Thesis of Ph.D. Dissertation

Miaomiao Zhang

Budapest

2024

HUNGARIAN UNIVERSITY OF
AGRICULTURE AND LIFE SCIENCES

Institute of Food Science and Technology

Department of Nutrition

The Role of Fatty Acids in the Development of Obesity and Diabetes

Miaomiao Zhang

Budapest

2024

Doctoral School

Name: Doctoral School of Food Science

Discipline: Food Science

Head: **Prof. Dr. Livia Simon Sarkadi**
Full Professor, DSc
MATE, Institute of Food Science and Technology
Department of Nutrition

Supervisors: **Prof. Dr. Livia Simon Sarkadi**
Full Professor, DSc
MATE, Institute of Food Science and Technology
Department of Nutrition

Dr. Márta Üveges
Chemist, Food Science PhD
National Center for Public Health and Pharmacy
Department of Methodology and Public Health
Laboratories, Division of Chemical, Noise,
Vibration, and Lighting Technology Laboratories

.....	….....
Head of Doctoral School	Signature of the Supervisor
	….....
	Signature of the Supervisor

1. INTRODUCTION AND OBJECTIVES

The global prevalence of obesity and diabetes, including gestational diabetes, has become a major public health issue. According to the WHO, over 890 million people are obese, and more than 422 million have diabetes. Gestational diabetes affects about 14% of all pregnancies worldwide, posing serious health risks to both mothers and infants.

Human milk, recognized as the ideal source of infant nutrition. Containing about 4% fats, of which 98% are triglycerides, its fatty acid composition significantly influences infant growth, neurodevelopment, and long-term metabolic health.

Variations in the fatty acid profile of human milk caused by maternal health conditions such as obesity and gestational diabetes, are associated with metabolic risks. High levels of saturated fatty acids (SFAs) and n-6 polyunsaturated fatty acids (PUFAs) have been linked to inflammation and insulin resistance, whereas n-3 PUFAs are known to have anti-inflammatory effects. Geographical dietary differences have a further impact the FA composition of human milk. Diets high in n-3 PUFAs are associated with improved metabolic outcomes, whereas diets high in SFAs and n-6 PUFAs may contribute to metabolic dysfunction, affecting infant nutrition and health.

The precise role of milk fatty acids in the early development of obesity and diabetes is still not well known. Using samples from Hungarian and Ukrainian mothers, my research examines the effects of maternal health, body mass index, nationality, infant sex, delivery methods, and Holder pasteurization on the fatty acid composition of human milk.

The objective was to provide information on the factors shaping breast milk fatty acid profiles, contributing to enhanced nutritional guidelines and public health strategies aimed at improving maternal and infant health.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Human milk samples

Breast milk samples were collected as part of three international research projects in collaboration with the Regional Cooperation in the Fields of Health, Science, and Technology (RECOOP HST) Association and Cedars-Sinai Medical Center. All research complied with ethical guidelines approved by the Regional and Local Research Ethics Committees (PTE KK 7072-2018, Hungary; Lviv City Children's Clinical Hospital, 16 November 2018 No. 6, Ukraine).

Project 1: 69 samples (Ukraine: 60; Hungary: 9) categorized by maternal BMI and gestational diabetes (GD) status.

Project 2: 17 samples (Hungary), grouped by maternal BMI (normal weight, overweight and obese).

Project 3: Breast milk samples from 56 donor mothers with normal BMI (Hungary) were analyzed as raw samples and pooled samples subjected to Holder pasteurization.

Samples from **Projects 1** and **2** were collected between the 10^{th} and 12^{th} postpartum weeks; samples from **Project 3** were collected from 1 to 13 months postpartum.

2.2. Methods

2.2.1. Sample preparation

Project 1: Fatty acid methyl esters (FAME) were prepared following Simon Sarkadi et al. (2022). Samples were stored at -18 °C, and FAMEs were analyzed by gas chromatography with flame ionization detection (GC-FID) and confirmed with gas chromatography with mass spectrometry (GC-MS).

Project 2: FAME preparation followed ISO 16958:2015 with minor modifications, and analysis was performed using GC-FID (M. Zhang et al., 2022).

Project 3: Fresh breast milk was collected following standardized protocols. Pooled samples underwent Holder pasteurization (62.5 °C, 30 minutes) to evaluate its impact on fatty acid composition. Both unpasteurized (n=56) and pasteurized (n=10) samples were prepared and analyzed as described in Project 2.

2.2.2. Gas chromatography

Fatty acid methyl esters were analyzed using GC-FID with project-specific conditions. Identification was based on retention times compared to standard mixes, and quantification employed normalization methods (Simon Sarkadi et al., 2022).

2.2.3. Statistical analysis

Data analysis was conducted using SPSS (Version 23). ANOVA with Tukey's post hoc test was applied to identify significant differences ($p < 0.05$). Principal Component Analysis (PCA) was used for clustering and variation visualization. Quadratic Discriminant Analysis (QDA) was employed for sample classification and validated by leave-one-out cross-validation.

3. RESULTS

3.1. Fatty acid composition of human milk: impact of maternal BMI and health condition

In the first project, the samples were categorized into four groups based on maternal BMI and health status. There was a significant variation in maternal BMI between the groups. Specifically, the BMI of mothers in the obese group (31.5 ± 0.6) was considerably higher than that of mothers in the normal BMI group (23.4 ± 0.3). Notably, among all the samples, obese mothers with GD exhibited the highest BMI (32.5 ± 0.5). Our findings showed that the lauric acid (C12:0) content in the O+GD group was significantly ($p < 0.05$) lower than in the other groups. Similarly, the myristic acid (C14:0) content in the normal BMI group was higher than in the obese group, and the palmitic acid (C16:0) content in the nBMI group was also lower compared to the other groups.

Among the monounsaturated fatty acids (MUFA) the main representatives were oleic acid (C18:1 n-9) ranged from 3% to 4%, palmitoleic acid (C16:1) from 2% to 3%, and eicosenoic acid (C20:1) was less than 0.4% (Figure 1).

Regarding the long-chain polyunsaturated fatty acid (LCPUFA) content of the samples, linoleic acid (LA, C18:2) and alpha-linolenic acid (ALA, C18:3) were the most abundant fatty acids within the LCPUFA group, comprising 23–28% and 15–17% of total fatty acids, respectively (Figure 2). The levels of LA in the milk from mothers with nBMI (23.8%) were significantly lower compared to the nBMI+GD (25.8%), O (26.8%), and O+GD (27.8%) groups.

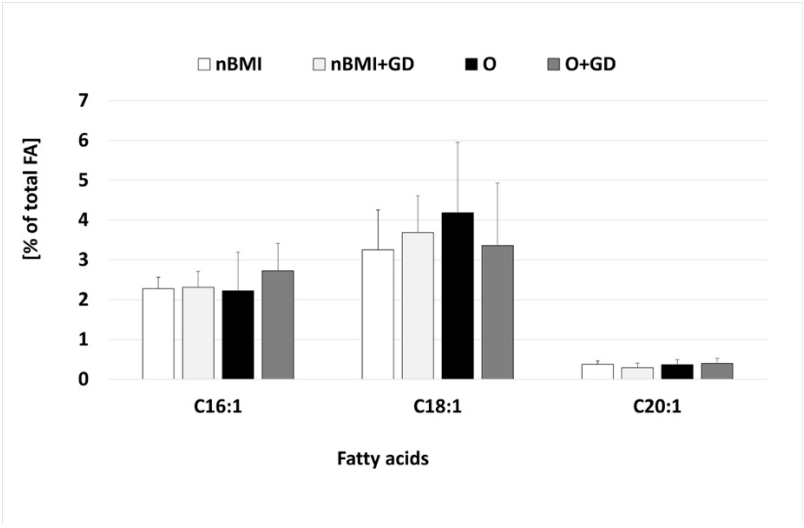

Figure 1. Monounsaturated fatty acids in breast milk samples from Ukrainian mothers

(Total number of samples: 58, 15 per group (nBMI, nBMI+GD), 14 per group (O, O+GD). FA—fatty acid; nBMI—women with normal BMI; nBMI+GD—women with normal BMI and GD; O—obese women; O+GD—obese women with GD; C16:1—palmitoleic acid; C18:1—oleic acid; C20:1—eicosenoic acid.)

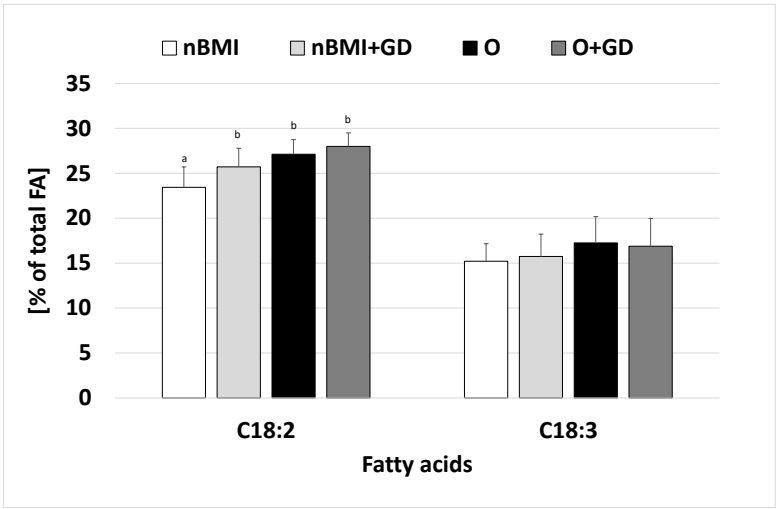

Figure 2. Long chain polyunsaturated fatty acids in breast milk samples from Ukrainian mothers

(Total number of samples: 58, 15 per group (nBMI, nBMI+GD), 14 per group (O, O+GD). FA—fatty acid; nBMI—women with normal BMI; nBMI+GD—women with normal BMI and GD; O—obese women; O+GD—obese women with GD; C18:2—linoleic acid; C18:3—alpha-linolenic acid; different letters indicate significant differences at the $p \leq 0.05$ levels.)

We employed supervised discriminant analysis to determine whether Ukrainian breast milk samples could be classified according to their fatty acid profiles (Figure 3). Canonical function 1 predominantly differentiated samples based on maternal BMI, with palmitic acid (C16:0), oleic acid (C18:1) and gamma-linolenic acid (C18:3) making the most significant contributions of the obese group. Canonical function 2 seemed to facilitate the segregation of nBMI and nBMI+GD mothers, with fatty acids such as caproic acid (C6:0), eicosadienoic acid (C20:2), heneicosanoic acid (C21:0), and lignoceric acid (C24:0) displaying the highest discriminant coefficients.

Based on the results of discriminant analysis conducted on four groups, the analysis was also performed on two groups, categorized solely by the mothers' BMI, the model's accuracy post-cross-validation reached 89.8%.

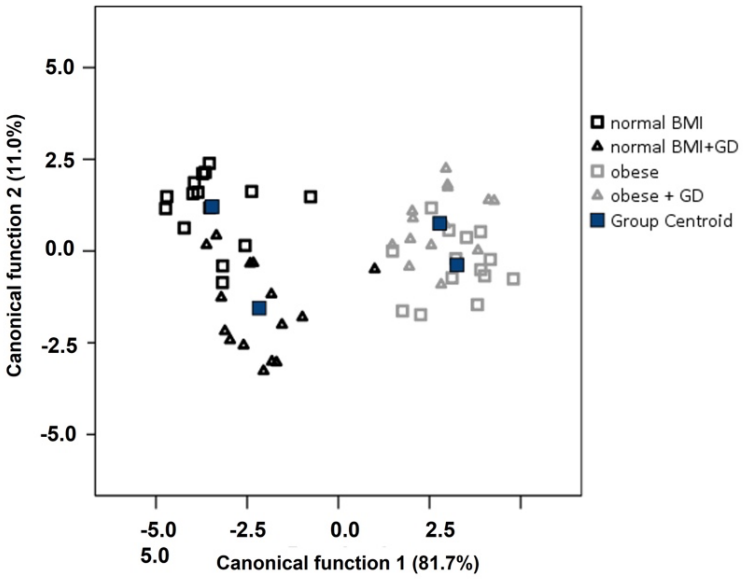

Figure 3. Discriminant analysis of Ukrainian breast milk samples

3.2. Variations in fatty acid profiles in human milk based on geographical location

We compared breast milk samples from mothers with normal BMI in Ukraine and Hungary to explore differences in the fatty acid composition based on nationality. Descriptive statistics revealed significant differences between the Hungarian (H) and Ukrainian (U) samples in the concentrations of several fatty acids. Notably, palmitoleic acid (C16:1) levels were higher in Hungarian samples (2.91 ± 0.67%) compared to Ukrainian samples (2.26 ± 0.28%), as were palmitic acid (C16:0) (H: 32.44 ± 3.94% vs. U: 25.80 ± 2.35%) and linoleic acid (C18:2) (H: 28.44 ± 2.36% vs. U: 23.43 ± 2.28%). Conversely, alpha-linolenic acid (C18:3) was more prevalent in Ukrainian samples (15.20 ± 1.97%) than in Hungarian samples (9.33 ± 2.43%) (Figure 4).

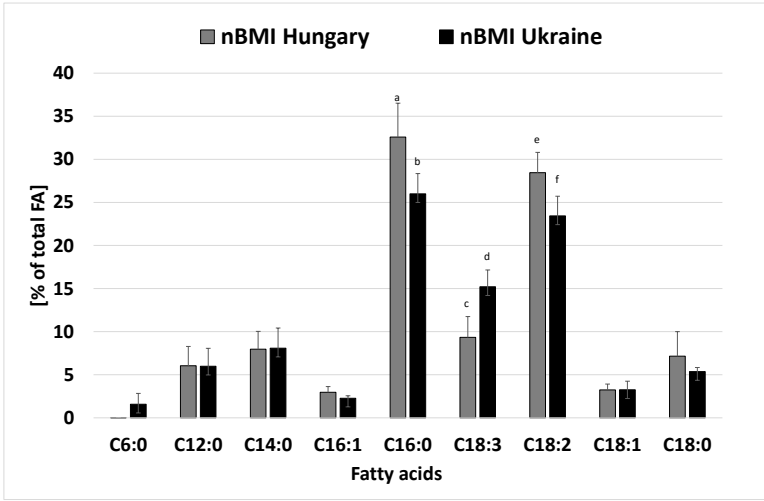

Figure 4. Main fatty acids in breast milk of nBMI women from Ukraine and Hungary

(FA—fatty acid; nBMI—women with normal BMI; C6:0—caproic acid; C12:0—lauric acid; C14:0—myristic acid; C16:0—palmitic acid; C18:0—stearic acid; C16:1—palmitoleic acid; C18:1—oleic acid; C18:2—linoleic acid; C18:3—alpha-linolenic acid; different letters indicate significant differences at the $p \leq 0.05$ levels.)

The fatty acid profiles of nBMI breast milk samples from Ukraine and Hungary were statistically analyzed using Principal Component Analysis (PCA). The analysis explained 79% of the dataset's total variance with PC1 (59%) and PC2 (20%) (Figure 5A) where PC1 was primarily responsible for differentiating samples based on geographic origin. Significant differences in the levels of palmitic acid (C16:0), linoleic acid (C18:2), and alpha-linolenic acid (C18:3) between the two groups were confirmed by t-tests. The roles of eicosadienoic acid (C20:2) and eicosatrienoic acid (C20:3) were particularly notable in Ukrainian samples. According to the loading plot (Figure 5B), the distribution of samples along PC2 was most influenced by the levels of capric acid (C10:0), lauric acid (C12:0), myristic acid (C14:0), and linoleic acid (C18:2).

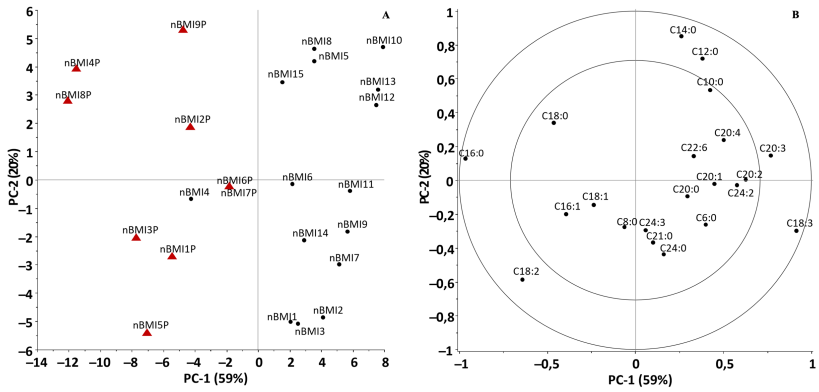

Figure 5. (A) Scores plot of principal component analysis, (B) Principal component loading of the fatty acid profile of breast milk samples from women with normal BMI in Hungary and Ukraine

(Red triangles: Hungary; black dots: Ukraine. C6:0, caproic acid; C8:0, caprylic acid; C10:0, capric acid; C12:0, lauric acid; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C20:0, arachidic acid; C21:0, heneicosylic acid; C24:0, lignoceric acid; C16:1, palmitoleic acid; C18:1, oleic acid; C20:1, eicosenoic acid; C18:2, linoleic acid; C20:2, eicosadienoic acid; C18:3, alpha-linolenic acid; C20:3, dihomo-gamma-linolenic acid; C20:4, arachidonic acid; C22:6, docosahexaenoic acid. Total number of samples was 24.)

3.3. Fatty acid composition of human milk in Hungarian mothers with varying BMI levels

In this study, we conducted an in-depth analysis of the fatty acid composition of HM among Hungarian mothers with different BMI levels. Saturated fatty acids were the most prevalent, with higher concentrations observed in the milk from obese mothers (54.21%) compared to those with normal BMI (48.33%). Monounsaturated fatty acids followed, with similar levels in both the normal BMI (33.35%) and obese groups (33.52%). Polyunsaturated fatty acids were less abundant, with the normal BMI group having 15.76% and the overweight or obese group showing a lower percentage at 11.50%.

The results indicate that most fatty acids with significant differences exhibited higher percentage ratios in the O group, except for palmitoleic acid (C16:1) and linoleic acid (C18:2), which were higher in the nBMI group (Figure 6).

When comparing the PUFA profiles of breast milk from mothers with normal BMI to those who were overweight and obese, we found that the n-6 to n-3 ratio was 53% higher in milk from the O group (Figure 7).

The fatty acid composition of breast milk samples was statistically analyzed using PCA to identify hidden patterns within the data. The dataset was mean-centered, and full cross-validation was utilized to assess the model's parameters (Figure 8). The analysis revealed that the first three principal components accounted for a significant portion (95%) of the total variance: PC1 explained 69%, PC2 accounted for 14%, and PC3 for 12%.

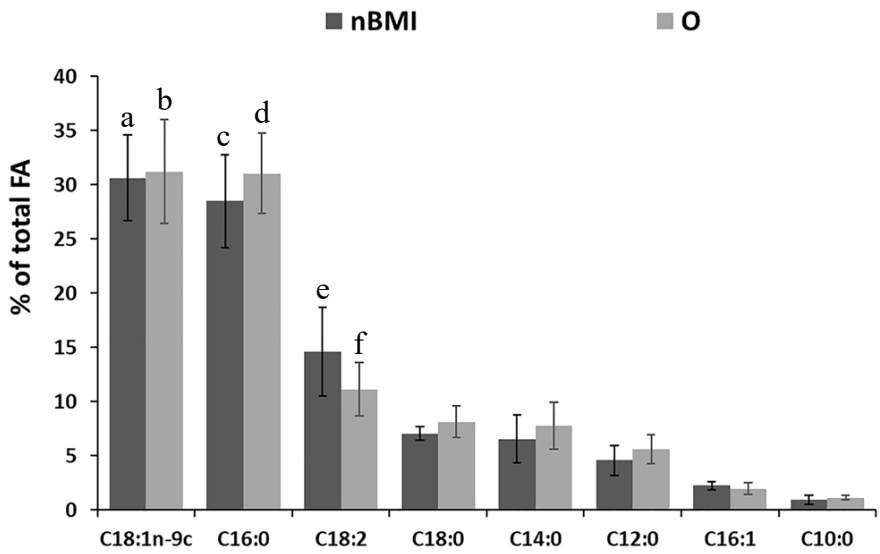

Figure 6. Distribution of significantly different fatty acids in breast milk samples from mothers with different health statuses

(FA: fatty acid; nBMI: women with normal body mass index (BMI); O: overweight and obese women; different letters indicate significant differences at the $p \leq 0.05$ levels.)

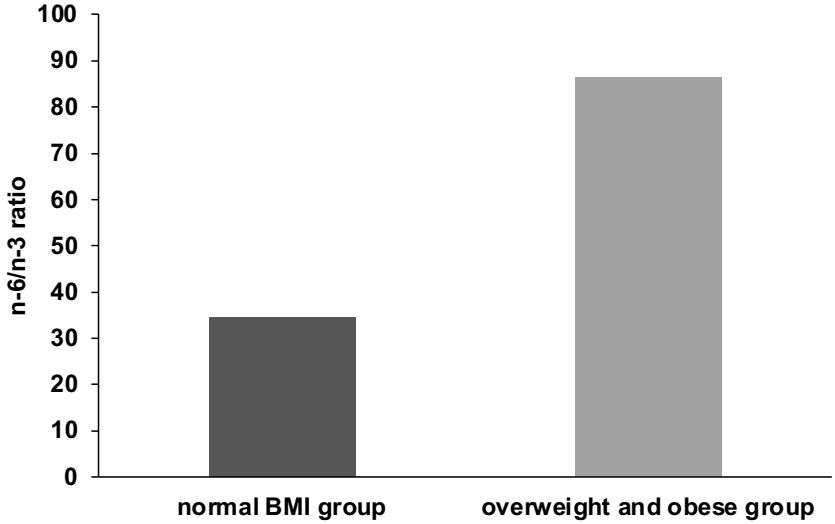

Figure 7. n-6/n-3 ratio in breast milk from mothers with different health statuses

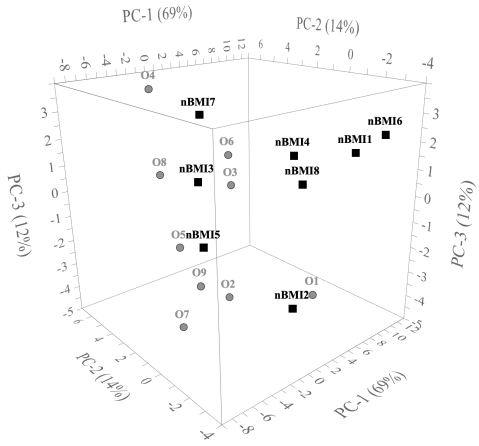

Figure 8. The scores plot of principal component analysis of the fatty acids in human milk samples
(squares: normal BMI; dots: overweight and obese samples)

In addition to PCA, quadratic discriminant analysis (QDA) was applied to further classify the samples based on the relative percentages of fatty acids to the total fatty acid's ratio, as depicted in (Figure 9). The QDA model achieved a classification accuracy of 88.24%. The discriminant analysis effectively differentiated samples belonging to the normal BMI group from those in the obese group based on their distinct fatty acid profiles.

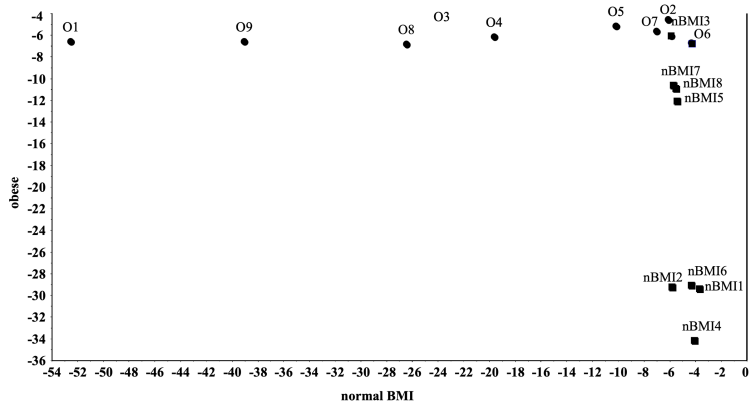

Figure 9. Quadratic discriminant analysis (QDA) of human milk samples
(squares: normal BMI; dots: overweight and obese samples)

3.4. Effect of infant gender on human milk fatty acid composition

Our result showed that the concentration of eicosadienoic acid (C20:2 n-6c) was significantly higher in the breast milk produced for female infants. The average percentage ratios were calculated as 0.25 ± 0.04 for boys and 0.34 ± 0.07 for girls (Figure 10).

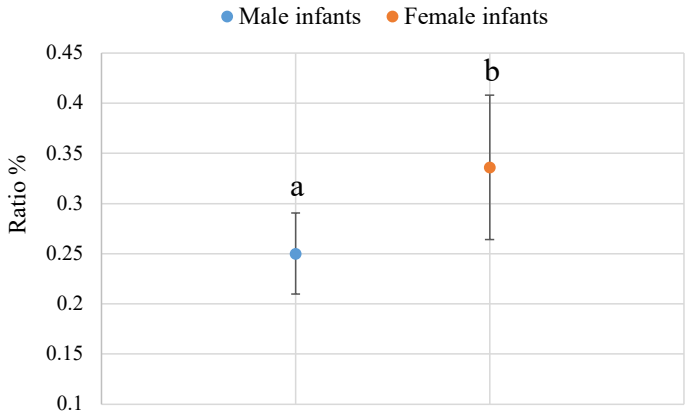

Figure 10. Average values of eicosadienoic acid (C20:2 n-6c) in different groups of human milk samples
(Orange dots represent human milk for girls, blue dots represent human milk for boys; different letters show significant differences at $p \leq 0.05$ levels.)

When considering the third principal component (PC3), the samples showed distinct separation based on the sex of the infants. Clear differences between the samples were visible for the second and third principal components (PC2 and PC3). For PC2, the concentration of oleic acid (C18:1 n-9c) fatty acid significantly influenced the positioning; for PC3, the contents of myristic acid (C14:0), lauric acid (C12:0), and capric acid (C10:0) substantially impacted the positioning of samples, facilitating the observed separation. Positions in the negative range on PC2 could be explained by higher contents of linoleic acid (C18:2 n-6c), while samples in the positive range were influenced by margaric acid (C17:0). According to the corresponding loadings (Figure 11), the latter had a lesser impact.

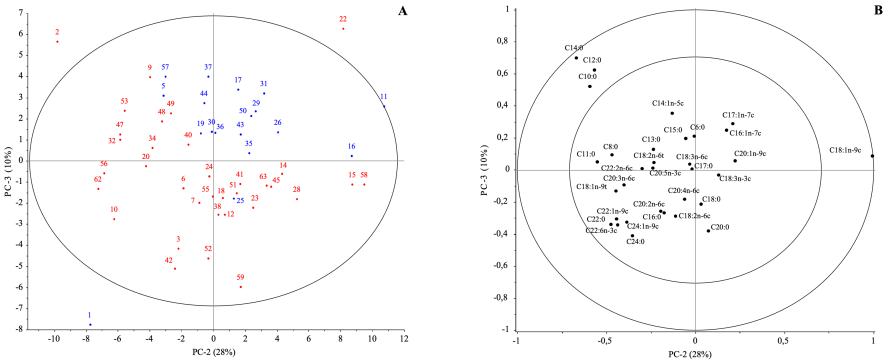

Figure 11. Scores (A) and correlation loadings (B) of the samples (PC2-PC3)

(The samples were marked with colors according to the sex of the infant: girl-red; boy-blue.)

3.5. Impact of different neonatal delivery modes on human milk fatty acid composition

Nearly 57.6% of the participating mothers delivered their babies by caesarean section, while 42.4% delivered vaginally. Regarding the mode of delivery, our study found that breast milk from mothers who delivered via C-section contained lower concentrations of specific fatty acids, including lauric acid (C12:0), pentadecanoic acid (C15:0), palmitic acid (C16:0), margaric acid (C17:0), stearic acid (C18:0), and compared to those who delivered vaginally. In contrast, levels of linoleic acid (C18:2 n-6c), and docosahexaenoic acid (C22:6 n-3c) were significantly higher in breast milk from mothers who delivered by C-section.

The n-6 to n-3 fatty acid ratios were calculated accordingly. As shown in Figure 12, this higher rate can be attributed to the fact that both ARA and DHA levels are elevated in mothers who have undergone a caesarean section, with the increase in ARA being more pronounced.

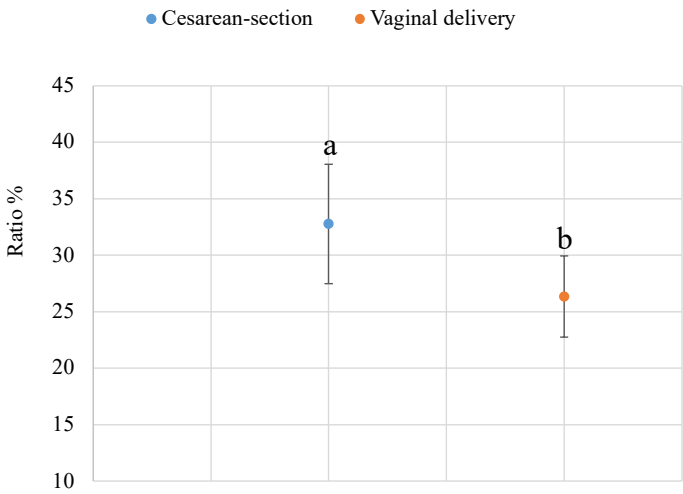

Figure 12. Comparison of inflammatory n-6 to n-3 fatty acid average ratios between groups of C-section and vaginal delivery

(Orange dots represent vaginal delivery, blue dots represent C-section; different letters show significant differences at $p \leq 0.05$ levels.)

These findings were further supported by PCA statistical analysis. When the samples were categorized by mode of delivery in the PCA plot (Figure 13), a clear separation between the groups emerged based on their fatty acid profiles.

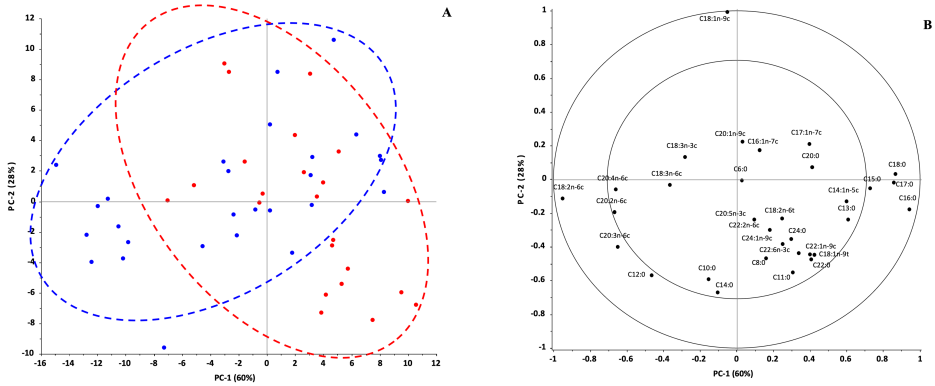

Figure 13. PCA results of fatty acids in breast milk from caesarean and vaginal deliveries

(Blue dots represent caesarean section samples, and red dots represent vaginal delivery samples. (A) Scores and (B) correlation loadings of the samples (PC1-PC2).)

3.6. Holder pasteurization's impact on the fatty acid composition of donated human milk

Our findings indicate significant changes in the concentrations of 14 fatty acids following Holder pasteurization. Specifically, the concentrations of caproic acid (C6:0), caprylic acid (C8:0), capric acid (C10:0), myristoleic acid (C14:1 n-5c), oleic acid (C18:1 n-9c), gamma-linolenic acid (C18:3 n-6c), alpha-linolenic acid (C18:3 n-3c), and arachidonic acid (C20:4 n-6c) decreased after HoP treatment. In contrast, concentrations of myristic acid (C14:0), palmitic acid (C16:0), *trans*-oleic acid (*trans*-C18:1 n-9), lignoceric acid (C24:0), nervonic acid (C24:1 n-9c), and docosahexaenoic acid (C22:6 n-3c) increased post-treatment.

PCA was employed to analyze the fatty acid profiles of both pasteurized and unpasteurized (raw) samples, with the results summarized in (Figure 14). The first two principal components accounted for 93% of the variance in the data. The results clearly indicated that pasteurization significantly affected the fatty acid profiles of the samples, showing good separation along PC1 and PC2 for all samples except for sample p10. Both principal components had a significant impact on the positioning of the samples. Except for sample p1, the pasteurized samples were predominantly positioned in the negative region of PC1, which was primarily associated with a higher percentage of oleic acid (C18:1 n-9c). This significance is supported by the Kruskal-Wallis test, which identified statistically significant differences ($p<0.05$). The positive region of PC1 was mainly explained by a higher proportion of palmitic acid (C16:0), more common in the unpasteurized samples.

Classification methods were applied to evaluate the effects of pasteurization. The cubic support vector machine provided the best results. The accuracy of the model was 100%, demonstrating the distinct impact of pasteurization on the fatty acid composition in human milk.

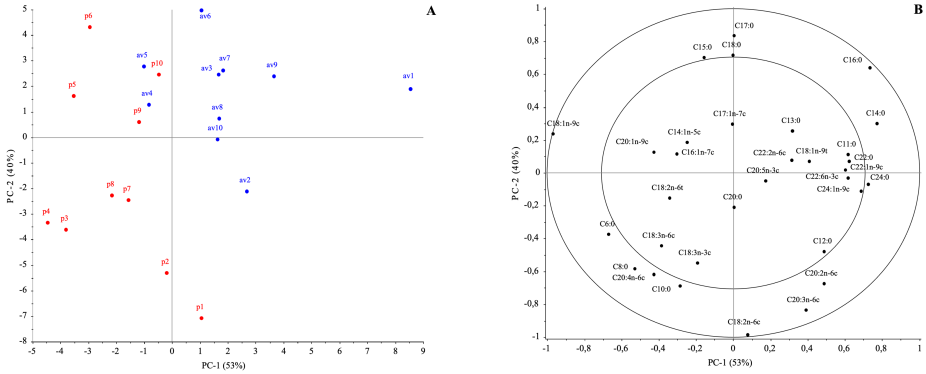

Figure 14. PCA results of raw and holder pasteurized human milk samples (Scores plot (A); Correlation loadings (B). Holder-pasteurized samples are indicated in red, and raw samples are indicated in blue.)

4. CONCLUSIONS AND RECOMMENDATIONS

Maternal BMI has a significant impact on breast milk composition. Mothers with a normal BMI exhibited lower levels of linoleic acid (C18:2 n-6) compared to those with obesity and/or gestational diabetes (GD), while lauric acid (C12:0) was significantly lower in the O+GD groups.

Breast milk from Hungarian mothers contained higher levels of saturated fatty acids (SFAs), such as palmitic acid (C16:0), and n-6 PUFAs, including linoleic acid (C18:2 n-6). In contrast, breast milk from Ukrainian mothers exhibited higher levels of alpha-linolenic acid (C18:3 n-3).

Milk provided to female infants contained significantly higher concentrations of eicosadienoic acid (C20:2 n-6), while cesarean delivery was associated with increased levels of n-6 fatty acids in breast milk.

Holder pasteurization reduced the levels of medium-chain fatty acids (MCFAs) and certain key PUFAs but increased the concentration of docosahexaenoic acid (C22:6 n-3).

These findings can be attributed to differences in maternal metabolic states, dietary habits, and regional environmental factors. Further research is recommended to explore the underlying mechanisms of these variations and their potential implications for infant health. Additionally, maternal nutrition and breastfeeding support strategies should be tailored to address these influencing factors to optimize breast milk composition.

5. NEW SCIENTIFIC RESULTS

My research has shown that the fatty acid composition of human milk is greatly influenced by the health status of the mother.

The following are my new scientific results:

1. I found significant differences in the levels of saturated fatty acids (SFAs) among Ukrainian mothers with different health statuses. Specifically, short-chain SFAs, such as caproic acid (C6:0), medium-chain SFAs like capric acid (C10:0) and lauric acid (C12:0), as well as long-chain SFAs, including myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0), varied notably among the groups. Obese mothers exhibited significantly higher levels of oleic acid (C18:1 n-9), whereas mothers with a normal BMI showed significantly lower concentrations of linoleic acid (C18:2 n-6).
2. My research revealed that overweight and obese Hungarian mothers have significantly higher levels of SFAs, including capric acid (C10:0), lauric acid (C12:0), and myristic acid (C14:0). They also exhibited elevated levels of oleic acid (C18:1 n-9), but no significant difference was observed in the total MUFA content between the groups. The obese mothers had lower ratios of polyunsaturated fatty acids (PUFAs), such as linoleic acid (C18:2 n-6) and alpha-linolenic acid (C18:3 n-3), compared to normal BMI mothers. We found that the n-6 to n-3 ratio was about 50% higher in milk from the obese group compared to the normal BMI mothers.
3. I identified significant differences in the fatty acid composition of human milk based on geographical location. Hungarian mothers with normal BMI showed higher levels of palmitic acid (C16:0) and linoleic acid (C18:2 n-6) in their milk, while Ukrainian mothers exhibited higher levels of PUFAs, particularly alpha-linolenic acid (C18:3 n-3).

4. I discovered that the sex of the infant influences the fatty acid profile of human milk. Milk provided to female infants contained significantly higher levels of eicosadienoic acid (C20:2 n-6) compared to milk provided to male infants.
5. I demonstrated that Holder pasteurization significantly alters the fatty acid profile of human milk. Pasteurization resulted in reduced levels of SFAs (caproic acid (C6:0) to capric acid (C10:0)), MUFAs (oleic acid (C18:1 n-9)), and PUFAs (alpha-linolenic acid (C18:3 n-3), gamma-linolenic acid (C18:3 n-6) arachidonic acid (C20:4 n-6)), while increasing the levels of long-chain SFAs (palmitic acid (C16:0)) and MUFAs (nervonic acid (C24:1 n-9)). I found that considering the fatty acid profile of the samples, it is possible to classify the raw and pasteurized samples with up to 100% accuracy using the cubic support vector machine classification model.

6. PUBLICATIONS

Publication–Journal

1. **Zhang, M**., Simon Sarkadi, L., Üveges, M., Tormási, J., Benes, E., Vass, R.A. and Vari, S.G., 2022. Gas chromatographic determination of fatty acid composition in breast milk of mothers with different health conditions. *Acta Alimentaria*, 51(4), pp.625–635, [Available from: https://doi.org/10.1556/066.2022.00120].
2. Simon Sarkadi, L., **Zhang, M**., Muránszky, G., Vass, R.A., Matsyura, O., Benes, E. and Vari, S.G., 2022. Fatty Acid Composition of Milk from Mothers with Normal Weight, Obesity, or Gestational Diabetes. *Life*, 12(7), p.1093, [Available from: https://doi.org/10.3390/life12071093].
3. Vass, R.A., **Zhang, M**., Simon Sarkadi, L., Üveges, M., Tormási, J., Benes, E.L., Ertl, T. and Vari, S.G., 2024. Effect of Holder Pasteurization, Mode of Delivery, and Infant's Gender on Fatty Acid Composition of Donor Breast Milk. *Nutrients*, 16(11), p.1689, [Available from: https://doi.org/10.3390/nu16111689].

Publication–Abstracts

1. **Zhang, M**., Üveges, M., Muránszky, G., Simon Sarkadi, L., Matsyura, O., Ertl, T., Vass, R., Vari, S.G. (2021): Fatty Acid Composition of Mother Milk. XXI EuroFoodChem, 22-24 November 2021, online conference. Book of Abstract (ISBN 978-989-8124-34-0), pp.170.
2. Simon Sarkadi, L., Üveges, M., **Zhang, M**., Tormási, J., Benes, E., Vass, R., Vari, S.G. (2022): Fatty acid composition of human milk of pregnant women with obesity and Gestational Diabetes. RECOOP 17th Bridges in Life Sciences Conference, 6-9 April, 2022, Prague, Czech Republic. Book of Abstract (ISBN 978-615-6006-03-5), pp. 88.
3. Simon Sarkadi, L., **Zhang, M**., Muránszky, G., Vass, R.A., Matsyura, O., Vari, S.G. (2022): Impact of pregnant women's obesity and Gestational Diabetes on the fatty acid composition of human milk. RECOOP 17th Bridges in Life Sciences Conference, 6-9 April, 2022, Prague, Czech Republic. Book of Abstract (ISBN 978-615-6006-03-5), pp. 89.
4. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J., Benes E., Vass R., Vari SG. (2023): Gas chromatographic determination of fatty acid composition in breast milk of mothers at different lactation periods. RECOOP 5th International Student Conference, 20-21 April, 2023, Budapest, Hungary. Book of Abstract (ISBN 978-615-6006-04-2), pp. 66.
5. Üveges M., **Zhang M**., Simon Sarkadi L., Tormási J., Benes E., Vass R., Vari SG. (2023): Fatty acid profile of human milk from healthy mothers at various lactation periods. RECOOP 18th Bridges in Life Sciences

Conference, 20-21 April, 2023, Budapest, Hungary. Book of Abstract (ISBN 978-615-6006-04-2), pp. 117.

6. **Zhang M**., Simon Sarkadi L., Üveges M., Benes E., Vass R., Matsyura O., Vári S. (2023): Comparison of fatty acid composition of human milk of pregnant women with obesity and gestational diabetes. NUTRITION SCIENCE RESEARCH XI. PhD Conference, 5 May, 2023, Budapest, Hungary. Book of Abstract (ISBN 978-615-5606-14-4), pp. 37.
7. **Zhang M**., Üveges M., Tormási J., Benes E., Simon Sarkadi L., Vass R., Vári S. (2023): Determination of fatty acid composition in breast milk. 4th Young Researchers'International Conference on Chemistry and Chemical Engineering (YRICCCE IV), 1-3 June, 2023, Debrecen, Hungary. Book of Abstract (ISBN 978-615-6018-16-8), pp. 82–83.
8. Üveges, M., **Zhang, M**., Simon Sarkadi, L., Tormási, J., Benes, E., Vass, R., Vari, S.G. (2023): Eltérő Laktációs Időszakból Származó Anyatej Minták Zsírsav-Profil Vizsgálata. MKE 4. Nemzeti Konferencia, 10-12 July, 2023, Eger, Hungary. Book of Abstract (ISBN 978-615-6018-18-2), pp. 87.
9. Simon Sarkadi, L., **Zhang, M**., Üveges, M., Matsyura, O., Vass, R., Vári, S. (2023): The effect of a mother's health on breast milk fatty acid composition. Global Summit of Food Health Conference, 22-24 November, 2023, Tainan, Taiwan. Book of Abstract, pp. 37.
10. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J., Kolobarić N., Drenjančević I., Vari SG. (2024): Analysis of Fatty Acid Composition in Human Aortic Endothelial Cells Using Gas Chromatography-Flame Ionization Detection. RECOOP 19th Bridges in Life Sciences Conference, 11-12 April, 2024, Bratislava, Slovakia. Book of Abstract (ISBN 978-615-6006-05-9), pp. 129.
11. Üveges M., **Zhang M**., Benes E., Tormási J., Simon Sarkadi L., Vass R, Vari SG. (2024): Effect of different neonatal delivery modes and infant gender on human milk fatty acid profile. RECOOP 19th Bridges in Life Sciences Conference, 11-12 April, 2024, Bratislava, Slovakia. Book of Abstract (ISBN 978-615-6006-05-9), pp. 135.

Oral presentation

1. Simon Sarkadi, L., Üveges, M., **Zhang, M**., Tormási, J., Benes, E., Vass, R., Vari, S.G. (2022): Fatty acid composition of human milk of pregnant women with obesity and Gestational Diabetes. RECOOP 17th Bridges in Life Sciences Conference, 6-9 April, 2022, Prague, Czech Republic.
2. Simon Sarkadi, L., **Zhang, M**., Muránszky, G., Vass, R.A., Matsyura, O., Vari, S.G. (2022): Impact of pregnant women's obesity and Gestational Diabetes on the fatty acid composition of human milk. RECOOP 17th Bridges in Life Sciences Conference, 6-9 April, 2022, Prague, Czech

Republic.

3. **Zhang M.**, Simon Sarkadi L., Üveges M., Tormási J., Benes E., Vass R, Vari SG. (2023): Gas chromatographic determination of fatty acid composition in breast milk of mothers at different lactation periods. RECOOP 5th International Student Conference, 20-21 April, 2023, Budapest, Hungary.
4. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J., Kolobarić N., Drenjančević I., Vari SG. (2023): Comparison of fatty acid composition of human milk of pregnant women with obesity and gestational diabetes. Nutrition Science Research XI. PhD Conference, 5 May, 2023, Budapest, Hungary.
5. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J., Kolobarić N., Drenjančević I., Vari SG (2024): Analysis of Fatty Acid Composition in Human Aortic Endothelial Cells Using Gas Chromatography-Flame Ionization Detection. RECOOP 19th Bridges in Life Sciences Conference, 11-12 April, 2024, Bratislava, Slovakia.
6. Üveges M., **Zhang M**., Benes E., Tormási J., Simon Sarkadi L., Vass R, Vari SG. (2024): Effect of different neonatal delivery modes and infant gender on human milk fatty acid profile. RECOOP 19th Bridges in Life Sciences Conference, 11-12 April, 2024, Bratislava, Slovakia.

Poster presentation

1. **Zhang, M**., Üveges, M., Muránszky, G., Simon Sarkadi, L., Matsyura, O., Ertl, T., Vass, R., Vari, S.G. (2021): Fatty Acid Composition of Mother Milk, XXI EuroFoodChem, 22-24 November, 2021, online, Budapest, Hungary.
2. **Zhang, M**., Muránszky, G., Üveges, M., Tabi, T., Gaspar, R., Simon Sarkadi, L., Vari, S.G. (2021): Fatty acids in obesity, Lippay János - Ormos Imre - Vas Károly Scientific Congress, Ifjú Tehetségek Találkozója – SZIEntific Meeting for Young Researchers conference. 29th November, 2021, Budapest, Hungary.
3. **Zhang, M**., Simon Sarkadi, L., Üveges, M., Tormási, J., Benes, E., Vass, R., Vari, S.G. (2022): Gas chromatographic determination of fatty acid composition in breast milk, 4th FoodConf, 9-11 June, 2022, Budapest, Hungary.
4. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J, Benes E., Vass R., Vari SG. (2023): Gas chromatographic determination of fatty acid composition in breast milk of mothers at different lactation periods. RECOOP 5th International Student Conference, 20-21 April, 2023, Budapest, Hungary.
5. **Zhang M**., Üveges M., Tormási J., Benes E., Simon Sarkadi L., Vass R., Vari SG. (2023): Determination of fatty acid composition in breast milk.

4th Young Researchers'International Conference on Chemistry and Chemical Engineering (YRICCCE IV), 1-3 June, 2023, Debrecen, Hungary.

6. **Zhang M**., Simon Sarkadi L., Üveges M., Tormási J., Kolobarić N., Drenjančević I., Vari SG. (2024): Analysis of Fatty Acid Composition in Human Aortic Endothelial Cells Using Gas Chromatography-Flame Ionization Detection. RECOOP 19th Bridges in Life Sciences Conference, 11-12 April, 2024, Bratislava, Slovakia.