese types. Ras and Gouda cheese samples were moderate to high AI and TI, indicating a potential risk of cardiovascular diseases. This research offers valuable insights for cheese producers and consumers concerning the lipid quality indices and fatty acid profiles of the examined cheese varieties and how the lipid content impacts the cheese quality and human health.

Introduction

Cheeses contain a diverse range of biologically active substances, with particular emphasis regarding specific fatty acids that play a crucial role. The overall fatty acid (FA) composition of milk fat plays an important role in determining the quality of cheese. It has a significant impact on the flavor, texture, and health benefits of cheese (Ash and Wilbey, 2010). Cheese composition and nutritional value rely on milk microbiology, chemistry, technology, ripening time, additives, and manufacturing conditions. The composition of fatty acids in cheese can vary from that of milk because of the influence of starter cultures that facilitate the breakdown of lactose, protein, and fat as the cheese matures. The formation of bioactive compounds during these processes has a significant impact on the flavor and nutritional value of cheese (Mureşan *et al*., 2021).

Milk fat includes 400 fatty acids with various biological and physiological effects (Gómez-Cortés *et al*., 2018; MacGibbon, 2020). The composition of fatty acids in milk fat can be affected by several factors, including the animal's diet, breed, lactation stage, individual characteristics, the weather, healthcare, and their age (Palmquist *et al*., 1993; Samková *et al*., 2012). Milk contains different types of fatty acids, which are categorized based on the number and position of double bonds in their carbon chains. These categories include saturated (SAT), monounsaturated (MONO), and polyunsaturated (POLY) fatty acids. Basically, the predominating class of milk fat is the saturated fatty acids (SFAs) which include short-chain fatty acids (SCFAs), medium- and long-chain fatty acids, odd fatty acids (OCFAs), and branched-chain fatty acids (BFAs) (Unger *et al*., 2019). Nevertheless, the human diet consists of various classes and types of fatty acids that have a wide range of effects on human health. Consider, as an instance, certain saturated fatty acids (SFAs) like Myristic acid (C14:0) has been linked to a greater tendency of acquiring cardiovascular diseases (Paszczyk and Łuczyńska, 2020), On the other hand, butyric acid (C4:0) has been found to have positive effects on intestinal tract health and inflammation-related ailments (Banasiewicz *et al*., 2020). Consuming omega-6 and omega-3 fatty acids, known as polyunsaturated fatty acids (PUFAs), can have a beneficial impact on human health, particularly in terms of preventing and treating chronic diseases (Simopoulos, 2009).

MUFAs and PUFAs are known for their positive impact on cholesterol levels, helping to decrease bad cholesterol and increase good cholesterol in the blood (Paszczyk *et al*., 2020). It was suggested that optimal milk lipid composition for good human health prefers to be around 30% saturated fats, 60% monounsaturated fats, and 10% polyunsaturated fats. This clarifies why the fatty acid profiles of cow milk and cheese are far from ideal as the fat content in cow milk is composed approximately of 70% saturated fatty acids (SAT), 25% monounsaturated fatty acids (MONO), and 5% polyunsaturated fatty acids (Hayes and Khosla, 1992; Pascal, 1996; Soyeurt *et al*., 2006).

Trans fatty acids (TFAs) are a type of unsaturated fatty acids that have at least one double bond in the trans configuration (Bhardwaj *et al*., 2011). These compounds can be found in foods derived from ruminants, thanks to the activity of bacteria in the ruminant stomach, as well as in partially hydrogenated vegetable oils (PHPOs). PHVOs are created through the transformation of vegetable oils into a semi-solid form, which is then utilized in the production of margarines, commercial cooking, and various manufacturing processes (Ledoux *et al*., 2007). PHVOs possess excellent durability, maintaining stability even when subjected to deep frying. Their semi-stable nature further enhances the delectable taste of baked goods and sweets. Nevertheless, TFAs can have negative impacts on health, including raising LDL levels and lowering HDL levels in the blood (Islam *et al*., 2019). The levels of natural trans isomers in the milk and meat of ruminants can account for up to 6% of the total content of fatty acids, whereas processed food can contain up to 60% of industrial trans fats. Research has indicated that when it comes to HDL cholesterol, natural trans FAs are found to be less detrimental compared to industrial trans FAs (Verneque *et al*., 2022). Milk fat contains natural TFAs such as vaccenic acid (trans11

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C18:1, VA) and conjugated linoleic acid (cis9trans11 C18:2; CLA). These compounds have been found to have various beneficial effects, including anti-tumor, anti-atherosclerotic, antioxidant, and anti-inflammatory properties (Yang *et al*., 2015).

High dietary intake of TFAs is considered an important risk factor for coronary heart diseases (CHD) (Bendsen *et al*., 2011). The World Health Organization (WHO) advises a TFA intake of less than 1% of total energy percent and has introduced the REPLACE TFA action package to eliminate industrially produced TFAs from national food supplies by 2023 (Islam *et al*., 2019). The Food and Drug Administration (FDA) implemented a ruling stating that starting January 1, 2006, all conventional foods and supplements must include information about the amount of TFAs on their nutrition labels (Satchithanandam *et al*., 2004).

The fatty acid compositions of Ras, Cheddar, and Gouda cheeses produced in Egypt are not well-documented. With the use of gas chromatography–mass spectrometry (GC–MS), this investigation aimed to analyze the fatty acid composition and lipid nutritional quality indices of these cheese varieties. Our objective was to perform an in-depth investigation comparing their nutritional quality to the optimal milk lipid composition that supports human well-being.

Materials and methods

Sample collection

Fifteen randomly selected samples of Ras, Gouda, and cheddar cheeses (5 Ras, 6 Gouda, and 4 Cheddar) were collected from the Cairo and Giza markets. The samples were identified, labeled, and transported in an insulating ice box, with a minimum delay to be immediately examined.

Total lipid extraction (Folch et al., 1957)

The lipids were extracted using the modified Folch procedure. The cheese samples were thoroughly crushed and carefully mixed. Approximately 3 grams of each sample were thoroughly mixed with 30 milliliters of methanol by using the IKA Ultra-Turrax ®T18 digital for a duration of one minute. Subsequently, 30 ml of chloroform was added, and the process was carried out for a duration of 2 minutes.

The mixture was subjected to filtration, the remaining solid matter was mixed with 60 mL of chloroform:methanol (2:1 v/v) and thoroughly blended for an extra 3 minutes. The concoction was transferred to an identical cylinder. Subsequently, a solution containing 0.88% sodium chloride in water was introduced to the entire filtrate, constituting a volume equal to one-fourth of the filtrate.

The water pump was employed to eliminate the uppermost layer. A methanol:water solution (1:1 v/v) was introduced into the lowermost section. The process of cleansing was repeated. After filtration through anhydrous (VI) sodium sulphate, the remaining material was distilled to ensure that the solvent was completely evaporated.

Determination of fatty acid composition by GC–MS (Zahran and Tawfeuk, 2019)

The fatty acid composition was determined using the process of transmethylation, which entails converting fatty chains into fatty acid methyl esters (FAMEs). The FAMEs were purified using a gas chromatography technique (HP 6890 plus, Hewlett Packard, USA) equipped with a Supelco™ SP-2380 capillary column (60 m×0.25 mm×0.20 µm) (Sigma–Aldrich, USA). A detector (FID) was utilized, and both the injector and detector temperature were set at 250°C. The column temperature was set at 140°C for 5 minutes, after which it gradually increased to 240°C at a rate of 4°C per minute. It was then maintained at 240°C for a duration of 10 minutes. The carrier gas used was helium with a flow rate of 1.2 ml/min. FAMEs were recognized by comparing their relative and absolute retention times to those of authentic standards of FAMEs (SupelcoTM 37component FAME mix). The fatty acid composition was expressed as a percentage relative to the total peak area.

Lipid Nutritional Quality Indices (LNQI)

The atherogenic index (AI) and thrombogenic index (TI) were calculated according to Ulbricht and Southgate (1991), while the nutritive value index (NVI) was calculated according to Chen *et al*. (2016).

$AI = (C12:0 + (4 \times C14:0) + C16:0)/(\Sigma MUFA + \Sigma n\text{-}6 + \Sigma n\text{-}3)$

$TI = (C14:0 + C16:0 + C18:0)/[(0.5 \times \Sigma MUFA) + (0.5 \times \Sigma n\text{-}6) + (3 \times \Sigma n\text{-}3) + (\Sigma n\text{-}3/\Sigma n\text{-}6)]$

$NVI = (C\ 18:0 + C18:1)/C\ 16:0$

Statistical analysis

The data was analyzed using IBM SPSS statistics 23 for Windows. A one-way analysis of variance (ANOVA) was conducted, along with a post hoc test, to identify any significant differences between the means. Statistically significant differences were deemed acceptable at a p-value of less than 0.05.

Results

The GC–MS profiles of selected samples are presented in Figure 1, which shows the presence of different fatty acids with different retention times. Table 1 shows the saturated fatty acid (SFA) compositions of the Ras, Cheddar, and Gouda cheeses. The examined Cheese samples had varied amounts of total saturated fatty acids (SFAs), with Cheddar Cheese having the lowest content (68.89±0.35%).

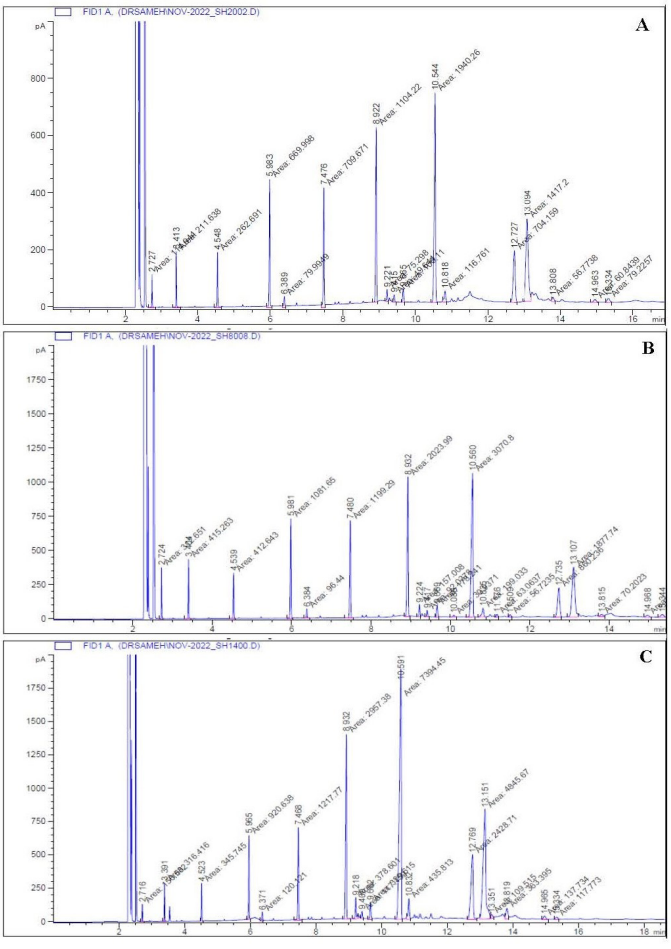

Figure 1. Chromatogram of GC–MS separation obtained for selected Ras cheese samples (A), Cheddar cheese samples (B) and Gouda cheese samples (C).

Individually, Gouda Cheese had the greatest palmitic acid (C16:0) values (mean = 31.47±0.57%). Compared with Ras Cheese (28.89±1.77%) and cheddar Cheese (30.44±3.22%), Cheddar Cheese had a much lower content of myristic acid (C14:0) (12.04±2.33%). Ras Cheese had the highest percentage of pentadecanoic acid (C15:0) at 2.00±0.22%. The levels of other fatty acids, including butyric, caproic, caprylic, capric, lauric, stearic, and heptadecanoic acids, were similar across the different types of cheese.

Our study revealed that the MUFA and PUFA contents were significantly greater ($p < 0.05$) in Cheddar cheese. Oleic acid (C18:1n9c) was the predominant monounsaturated fatty acid (MUFA) according to Table 2. the Oleic acid trans isomer (C18:1n9, t) was detected in two of five Ras cheese samples (40%), one of four Cheddar cheese samples (25%) and two of six Gouda cheese samples (33.3%), with mean values of 0.23, 0.06 and 0.15, respectively.

Linoleic acid (C18:2 n6c) was identified as the primary polyunsaturated fatty acid (PUFA) in all the cheese samples analyzed, as shown in Table 3. Interestingly, Cheddar Cheese exhibited the highest PUFA content (4.4±2.75%), followed by Gouda Cheese (3.31±0.74%) and Ras Cheese (3.04±0.76%)., these differences were statistically significant (Table 3). In this study, the ω 3 PUFA content was significantly lower ($p < 0.05$) in the Ras cheese than in the other cheeses, whereas the ω 6 PUFA content was significantly greater ($p < 0.05$) in the Cheddar cheese (Table 4).

The lipid nutritional indices include PUFAs/SFAs, n-6/n-3, the atherogenic index (AI), the thrombogenic index (TI), and the nutritive value index (NVI). They are frequently applied to assess the nutritional content of fat in dairy products. Data obtained in Table 4 revealed that the P/S ratio, which represents the ratio of polyunsaturated fatty acids (PUFAs) to SFAs, was significantly different between Cheddar Cheese (0.06±0.01) and the other two cheeses (0.04±0.005). However, there were no significant differences observed between Ras Cheese and Gouda Cheese. The AIs were nearly similar for both the Ras and Gouda cheeses, while the lowest AI was recorded for the cheddar cheese. The same pattern was observed for TI, in which that of the Ras cheese was the highest, followed by that

Table 1. Saturated fatty acid profile of the examined cheese samples (n = 15).

SFA	[a] A.F	Ras Cheese	Chedder Cheese	Gouda Cheese
Butyric acid	(C4:0)	1.91±0.49*[a]	1.57±0.66*[a]	1.17±0.44*[a]
Caproic acid	(C6:0)	2.43±0.53*[a]	2.14±0.85*[a]	1.79±0.28*[a]
Caprylic acid	(C8:0)	2.29±0.47*[a]	2.05±0.81*[a]	1.89±0.18*[a]
Capric acid	(C10:0)	5.33±1.17*[a]	5.12±1.80*[a]	5.06±0.47*[a]
Lauric acid	(C12:0)	5.78±1.00*[a]	5.50±1.74*[a]	5.90±0.46*[a]
Myristic acid	(C14:0)	13.97±0.73*[a]	12.04±2.33*[b]	13.54±0.52*[c]
Pentadecanoic acid	(C15:0)	2.00±0.22*[a]	1.24±0.46*[b]	1.63±0.18*[c]
Palmitic acid	(C16:0)	28.89±1.77*[a]	30.44±3.22*[a]	31.47±0.57*[a]
Stearic acid	(C18:0)	9.22±0.69*[a]	8.53±0.79*[a]	9.60±0.44*[a]
Heptadecanoic acid	(C17:0)	0.50±0.31*[a]	0.26±0.15*[a]	0.42±0.19*[a]
SFAs		72.32±0.10*[a]	68.89±0.35*[b]	72.47±0.29*[a]

*Data represent the percentage (%) of each fatty acid relative to the total fatty acid content; SFAs: Saturated fatty acids. SFAs: total saturated fatty acids. [a] A.F.: Abbreviated Form. [a, b, c] Means in the same row with different superscripts are significantly different ($P<0.05$).

Table 2. Monounsaturated fatty acid profile of the examined cheese samples (n = 15).

MUFA	[a] A.F	Ras Cheese	Chedder Cheese	Gouda Cheese
Caproleic acid	(C10:1)	0.62±0.17*[a]	0.48±0.17*[a]	0.42±0.09*[a]
Myristoleic acid	(C14.1)	1.56±0.26*[a]	0.96±0.32*[b]	1.55±0.10*[c]
Tridecanoic acid	(C13:1)	0.13±0.13	ND	ND
Cis-10-Pentadecenoic	(C15:1)	0.12±0.10*[a]	0.15±0.08*[b]	ND
Palmitoleic acid	(C16:1),n9	2.30±0.25*[a]	2.38±0.38*[a]	2.17±0.13*[a]
Palmitoleic acid	(C16:1),n7	0.15±0.10*[a]	0.24±0.14*[a]	0.21±0.13*[a]
Oleic acid	(C18:1n9c)	19.55±1.11*[a]	22.46±4.01*[a]	19.76±0.93*[a]
Oleic acid	(C18:1n9, t)	0.23±0.18*[a]	0.06±0.01*[a]	0.15±0.09*[a]
MUFAs		24.66±0.05*[a]	26.73±0.73*[b]	24.26±0.34*[a]

*Data represent the percentage (%) of each fatty acid relative to the total fatty acid content; MUFAs: Monounsaturated fatty acids. MUFAs: monounsaturated fatty acids, ND: not detected. [a] A.F.: Abbreviated Form. [a, b, c] Means in the same row with different superscripts are different ($P<0.05$).

Table 3. Polyunsaturated fatty acid profile of the examined cheese samples (n = 15)

PUFA	[a] A.F	Ras Cheese	Chedder Cheese	Gouda Cheese
Myristolinoleic acid	(C14.2)	1.22±0.17*[a]	0.24±0.14*[b]	0.60±0.13*[c]
Linoleic acid	(C18:2 n6c)	1.34±0.22*[a]	3.42±2.18*[b]	1.92±0.34*[c]
α- Linolenic acid	(C18:3 n3)	0.28±0.17*[a]	0.33±0.19*[b]	0.56±0.12*[c]
γ- Linolenic acid	(C18:3 n3)	0.20±0.20*[a]	0.41±0.24*[a]	0.23±0.15*[a]
PUFAs		3.04±0.04*[a]	4.4±0.05*[b]	3.31±0.04*[a]
UFAs		27.7±0.05*[a]	31.13±0.32*[b]	27.57±0.18*[a]

*Data represent the percentage (%) of each fatty acid relative to the total fatty acid content; PUFA: polyunsaturated fatty acid, PUFA: polyunsaturated fatty acid, UFA: total unsaturated fatty acid. [a] A.F.: Abbreviated Form. [a, b, c] Means in the same row with different superscripts are different ($P<0.05$).

Table 4. Lipid Nutritional Quality Indices (LNQI).

	Ras Cheese (n.=5)	Chedder Cheese (n.=4)	Gouda Cheese (n.=6)
SFAs	72.32±0.10^{*a}	68.89±0.35^{*b}	72.47±0.29^{*a}
UFAs	27.7±0.05^{*a}	31.13±0.32^{*b}	27.57±0.18^{*a}
P/S Ratio	0.04±0.005^{*a}	0.06±0.01^{*a}	0.04±0.005^{*a}
TFA	0.23±0.01^{*a}	0.06±0.005^{*b}	0.15±0.01^{*c}
(Omega 3) n 3	0.48±0.01^{*b}	0.74±0.01^{*a}	0.79±0.01^{*a}
(Omega 6) n 6	1.34±0.005^{*a}	3.42±0.01^{*b}	1.92±0.05^{*c}
(Omega 7) n 7	0.15±0.10^{*a}	0.24±0.14^{*b}	0.21±0.13^{*c}
(Omega 9) n 9	19.55±0.03^{*a}	22.46±0.01^{*b}	19.76±0.10^{*a}
n-3/n-6	0.33±0.005^{*a}	0.23±0.012^{*b}	0.43±0.008^{*a}
n-6/n-3	2.86±0.02^{*a}	4.76±0.04^{*b}	2.62±0.05^{*c}
AI	3.41±0.005^{*a}	2.92±0.008^{*b}	3.39±0.1^{*c}
TI	3.51±0.008^{*a}	2.91±0.015^{*b}	3.44±0.011^{*c}
NVI	1.002±0.001^{*a}	1.035±0.008^{*b}	0.94±0.003^{*c}

SFAs: total saturated fatty acids; UFAs: total unsaturated fatty acids; AI: atherogenic index; TI: thrombogenic index; NVI: nutritive value index. TFA: Trans fatty acids, unsaturated fatty acids (UFA) = MUFA+PUFA, polyunsaturated fatty acids/saturated fatty acids (P/S) ratio, Omega 3 (n3), Omega 6 (n6), Omega 9 (n9), Omega 7 (n7). a, b, c Means in the same row with different superscripts are different (P<0.05).

of the Gouda cheese.

Discussion

In the past decade, consumers have increasingly become concerned about the fat content and composition of dairy products, including cheese. As a result, several nutritional approaches have been devised to enhance the fatty acid (FA) composition of cheese (Vera *et al*., 2009). Recently, our group evaluated the chemical composition of hard and semi-hard cheese samples that are regularly consumed in Egypt (cheddar, Ras and gouda), and the results obtained revealed that all cheddars were acceptable to the Egyptian standards, followed by Gouda and Ras (Shawki *et al*., 2024). The lipid profiles of these samples were carefully examined to evaluate how variations in cheese processing can impact the fatty acid composition.

The preponderance of saturated fatty acids (SFAs) in cheese is attributed to their association with elevated blood cholesterol levels and cardiovascular disease (Siri-Tarino *et al*., 2010). However, some SFAs, such as butyric acid, have beneficial effects on the intestinal mucosal immune barrier and prevent inflammation (Murakoshi *et al*., 2011; Tralongo *et al*., 2014; Peng *et al*., 2022). In this study, we analyzed the SFA content and profile of three cheese varieties: Ras, Cheddar, and Gouda. We found that Cheddar cheese had a significantly lower SFA content (68.89±0.35%, $p < 0.05$) than did the other two cheeses, which agrees with the findings of Białek *et al*. (2020), who confirmed that SFAs predominated in all examined types of cheese, constituting more than 60% of all fatty acids. Additionally, nearly the same results were obtained by Prandini *et al*. (2007) and Paszczyk and Łuczyńska (2020). In contrast, (Paszczyk *et al*. 2022) reported lower SFA contents (58.61 and 62.30%) in summer and winter cheese, respectively. Moreover, myristic acid (C14:0) and pentadecanoic acid (C15:0) showed significant differences among the examined samples, suggesting potential variations in the composition and nutritional characteristics of the examined cheeses. Presently, there is a growing fascination with the correlation between nutrition and noncommunicable diseases, specifically cardiovascular disease (CVD). Poor dietary habits and excessive intake of saturated fatty acid (SFA)-rich foods are factors that can be contribute to the development of chronic disorders (Kaminsky *et al*., 2022). Palmitic acid is considered a hypercholesterolemic SFA because it increases the levels of LDL cholesterol in the blood; therefore, most recent reviews suggest that reducing palmitic acid, which is abundant in milk fat, should be the main goal of improving the quality of dairy products (Haug *et al*., 2007; Murru *et al*., 2022). Myristic acid is another hypercholesterolemic SFA that has a stronger effect on increasing LDL cholesterol than palmitic acid (Feingold, 2021).

The presence of MUFAs in the diet has an important role in the prevention of a wide range of chronic diseases Eskander *et al*. (2023). PUFAs, especially omega 3 (ω3) and omega 6 (ω6), have cardioprotective and antihypercholesterolemic effects Shahidi *et al*. (2018).

Higher contents of MUFAs and nearly similar PUFAs to our results were demonstrated by Prandini *et al*. (2007), who reported that the MUFA content about 30%%, and the PUFA content ranged from 3.48% to 4.17%. Similar results were obtained by Paszczyk and Łuczyńska (2020), who demonstrated that the contents of MUFAs and PUFAs in commercial cheeses produced in winter were 27.92% and 3.31%, respectively.

The metabolic pathways of ω6 and ω3 fatty acids are complicated and competitive, and their imbalance in the diet can lead to serious disorders, including atherosclerosis, thrombosis, hypertension and cardiac arrhythmias (Simopoulos, 2008). To prevent the incidence of these diseases, the human diet must have a balanced intake ratio of 3 to 4 (Simopoulos, 2002). All tested cheese samples complied with this recommendation and agreed with Prandini *et al*. (2007) and Paszczyk and Łuczyńska (2020). The presence of linoleic acid (18:2c) as a ω6 FA was detected in all tested samples (1.34–3.42%), and the presence of α-linolenic acid (18:3), a representative ω3 FA, ranged from 0.28–0.56%, while the presence of γ-linolenic acid (18:3) ranged from 0.20–0.41% (Table 3).

The majority of unsaturated fatty acids found in the human diet have a cis configuration. Nevertheless, trans fatty acids (TFAs) can be found in the food we eat (Song *et al*., 2015). Companies are no longer allowed to produce foods with trans fats, as per regulations set by the WHO and FDA. However, it is possible that some of these items may still contain artificially produced trans fats (Bhandari *et al*., 2020). Our data revealed that the Oleic acid trans isomer (C18:1n9, t) was detected in two of five Ras cheese samples (40%), one of four Cheddar cheese samples (25%) and two of six Gouda cheese samples (33.3%), with mean values of 0.23, 0.06 and 0.15, respectively. In foods consumed in Japan, trans-10-18:1 emerged as the primary trans-18:1 positional isomer in 2019 (Gotoh *et al*., 2019). Many factors can affect the content of TFA in cheese, including geographic factors. For example, Kramer *et al*. (1998) reported that cheese produced from the milk of cows grazing on plains in the Jura Mountains or at medium altitudes contained more CLA than cheeses from the milk of cows grazing on the high plateau. Moreover, heat processing during cheese manufacturing can affect the TFA content. It was found that subjecting milk to pasteurization or heating it in a microwave resulted in an increase in the trans isomers (Herzallah *et al*., 2005). On the other hand, Lin *et al*. (1998) demonstrated that processing steps and storage had a minor influence on the formation of CLA in Cheddar cheese.

Many nutritional quality indicators have been developed to evaluate the nutritional and health advantages of different lipid fractions. The AI indicates the correlation between saturated pro-atherogenic fats, including lauric, myristic and palmitic acid, excluding stearic acid, and unsaturated FAs that are anti-atherogenic (Hanuš *et al*., 2016). The difference in the TI between pro-thrombogenic and anti-thrombogenic FAs signifies the thrombogenic potential of FAs. Consuming foods with low AI and TI can reduce the potential risk of cardiovascular disease (Summer *et al*., 2017). Similar results were obtained previously by Aguilar *et al*. (2014); Hirigoyen *et al*. (2018) and Paszczyk and Łuczyńska (2020), who reported AI indices greater than 2 in their cheese samples under investigation. The high values of AI and TI in Ras cheese may be attributed to the use of coconut oil, animal fat or hydrogenated oils during production, which are characterized by very high contents of the atherogenic fats lauric and myristic acid and low contents of MUFAs and PUFAs. The decreases in the AI and TI in Cheddar cheese may be due to the increased content of antiatherogenic (omega 6) and antithrombogenic FAs (MUFAs, omega 6 and omega 3). Since milk fat contains significant amounts of atherogenic fats, the nutritional value of the lipid fraction of hard cheese can be increased by replacing some milk fat with appropriate vegetable fat rich in antiatherogenic and antithrombogenic FAs, including MUFAs and omega 3 and omega 6 FAs.

The essential ω-3 and ω-6 fatty acids are essential for human health and normal physiological functioning; however, a high intake of omega-6 polyunsaturated fatty acids (PUFAs) in food combined with a low intake of omega-3 PUFAs results in an imbalance in the ω-6/ω-3 ratio, and thus, a high omega 6/omega 3 ratio promotes cardiovascular disease, cancer, and inflammatory diseases and plays an important role in obesity (Paszczyk and Łuczyńska, 2020) . The ratio of polyunsaturated fatty acids to saturated fatty acids is one of the most important metrics currently used to evaluate the nutritional value of the lipid content of foods. Nutritional guidelines recommend a PUFA/SFA ratio above 0.4 and not less than 0.1 (WHO, 2003; FAO, 2010). Unfortunately, all the ratios of all the examined cheese types were below the recommended range (0.04 – 0.06).

Numerous studies have provided evidence that a diet high in trans fatty acids leads to negative alterations in the plasma lipoprotein profile. This includes an elevation in LDL levels and a reduction in HDL levels (Đurović *et al*., 2022; Patel *et al*., 2022). For this reason, the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) recommended in 1994 that fats for human consumption contain less than 4% of the total fat as trans (Dhaka *et al*., 2011; Pipoyan *et al*., 2021).

Conclusion

The results of this study have important implications for the quality and health effects of cheese. The nutritional quality and lipid content of the most consumed hard and semihard cheese types (Ras, Cheddar and Gouda) in Egypt were assessed. The predominant saturated fatty acid is palmitic acid, while the major monounsaturated fatty acid was oleic acid, and the principal polyunsaturated fatty acid is linoleic acid. Cheddar cheese has the best fatty acid profile, with the lowest contents of SFAs and TFA, the highest UFAs, omega 6 and omega 9 and the highest n6/n3 ratio. Additionally, lower values of lipid indices (AI and TI) and the highest NVI are more favorable. The results obtained within this study indicate the superiority of Cheddar cheese among the other two cheese types and highlight the paramount significance of fatty acid profiling in the era of cheese quality and safety.

Conflict of interest

The authors have no conflict of interest to declare.

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