Doctoral School of Interdisciplinary Medicine

MICRONUTRIENT SUPPLEMENTATION AMONG HUNGARIAN PREGNANT WOMEN WITH A SPECIAL FOCUS ON VITAMIN D

PhD Thesis

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LIST OF PUBLICATIONS

Publications Related to the Thesis

1. **Polanek, Evelin**; Rárosi, Ferenc; Béky, Csenge Fruzsina; Molnár, Regina; Németh, Gábor; Orvos, Hajnalka; Paulik, Edit; Szabó, Andrea. Beyond the Pill: Unveiling the Characteristics of Prenatal Micronutrient Consumption Among Hungarian Pregnant Women According to Different Levels of Adherence NUTRIENTS 17: 17 Paper: 2732, 27 p. (2025) *SJR indicator: D1; IF: 5.*
2. **Polanek, Evelin**; Sisák, Anita; Molnár, Regina; Máté, Zsuzsanna; Horváth, Edina; Németh, Gábor; Orvos, Hajnalka; Paulik, Edit; Szabó, Andrea. A Study of Vitamin D Status and Its Influencing Factors among Pregnant Women in Szeged, Hungary: A Secondary Outcome of a Case–Control Study NUTRIENTS 16: 10 p. 1431, 16 p. (2024) *SJR indicator: D1; IF: 5.*

List of Other Publications

1. **Polanek, Evelin**; Karai, Adrienn; Molnár, Regina; Németh, Gábor; Orvos, Hajnalka; Balogh, Péter; Paulik, Edit. Association between sociodemographic, obstetric, and lifestyle factors among Hungarian pregnant women—A cross-sectional study JOURNAL OF OBSTETRICS AND GYNAECOLOGY RESEARCH 48: 10 pp. 2541-2551., 11 p. (2022)
2. **Polanek, Evelin**; Gál, Eszter; Mremi, Dorisz; Vigula, Fanni; Horváth, Edina; Szabó, Andrea; Gyurkovits, Zita; Orvos, Hajnalka; Paulik, Edit. Anyai/újszülöttkori D-vitamin státusz és befolyásoló tényezői In: Dvorák, M (szerk.) Magyar Életmód Orvostani Társaság II. Kongresszusa Budapest, Magyarország: Magyar Életmód Orvostani Társaság (2020) 55 p. pp. 55-55., 1 p.
3. **Polanek, Evelin**; Jónás, Noémi. Pregnant women's dietary behavior, dietary supplement intake and its influencing factors. In: EUGLOH Annual Student Research Conference (Book of Abstracts) (2020) 98 p. pp. 72-72., 1 p.
4. **Polanek, Evelin**; Soós, Alexandra; Paulik, Edit; Szabó, Andrea. Is there any association between vitamin D and male fertility? NÉPEGÉSZSÉGÜGY 97: 2 pp. 264-264. Paper: P I/6, 1 p. (2019)
5. Sisák, Anita; **Polanek, Evelin**; Molnár, Regina; Szabó, Andrea; Rárosi, Ferenc; Hosseini, Armita; Németh, Gábor; Orvos, Hajnalka; Paulik, Edit. The Association Between Psychosocial Stress and Perinatal Maternal Depressive Symptoms: A Case–Control Study in a Regional Medical Center in Hungary JOURNAL OF PERSONALIZED MEDICINE 15: 7 Paper: 287, 14 p. (2025)
6. Sisák, Anita; Rárosi, Ferenc; **Polanek, Evelin**; Szabó, Andrea; Németh, Gábor; Orvos, Hajnalka; Paulik, Edit. Association between psychosocial stress and maternal depressive symptoms NÉPEGÉSZSÉGÜGY 100: 2 pp. 86-87. Paper: P/2, 2 p. (2023)
7. Paulik, Edit; Horváth, Edina; Szabó, Andrea; **Polanek, Evelin**; Gyurkovits, Zita; Németh, Gábor; Orvos, Hajnalka. Vitamin D status and its influencing factors among pregnant women in Szeged, Hungary EUROPEAN JOURNAL OF PUBLIC HEALTH 31: Supplement 3 pp. iii30-iii30., 1 p. (2021)
8. Paulik, Edit; Horváth, Edina; Szabó, Andrea; **Polanek, Evelin**; Gyurkovits, Zita; Németh, Gábor; Orvos, Hajnalka. Health consciousness during pregnancy: the association between dietary supplementation and lifestyle EUROPEAN JOURNAL OF PUBLIC HEALTH 30: Supplement 5 pp. v896-v897., 2 p. (2020)

Abbreviations

aOR	Adjusted odds ratio
FFQ	Food frequency questionnaire
CI	Confidence interval
DHA	Docosahexaenoic acid
EFSA	European Food Safety Authority
EPA	Eicosapentaenoic acid
FA	Folic acid
FFQ	Food frequency questionnaire
GDM	Gestational diabetes mellitus
IQR	Interquartile range
NTDs	Neural tube defects
O3	Omega-3 fatty acids
OR	Odds ratio
PMM	Prenatal multiple micronutrient supplements
SD	Standard deviation
US	United States
UV	Ultraviolet
VD	Vitamin D
WHO	World Health Organization

1. Introduction

1.1. Micronutrient Requirements During Pregnancy

Pregnancy constitutes a physiologically demanding period, in which maternal nutritional intake must support the health of the mother while simultaneously ensuring the growth and development of the fetus. Insufficient intake of critical micronutrients has been consistently linked to maternal complications, impaired fetal development, and long-term negative health consequences for the child (Mendes et al., 2020). Despite international and national guidelines promoting adequate intake, micronutrient deficiencies remain highly prevalent worldwide (Hanley-Cook et al., 2022).

Folic Acid

Folic acid (FA) is among the most extensively investigated micronutrients in relation to pregnancy outcomes. Beyond its established role in reducing the incidence of neural tube defects (NTDs), FA sufficiency has been associated with a lower likelihood of congenital heart anomalies, improved gestational outcomes, and reduced risk of autism spectrum disorders (Levine et al., 2018; Viswanathan et al., 2023). Randomized trials and systematic reviews have confirmed that supplementation of 400 µg/day, initiated at least one month before conception and maintained throughout the first trimester, is the most effective means of prevention (EFSA NDA Panel, 2014; CDC, 2025). However, adherence to this recommendation is far from universal, and many women initiate FA supplementation only after recognition of pregnancy, when the critical window for NTDs prevention has already passed (Bognár et al., 2008). International data confirm similar challenges: only 27–36% of women in countries such as Australia and Germany use FA correctly (Malek et al., 2016; Doru et al., 2023), while rates are comparably low in Canada and the United States (Plumptre et al., 2013; Branum et al., 2012).

Vitamin D

Vitamin D (VD) is another micronutrient with far-reaching implications. Its biological functions extend beyond bone metabolism, encompassing immune modulation, placental function, and regulation of insulin sensitivity (Heyden & Wimalawansa, 2018). During pregnancy, low VD status may have particularly severe consequences. Observational studies have consistently associated maternal VD deficiency with an increased risk of infections, preeclampsia, GDM, impaired uterine contractility, low birth weight, preterm birth, and congenital malformations (Dovnik & Mujezinović, 2018; de Souza & Pisani, 2020; Tous et al., 2020; Mansur et al., 2022). Moreover, randomized controlled trials suggest that VD supplementation during pregnancy can reduce these risks and improve neonatal outcomes (Rostami et al., 2018). Although there is no universally accepted definition of sufficiency, most scientific societies consider serum 25-hydroxyvitamin D [25(OH)D] concentrations above 50 nmol/L to be sufficient, while others recommend targeting levels above 75 nmol/L for optimal maternal and neonatal outcomes (Bouillon et al., 2013; Holick et al., 2011). Evidence from randomized controlled trials has further confirmed the importance of supplementation: both Hollis et al. (2011) and Enkhmaa et al. (2019) demonstrated that higher-dose VD regimens were effective in reducing deficiency and improving maternal and neonatal outcomes.

Omega-3 fatty acids

Omega-3 fatty acids (O3), particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are crucial for fetal brain development and maternal cardiovascular regulation (Broś-Konopielko et al., 2023). Adequate O3 intake has been associated with a reduced risk of preeclampsia and GDM, prolonged gestation, and favorable effects on lipid metabolism (Lalooha et al., 2012; Coletta et al., 2010; Middleton et al., 2018). In addition, DHA plays a pivotal role in fetal neurocognitive development and visual function (Tonini et al., 2020). Hanley-Cook et al. (2022) emphasized the importance of dietary diversity when designing interventions to ensure adequate long-chain PUFA supply during pregnancy. European Food Safety Authority (EFSA) recommendations suggest a daily intake of 250 mg EPA + DHA, supplemented with an additional 100 mg DHA, starting around the 20th gestational week (EFSA NDA Panel, 2010), that was further protected by a clinical practice guideline approved by several international health societies (Cetin et al., 2024).

Prenatal multiple micronutrient supplements

Finally, prenatal multiple micronutrient supplements (PMM) provide an integrative approach, ensuring the intake of multiple essential nutrients, including FA, VD, iron, and others. The World Health Organization (WHO, 2020) recommends their use during pregnancy, particularly in low- and middle-income countries, where micronutrient deficiencies often co-occur. The recommended duration of PMM intake is not explicitly defined, but given the health benefits of their individual components, continued use across the entire course of pregnancy is generally advised. Concerns about PMM contributing to large-for-gestational-age neonates have largely been refuted by more recent analyses (Sudfeld & Smith, 2019). Further evidence has suggested that appropriately formulated multivitamins can fill critical nutrient gaps: Kodentsova et al. (2022) compared existing guidelines and concluded that multivitamin use during pregnancy remains essential, while Adams et al. (2022) outlined optimal prenatal supplement compositions in the US context.

Collectively, these four types of micronutrients —FA, VD, O3, and PMM—form the cornerstone of prenatal supplementation practices. However, widespread deficiencies persist, partly due to inadequate supplementation, but also due to poor adherence to timing, dosage, and duration recommendations (Talank et al., 2019).

1.2. Vitamin D Deficiency as a Persistent Global Public Health Issue

VD deficiency has emerged as a global public health concern over the past two decades. Worldwide, an estimated 50% of the population presents with VD insufficiency (<50 nmol/L), and 6–20% suffer from deficiency (<30 nmol/L) (Cui et al., 2023; Cashman, 2022; Amrein et al., 2020). These figures are striking in their universality, affecting populations in both developed and developing countries, across diverse geographical and cultural contexts. Large-scale prevalence surveys from diverse regions support this conclusion, including data from the United States (Bodnar et al., 2007b), Iran (Kazemi et al., 2009), China (Wang et al., 2010; Yang et al., 2021), and Qatar (Al Emadi & Hammoudeh, 2013).

The determinants of VD deficiency are multifaceted. Geographic latitude limits sunlight exposure during large portions of the year in temperate climates. Urbanization and the predominance of indoor lifestyles restrict natural UV-B exposure, while cultural practices such as clothing that covers most of the body or the use of sunscreen reduce cutaneous synthesis (Weishaar et al., 2016). Additional risk factors have been identified in epidemiological research, such as low sun exposure in rapidly urbanizing societies (Jiang et al., 2020) and dermatological considerations related to skin physiology and photoprotection (Matsui, 2020).

Dietary intake of VD is typically insufficient to meet daily requirements, with average intakes often below 5 μg/day (Spiro & Buttriss, 2014). Even in high-income countries with fortified foods, intakes frequently fall short of recommendations. This has been confirmed by biochemical studies demonstrating bone mineralization defects in patients with low serum VD levels (Priemel et al., 2010) and by pediatric data showing deficiency across maternal–child pairs (Elsori & Hammoud, 2018). Dietary sources of VD include sea fish, egg yolks, mushrooms, dairy products, and liver, as well as fortified foods such as margarine, juices, and certain dairy products, although these alone are generally insufficient to meet physiological requirements (Vaes et al., 2017).

Recommendations for VD intake during pregnancy vary internationally. Most guidelines suggest 10–15 μg (400–600 IU) daily, although some scientific societies argue that higher intakes are necessary to achieve sufficiency (Curtis et al., 2018; Pérez-López et al., 2020). The EFSA Scientific Panel (2016) determined that a daily intake of 15 µg would be sufficient for most of the population to achieve serum concentrations above 50 nmol/L. The American Endocrine Society, however, has recommended considerably higher intakes, with a target of 37.5–50 µg/day to reach 75 nmol/L (Holick et al., 2011). From a physiological perspective, adequate VD intake is required throughout all three trimesters to support maternal adaptations and fetal development (Mansur et al., 2022).

In Hungary, the national consensus guideline recommends a daily intake of 2000 IU (50 µg) during the UV-B radiation-free period, without differentiating between pregnant and non-pregnant adults (Takács et al., 2022). This threshold reflects growing recognition of the widespread prevalence of low VD status. Yet studies demonstrate that average dietary intakes remain extremely low, approximately 2 µg/day (National Centre for Public Health and Pharmacy, 2019). Consequently, supplementation remains the primary means of achieving sufficiency.

Laboratory-confirmed serum measurements provide a more objective assessment of maternal VD status than self-reported intake alone. Evidence suggests that despite relatively high rates of reported supplement use, only a minority of pregnant women achieve the optimal 75 nmol/L threshold (Christoph et al., 2020). This discrepancy highlights the importance of examining not only prevalence but also adherence, dosage, and biological outcomes of supplementation.

1.3. Adherence to Prenatal Micronutrient Supplementation

Although the prevalence of supplement use among pregnant women is relatively high in many high-income countries, adherence to proper supplementation practices—defined by correct timing, dosage, and duration—is considerably lower. This gap between use and adherence is critical because the benefits of supplementation are highly dependent on when and how consistently supplements are taken (Malek et al., 2016).

Adherence to FA supplementation is particularly problematic. Despite long-standing guidelines recommending initiation prior to conception, studies have shown that many women begin supplementation only after recognition of pregnancy. In Hungary, more than 90% of pregnant women who reported FA use started supplementation only after the seventh gestational week, well after neural tube closure (Paulik et al., 2009). Similar findings have been reported in other countries, with only 27–36% of women adhering to correct periconceptional FA use (Malek et al., 2016; Doru et al., 2023). Comparable data from Canada (Plumptre et al., 2013) and the United States (Branum et al., 2012) likewise show that while FA intake is widespread, correct preconceptional use remains limited.

VD supplementation demonstrates comparable challenges. While many women report taking multivitamins containing VD, few achieve sufficient serum concentrations. Studies from Ireland and Switzerland indicate that even among supplement users, VD deficiency is highly prevalent (Windrim et al., 2018; Christoph et al., 2020). This suggests that incorrect timing, inadequate dosage, or poor adherence compromise effectiveness. In Asian and Middle Eastern populations, the situation is similar: in Japan, 75% of pregnant women reported using dietary supplements, but knowledge of correct FA use was limited (Sato et al., 2013); in Saudi Arabia, 71.5% used supplements but inconsistencies in dosage and timing were reported (Alfawaz et al., 2017); and in China, supplement use exceeded 90%, though guideline adherence varied considerably (Xiang et al., 2022).

O3 supplementation also shows low adherence. Although evidence supports its benefits for fetal brain development and reduction of adverse pregnancy outcomes, only a minority of pregnant women report adequate intake. For example, a Swedish cohort found that only 25% used O3 (Bärebring et al., 2018b; Middleton et al., 2018). Similar gaps have been described in Iran, where around 69% of pregnant women reported supplement use but adherence to proper practices remained low (Talank et al., 2019).

PMM are widely used, particularly in high-income settings (Aronsson et al., 2013). However, their composition varies, and not all contain adequate amounts of FA, VD, or O3. Moreover, use of PMM does not guarantee adherence to specific nutrient recommendations, as women may not be aware of the precise contents of the supplements they consume (Aronsson et al., 2013). Qualitative studies also point to behavioral and cultural barriers: in Vietnam, women reported forgetfulness, cost, and limited awareness as major obstacles to adherence (Nechitilo et al., 2016).

Predictors of adherence include sociodemographic and obstetric characteristics. Studies have shown that older maternal age, higher education, higher income, planned pregnancy, primiparity, and early initiation of antenatal care are associated with better adherence (Arkkola et al., 2006; Bodnar et al., 2007a; Aronsson et al., 2013). Conversely, younger maternal age, lower education, and unplanned pregnancies are linked to lower adherence rates (Mathews, 2000; Yee et al., 2021).

1.4. The Hungarian Context

Hungary presents a particularly relevant setting for studying prenatal micronutrient intake and adherence. National dietary surveys have consistently demonstrated low intakes of several essential nutrients among women of reproductive age. For example, the National Nutritional Status Study (2019) found that average FA intake was only 133 µg/day, substantially below the recommended 400 µg, while average VD intake was only 2.1 µg/day (National Centre for Public Health and Pharmacy, 2019). Intake of O3 was similarly below recommendations, with an average of 160 mg/day of EPA + DHA, compared to the 250 mg recommended by EFSA (EFSA NDA Panel, 2010). The Hungarian supplement market is characterized by a lack of stringent regulatory oversight, with more than 25 000 dietary supplements available and no specific approval procedures for products targeted at vulnerable populations such as pregnant women (National Centre for Public Health and Pharmacy, 2025). Earlier reviews of international guidelines similarly highlight the absence of harmonized regulations, reinforcing the need for context-specific national policies (Kodentsova et al., 2022). This abundance complicates decision-making for consumers, who must rely on health literacy and professional guidance to select appropriate supplements. Yet health literacy among Hungarian pregnant women remains variable, and many demonstrate limited knowledge of proper supplementation practices (Bognár et al., 2008). Qualitative studies from Europe also reveal that even when supplements are used, awareness and understanding of proper intake remain insufficient (Bombas et al., 2024).

Although Hungarian antenatal care is comprehensive and includes compulsory visits to general practitioners, gynecologists, and midwives, the official pregnancy care decree only mandates attention to FA and VD supplementation (Ministry of Human Resources, 2014). No national guideline specifically recommends O3 or PMM, despite international evidence supporting their use (Cetin et al., 2024; WHO, 2020). This stands in contrast to other regions, such as North America, where Adams et al. (2022) emphasized the need for optimal prenatal supplement formulations that systematically include these components. This regulatory gap may contribute to inconsistent practices and poor adherence. Earlier Hungarian studies on FA supplementation revealed low rates of periconceptional initiation (Paulik et al., 2009). To date, no comprehensive Hungarian study has assessed adherence to FA, VD, O3, and PMM simultaneously, nor examined their association with pregnancy outcomes.

2. Aims

Given the global importance of prenatal micronutrient supplementation and the specific challenges observed in Hungary, there is a pressing need for integrated research that examines both self-reported intake and objective biological markers. Previous Hungarian studies have typically focused on single nutrients, most often FA or VD, and have rarely considered adherence in relation to guideline-based recommendations. Furthermore, the association of supplementation practices with maternal and neonatal outcomes has remained underexplored.

The rationale for this dissertation lies in addressing these gaps. By combining analyses of self-reported supplementation of FA, VD, O3, and PMM with laboratory-confirmed serum measurements of the most routinely available one (VD) together with clinical health documentation data, it provides a comprehensive picture of micronutrient intake, adherence, and outcomes among Hungarian pregnant women. The main aims of this dissertation were the following:

- Assessment of prevalence: determining the percentage of pregnant women reporting FA, VD, O3, and PMM use; with special focus on different sources of VD (dietary or supplemental).
- Evaluation of adherence: establishing whether pregnant women follow guidelines regarding timing, dosage, and duration.
- Identification of predictors: exploring how sociodemographic, obstetric, and lifestyle factors influence adherence.
- Biological validation: analyzing maternal serum VD levels to objectively confirm supplementation adequacy.
- Outcome associations: investigating how total VD intake, maternal serum VD level and adherence to supplementation affects pregnancy, delivery, and neonatal outcomes.

The central hypothesis is that while supplementation prevalence is relatively high in Hungary, adherence is low, resulting in suboptimal maternal serum levels and compromised pregnancy outcomes. Identifying predictors of adherence and establishing the relationship between intake and biological outcomes may provide a strong evidence base for improving Hungarian antenatal care guidelines and clinical practice.

3. Methods

3.1. Study Design and Participants

This dissertation builds upon the data collected within the *Quantifying Maternal Non-Obstetrical Risk Factors for Preterm Birth—Retrospective and Prospective Study* (MANOR study), a joint research project of the Department of Obstetrics and Gynecology and the Department of Public Health at the University of Szeged. The present analysis is based on the retrospective case–control branch, which was conducted between March and December 2019. During this period the participation was offered to each adult (>18 years) woman who had a preterm birth. A total of 2352 births occurred at the university hospital, of which 277 were preterm deliveries, defined as births before 37 completed weeks of gestation. After excluding multiple pregnancies, 191 women remained eligible for inclusion as preterm cases. Ultimately, 100 mothers with preterm deliveries agreed to participate and were enrolled as cases. For each of these participants, two mothers who had term deliveries (≥37 gestational weeks) were selected as controls, matched by maternal age and delivery date. This procedure resulted in a control group of 200 mothers and a total study population of 300 women.

For the present dissertation, however, the case and control groups were analyzed together, with the primary focus shifted from preterm birth to the evaluation of micronutrient supplementation practices, adherence to guidelines, and serum VD status.

3.2. Data Collection

Data collection employed a multi-source approach that combined self-administered questionnaires, validated dietary assessment instruments, medical documentation, and biological sampling. The questionnaire included items on sociodemographic and lifestyle factors, obstetric history, and pregnancy-related characteristics. Specifically, it gathered information on maternal age, educational attainment, type of residence, and relationship status. Conception-related aspects were also assessed, including contraceptive use prior to conception, infertility treatment, mode of conception, pregnancy planning, and parity. Women were asked about their previous pregnancy experiences, including miscarriages and preterm deliveries, as well as the gestational week of their first antenatal care visit. In addition, questions were included on lifestyle counseling received during pregnancy, the sources of such information, and whether participants had adopted more conscious dietary habits.

The questionnaire also explored supplementation patterns in detail. Participants were asked whether they had taken PMM, FA, VD, or O3, either in the form of a single component product or as a part of a complex multivitamin dietary supplement. They were required to indicate the product names, dosages, and duration of use. The VD content of each reported product was identified and quantified using information provided on the official websites of the respective manufacturers. In cases where a respondent initially indicated that she did not take any VD–containing supplements but mentioned elsewhere in the questionnaire a product that did, the corresponding VD content was also included in the calculation of supplemental intake. To assess dietary VD intake, a validated food frequency questionnaire (FFQ) developed by Bärebring et al. (2018a) was applied.

Medical documentation was reviewed to complement self-reported information. Maternal records were examined to obtain data on antenatal care, gestational complications, and pregnancy outcomes, including diagnoses of GDM and gestational hypertension. Delivery records were used to extract information on birth outcomes, such as gestational age at delivery, mode of delivery, inadequate uterine contraction, cephalopelvic disproportion, and premature rupture of membranes. Neonatal data included birth weight, categorized into low (<2500 g), normal (2500–4000 g), and high (>4000 g), as well as preterm status.

In addition to questionnaire and medical data, biological samples were obtained. Maternal venous blood was collected immediately after delivery, and serum 25-hydroxyvitamin D [25(OH)D] concentrations were measured at the Department of Laboratory Medicine, University of Szeged, using chemiluminescent microparticle immunoassay. For the purposes of classification, we used the US Institute of Medicine categorization (Institute of Medicine & National Research Council, 2010), thus deficiency was defined as serum concentrations below 30 nmol/L, insufficiency as levels between 30 and 50 nmol/L, sufficiency as levels of 50 nmol/L or above, and optimal status—according to Hungarian consensus recommendations—as concentrations of 75 nmol/L or higher (Takács et al, 2022).

3.3. Variables

Demographic and Obstetric Characteristics

The analysis incorporated a comprehensive set of maternal demographic and obstetric characteristics. Maternal age was categorized into three groups: ≤24 years, 25–34 years, and ≥35 years. Educational attainment was recorded for both mothers and fathers, distinguishing between primary, secondary, higher-level vocational training, and university degrees. Place of residence was classified as county town or capital, city, or village, while relationship status was dichotomized into partnered or single. Pregnancy-related variables included whether the pregnancy was planned or unplanned and whether it was the mother's first pregnancy (primiparous) or subsequent (multiparous). The history of reproductive outcomes was documented, particularly previous spontaneous abortions and preterm deliveries. Conception-related variables comprised the use of contraceptives prior to the index pregnancy, application of infertility treatment, and whether conception occurred spontaneously or through assisted reproductive techniques. In addition, the gestational week of the first antenatal care visit was registered and dichotomized as early (≤12 weeks) or late (>12 weeks).

Gestational weight gain was evaluated according to the reference categories established by the US Institute of Medicine (Institute of Medicine & National Research Council, 2009). When the observed weight gain relative to pre-pregnancy body mass index fell below the recommended level, it was classified as "less than optimal." Gains that matched the recommended interval were categorized as "normal," while values exceeding the recommendation were designated as "more than optimal."

Together, these variables provided a robust sociodemographic and obstetric profile of the participants.

Supplementation and Adherence

Information on supplementation focused on four products: PMM, FA, VD and O3. Each of them was further assessed for appropriateness of use according to guideline-based definitions presented in the introduction; the following three categories were applied: correctly used, incorrectly used and not used. Correct FA use was defined as supplementation initiated prior to conception and continued until at least the twelfth gestational week. VD and PMM supplementation were considered appropriate if they were initiated by the ninth gestational week and maintained until delivery. O3 supplementation was categorized as correct when started by the 20th gestational week and continued throughout the remainder of pregnancy. Intake that did not meet these definitions was considered inappropriate, while the absence of supplementation was recorded as non-use.

Although VD or PMM supplementation is ideally recommended throughout the entire course of pregnancy, in practice women generally begin using these products only after their pregnancy has been confirmed. The 9th gestational week was therefore selected as the reference starting point, reflecting Hungarian practice whereby the first prenatal care visit, including ultrasound confirmation and consultation with the designated midwife, is expected by the eighth week. It is assumed that counseling on micronutrient intake is provided at these visits, and thus supplementation with VD or PMM should reasonably commence from this stage onward.

To capture overall supplementation behavior, a composite adherence score was developed, integrating FA, VD, and O3 intake; taken from any sources (PMM or from a solo component product). For each nutrient, two points were awarded for appropriate use, one point for inappropriate use, and zero points for non-use. The possible cumulative score ranged from zero to six. Based on these scores, participants were further grouped into three adherence categories: high adherence (five to six points), moderate adherence (two to four points), and low adherence or non-users (zero to one point). This scoring system enabled a multidimensional evaluation of supplementation practices and adherence behaviors across the cohort.

Dietary Vitamin D Intake

Dietary VD intake was assessed using a validated food frequency questionnaire (FFQ), originally developed by Bärebring et al. (2018a). The FFQ included questions on the consumption frequency of VD-rich foods such as fish, milk, yogurt or sour milk, and margarine. Regarding milk and yoghurt, fat content was also considered. The VD content per serving of the possible answers was given in the original article; the maximum intake was calculated to be 14.95 μg/day. Responses were converted into daily intake estimates, expressed in micrograms per day. This measure allowed for the estimation of VD intake from dietary sources alone, independent of supplementation.

Outcome Variables

Outcome variables were grouped into pregnancy-related, delivery-related, and neonatal outcomes. The pregnancy-related outcomes included diagnoses of GDM and gestational hypertension, both recorded from medical documentation. Delivery-related outcomes comprised mode of delivery, specifically the occurrence of cesarean section, as well as labor complications, including inadequate uterine contraction, cephalopelvic disproportion, and premature rupture of membranes. Neonatal outcomes included gestational age at delivery, categorized into preterm (<37 weeks) and term (≥37 weeks), and birth weight, which was stratified into low (<2500 g), normal (2500–4000 g), and high (>4000 g). These outcome variables enabled the exploration of associations between supplementation adherence and clinically meaningful maternal and neonatal endpoints.

3.4. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 29.0. Descriptive statistics were employed to summarize participant characteristics, supplementation patterns, and serum VD levels. Frequencies and percentages were calculated for categorical variables, while continuous variables were expressed as means, medians, standard deviations, and interquartile ranges as appropriate. The chi-square test and Fisher's exact test were used to compare categorical variables, and Mann–Whitney U and Kruskal–Wallis tests were applied for non-normally distributed continuous variables (VD intake and serum VD levels), detected by Kolmogorov-Smirnov test. Correlations between dietary and supplemental VD intake and serum concentrations were analyzed using Spearman's rank correlation coefficients. To identify predictors of supplementation and adherence, univariable and multivariable logistic regression analyses were conducted, calculating odds ratios (OR), adjusted odds ratios (AOR), and 95% confidence intervals (CI). Finally, binary logistic regression models were applied to evaluate associations between adherence categories and pregnancy-, labour-, and neonatal-outcome parameters. A p-value of less than 0.05 was considered statistically significant.

3.5. Ethical Approval

Ethical approval for the study was obtained from the Regional and Institutional Human Medical Biological Research Ethics Committee of the University of Szeged, Hungary (Approval number: 4419, dated 10 December 2018). Participation in the study was voluntary, and all participants provided written informed consent before enrollment.

4. Results

4.1. Study Population Characteristics

The final study population consisted of 300 pregnant women, including 100 mothers with preterm deliveries and 200 with term deliveries. Characteristics of study population are shown in *Table 1*. The average maternal age was 32 years, ranging from 18 to 45 years. Approximately 42% of mothers were aged 35 years or older, while only 8% were under 25 years of age. Educational level varied: 41.5% of mothers had a university degree, whereas 8.5% had completed only primary school. Fathers' education levels showed a somewhat lower proportion of university degrees (30.8%) and a higher prevalence of secondary education (53.1%).

In terms of relationship status, nearly all participants (97.6%) lived with a partner. Regarding residence, 45% lived in a county town or the capital city, 29.9% resided in smaller cities, and 25.1% in villages. 43.5% of the women used some contraceptive method prior to the actual pregnancy, 11.8% participated in fertility treatment, and finally 96.3% conceived spontaneously. Most pregnancies were planned (80.8%), and 41.6% represented first pregnancies. A total of 23.2% of women reported a previous spontaneous abortion, while 9.7% had experienced a prior preterm birth. The weight gain during pregnancy was more than optimal in 39.3% of cases, while 30.2% get less gain than optimal. The majority of participants (83.7%) attended their first antenatal care visit before the 12^{th} weeks of gestation. Around three-quarters of women (77.6%) reported paying more attention to diet during pregnancy, and 73.3% received lifestyle counseling from a medical professional. Regarding gestational complications, 15.2% were diagnosed with GDM and 10.8% with gestational hypertension. Delivery outcomes revealed that 53.7% delivered by cesarean section, while 31.6% experienced inadequate uterine contractions, 7.5% cephalopelvic disproportion, and 35.5% abnormal rupture of membranes. Neonatal outcomes showed that 21.6% of newborns had a low birth weight (<2500 g), while 8.4% had a high birth weight (>4000 g). Preterm deliveries accounted for one-third of the births (33.3%).

Table 1. *Characteristics of study population*

Characteristics	*n*	%
	Demographic characteristics	
Age group (years)		
≤ 24	24	8.0
25-29	49	16.3
30–34	100	33.3
≥35	127	42.3
Education of mother		
primary	25	8.5
secondary	97	33.0
higher-level vocational training	50	17.0
university	122	41.5
Education of father		
primary	16	5.5
secondary	155	53.1
higher-level vocational training	31	10.6
university	90	30.8
Marital status		
single	7	2.4
in relationship	290	97.6
Residence		
capital city, county town	134	45.0
city	89	29.9
village	75	25.1
	Conception-related characteristics	
Use of contraceptives		
yes	128	43.5
no	166	56.5
Infertility treatment		
yes	35	11.8
no	261	88.2
Mode of conception		
spontaneous	287	96.3
assisted reproductive techniques	11	3.7
	Pregnancy-related characteristics	
Planned pregnancy		
yes	235	80.8
no	56	19.2
Parity		
first	124	41.6
second or more	174	58.4
Timing of first visit at pregnancy care		
≤12 weeks	241	83.7
>12 weeks	47	16.3
Advice regarding lifestyle during pregnancy		
from a medical professional	211	73.3
from a non-medical source	77	26.7
Previous spontaneous abortion		
yes	69	23.2
no	228	76.8

Previous preterm delivery		
yes	29	17.0
no	142	83.0
More attention on diet during pregnancy		
yes	228	77.6
no	66	22.4
Body weight gain during pregnancy		
More than optimal	116	39.3
Normal	90	30.5
Less than optimal	89	30.2
GDM		
yes	45	15.2
no	251	84.8
Gestational hypertension		
yes	32	10.8
no	264	89.2
Delivery and birth related characteristics		
Preterm birth		
yes	100	33-3
no	200	66.7
Birth weight		
<2500 g	64	21.6
2500 - 4000	207	69.9
4000 <	25	8.4
Inadequate uterine contraction		
yes	93	31.6
no	201	68.4
Cephalopelvic disproportion		
yes	22	7.5
no	272	92.5
Abnormal rupture of membranes		
yes	105	35.5
no	191	64.5
Caesarean section		
yes	160	53.7
no	138	46.3

4.2. Dietary Vitamin D Intake

The assessment of dietary VD intake demonstrated very low levels, as shown in *Table 2*. The mean daily intake from food sources was only 2.08 µg (SD 1.60). Milk was the most important source, with an average of 0.80 µg/day, followed by fish (0.60 µg/day), margarine (0.55 µg/day), and yogurt (0.13 µg/day). More than half of the participants reported not consuming fish during pregnancy, and only 8.2% consumed it at least twice per week. Daily milk consumption was reported by 66.3%, while 51.5% consumed yogurt daily. Margarine use was less frequent, with 30.2% consuming it daily and 32.1% never using it. No associations were found between dietary VD intake and any maternal demographic, conception-related, or pregnancy-related characteristics.

Table 2. *Dietary vitamin D intake of women*

Food	Minimum intake (μg/day)	Maximum intake (μg/day)	Mean (SD) (μg/day)
Fish	0.00	4.47	0.60 (1.04)
Milk	0.00	3.00	0.80 (0.82)
Yoghurt	0.00	1.90	0.13 (0.32)
Margarine	0.00	3.20	0.55 (0.70)
Total	0.00	8.23	2.08 (1.60)

4.3. Supplementation Patterns

Prevalence and Sources of Supplement Use

Supplementation was common, though patterns varied considerably across nutrients. As it is shown in *Table 3*, in total, 69% of women reported using PMM. With regard to specific micronutrients, 88.7% of women took FA, 77.6% VD, and 60.1% O3. Many women (35.8-55.3%) relied solely on PMM for supplementation, though combined use with single-component products was also reported (8.8-21.3%). For instance, 23.7% of FA users and 13.5% of VD users took both PMM and other sources, while 10.8% of O3 users combined PMM with separate supplements.

Table 3. *Sources of dietary supplements*

	Intake			
	Only from PMM	Only from other sources	Both from PMM and other sources	Altogether
	n (%)	n (%)	n (%)	n (%)
PMM	205 (69.0)	-	-	205 (69.0)
FA	131 (43.7)	64 (21.3)	71 (23.7)	266 (88.7)
VD	163 (55.3)	26 (8.8)	40 (13.5)	229 (77.6)
O3	106 (35.8)	40 (13.5)	32 (10.8)	178 (60.1)

PMM: Prenatal multiple micronutrient supplements, FA: folic acid, VD: vitamin D, O3: Omega-3 fatty acids

Vitamin D Supplementation

Among all participants, 68.8% reported using prenatal vitamins, and 22.3% additionally used other VD-containing dietary supplements. Overall, 77.6% of women consumed some form of VD supplementation. Overall supplemental (*Table 4*) intake was significantly more common among women aged 25–34 years (OR 2.67, p=0.019,), those with higher education (OR 3.49, p=0.012), those with planned pregnancies (OR 3.50, p=0.041), primiparas (OR 1.88, p=0.035), women who underwent infertility treatment or assisted reproductive techniques (OR 3.50, p=0.044), those who initiated antenatal care early (OR 2.27, p=0.020), and those who received advice about pregnancy (OR 2.12, p=0.035). According to adherence groups, only planned pregnancy (p=0.006) associated with more correct intake (*Table 5*).

Table 4. *Overall supplemental VD intake according to the characteristics of women*

Characteristics	**Overall VD supplementation (yes)**			
	n (%)	***p* Value***	**Odds Ratio (95% CI)**	***p* Value*****
Individual characteristics				
Age group (years)				
–24	21 (63.6)		1.00	
25–34	126 (82.4)	**0.047**	2.67 (1.17-6.07)	**0.019**
35–	81 (75.0)		1.71 (0.75-3.94)	0.204
Education				
primary	14 (60.9)		1.00	
secondary	70 (74.5)		1.88 (0.72-4.88)	0.198
higher-level vocational training	37 (74.0)	**0.049**	1.83 (0.64-5.22)	0.259
university	103 (84.4)		3.49 (1.32-9.19)	**0.012**
Relationship status				
single	4 (57.1)	0.182**	1.00	
in relationship	223 (78.5)		2.74 (0.60-12.58)	0.194
Residence				
capital city, county town	110 (82.7)		2.06 (1.05-4.04)	**0.035**
city	66 (75.9)	0.098	1.36 (0.67-2.73)	0.395
village	51 (69.9)		1.00	
Conception related characteristics				
Use of contraceptives				
yes	104 (82.5)	0.086	1.66 (0.93-2.95)	0.088
no	120 (74.1)		1.00	
Infertility treatment				
yes	32 (91.4)	**0.032****	3.50 (1.04-11.82)	**0.044**
no	192 (75.3)		1.00	
Mode of conception				
spontaneous	215 (76.5)		0.00 (0.00-1.34)	0.076
assisted reproductive techniques	11 (100.0)	0.076**	1.00	
Pregnancy related characteristics				
Planned pregnancy				
yes	186 (80.2)	**0.039**	1.97 (1.03-3.77)	**0.041**
no	37 (67.3)		1.00	
First pregnancy				
yes	102 (83.6)	**0.034**	1.88 (1.04-3.37)	**0.035**
no	125 (73.1)		1.00	
Timing of first visit at pregnancy care				
≤12 weeks	191 (79.9)	**0.018**	2.27 (1.14-4.54)	**0.020**

>12 weeks	28 (65.1)		1.00	
Advice regarding pregnancy				
yes	193 (80.4)	**0.032**	2.12 (1.06-4.28)	**0.035**
no	29 (65.9)		1.00	
Previous miscarriage				
yes	51 (75.0)	0.676	1.16 (0.58-2.33)	0.676
no	75 (72.1)		1.00	
Previous preterm delivery				
yes	23 (79.3)	0.427	1.48 (0.56-3.91)	0.429
no	101 (83.5)		1.00	

VD: Vitamin D, *Results based on Pearson chi-square test, **Results based on Fisher's exact test. *** Results based on univariable logistic regression; 95% CI: 95% confidence interval.

Table 5. *Characteristics of women taking VD according to different adherence levels of supplementation*

Characteristics	VD (Correctly Used) *n* (%)	VD (Incorrectly Used) *n* (%)	VD (Non-Users) *n* (%)	*p* Value
Age group				
–29	21 (32.3)	25 (38.5)	19 (29.2)	0.385
30–34	43 (46.2)	33 (35.5)	17 (18.3)	
35–	51 (41.8)	41 (33.6)	30 (24.6)	
Education of the mother				
primary	5 (22.7)	8 (36.4)	9 (40.9)	0.082
secondary	35 (38.9)	31 (34.4)	24 (26.7)	
higher-level vocational training	15 (32.6)	18 (39.1)	13 (28.3)	
university	58 (49.2)	41 (34.7)	19 (16.1)	
Education of the father				
primary	5 (35.7)	6 (42.9)	3 (21.4)	0.616
secondary	60 (41.7)	46 (31.9)	38 (26.4)	
higher-level vocational training	9 (30.0)	12 (40.0)	9 (30.0)	
university	38 (45.2)	31 (36.9)	15 (17.9)	
Marital status				
single	3 (33.3)	3 (33.3)	3 (33.3)	0.747
In a relationship	112 (41.8)	95 (35.4)	61 (22.8)	
Residence				
county town	53 (42.7)	48 (38.7)	23 (18.5)	0.093
city	31 (36.0)	34 (39.5)	21 (24.4)	
village	31 (44.9)	16 (23.2)	22 (31.9)	
Planned pregnancy				
yes	102 (46.2)	73 (33.0)	46 (20.8)	**0.006**
no	12 (22.6)	23 (43.4)	18 (34.0)	

VD: vitamin D

Interestingly, only 25.9% of women who consumed prenatal vitamins were aware that these products contained VD. Awareness (not illustrated) was significantly associated with information obtained from the internet ($p = 0.006$), previous preterm birth ($p = 0.034$), and, to a lesser extent, infertility treatment ($p = 0.061$) or ART ($p = 0.068$).

Folic Acid Supplementation

FA supplementation was reported by 88.7% of women, yet only 31% adhered to guidelines requiring initiation before conception and continuation until at least the twelfth week of gestation. A substantial proportion, 58%, used FA in an inappropriate manner, typically beginning supplementation too late. Higher adherence was observed among older mothers p=0.004), those with higher education (p<0.001), residents of county towns (p=0.007), and women with planned pregnancies (p<0.001). FA supplementation according to the participants' characteristics are shown in *Table 6*.

Table 6. *Characteristics of women taking FA according to different adherence levels of supplementation*

	FA (correctly used) n (%)	**FA (incorrectly used) n (%)**	**FA (non-users) n (%)**	***p***
Age group				
–29	9 (14.3)	42 (66.7)	12 (19.0)	**0.004**
30–34	36 (38.3)	53 (56.4)	5 (5.3)	
35–	40 (34.2)	64 (54.7)	13 (11.1)	
Education of the mother				
primary	1 (4.8)	12 (57.1)	8 (38.1)	**<0.001**
secondary	18 (20.5)	58 (65.9)	12 (13.6)	
higher-level vocational training	8 (18.2)	31 (70.5)	5 (11.4)	
university	58 (49.6)	55 (47.0)	4 (3.4)	
Education of the father				
primary	0 (0)	11 (84.6)	2 (15.4)	0.078
secondary	43 (30.1)	81 (56.6)	19 (13.3)	
higher-level vocational training	9 (31.0)	16 (55.2)	4 (13.8)	
university	32 (39.0)	46 (56.1)	4 (4.9)	
Marital status				
single	1 (11.1)	5 (55.6)	3 (33.3)	0.067
in relationship	84 (32.1)	151 (57.6)	27 (10.3)	
Residence				
county town	47 (38.8)	68 (56.2)	6 (5.0)	**0.007**
city	16 (19.3)	53 (63.9)	14 (16.9)	
village	22 (31.9)	37 (53.6)	10 (14.5)	
Planned pregnancy				
yes	83 (38.2)	118 (54.4)	16 (7.4)	**<0.001**
no	2 (3.9)	36 (70.6)	13 (25.5)	

FA: folic acid

Omega-3 Supplementation

O3 fatty acid supplementation was reported by 60.1% of the cohort, but adherence to the recommended initiation at week 20 was low. Only 37.5% were classified as appropriate users. Incorrect use was observed in 21.2%, and 41.3% reported no intake. Adherence was higher among university-educated women (p=0.006). O3 supplementation according to the participants' characteristics are shown in *Table 7*.

Table 7. *Characteristics of women taking O3 according to different adherence levels of supplementation*

	O3 (correctly used) n (%)	O3 (incorrectly used) n (%)	O3 (non-users) n (%)	*p*
Age group (years)				
–29	20 (29.9)	16 (23.9)	31 (46.3)	0.240
30–34	35 (36.5)	25 (26.0)	36 (37.5)	
35–	53 (42.4)	20 (16.0)	52 (41.6)	
Education of the mother				
primary	4 (18.2)	3 (13.6)	15 (68.2)	**0.006**
secondary	29 (30.9)	22 (23.4)	43 (45.7)	
higher-level vocational training	14 (29.8)	12 (25.5)	21 (44.7)	
university	60 (50.0)	23 (19.2)	37 (30.8)	
Education of the father				
primary	6 (40.0)	2 (13.3)	7 (46.7)	0.243
secondary	51 (34.7)	29 (19.7)	67 (45.6)	
higher-level vocational training	9 (29.0)	9 (29.0)	13 (41.9)	
university	42 (48.3)	18 (20.7)	27 (31.0)	
Marital status				
single	3 (30.0)	3 (30.0)	4 (40.0)	0.757
in relationship	104 (37.8)	57 (20.7)	114 (41.5)	
Residence				
county town	56 (43.1)	31 (23.8)	43 (33.1)	0.115
city	29 (34.1)	17 (20.0)	39 (45.9)	
village	23 (31.9)	12 (16.7)	37 (51.4)	
Planned pregnancy				
yes	92 (40.7)	46 (20.4)	88 (38.9)	0.076
no	13 (24.1)	14 (25.9)	27 (50.0)	

O3: Omega-3 fatty acids

Prenatal Multiple Micronutrient Supplementation

Among all participants, 69% consumed PMM during pregnancy. However, only 36% were classified as appropriate users, 31.6% as inappropriate, and 32.4% as non-users. Only planned pregnancy showed significant association with PMM adherence (p=0.004). PMM supplementation according to the participants' characteristics are shown in *Table 8*.

Table 8. *Characteristics of women taking PMM according to different adherence levels of supplementation*

	PMM (correctly used) n (%)	**PMM (incorrectly used) n (%)**	**PMM (non-users) n (%)**	***p***
Age group (years)				
–29	16 (25.0)	24 (37.5)	24 (37.5)	0.142
30–34	35 (37.6)	33 (35.5)	25 (26.9)	
35–	49 (40.5)	31 (25.6)	41 (33.9)	
Education of the mother				
primary	4 (19.0)	7 (33.3)	10 (47.6)	0.274
secondary	32 (35.2)	27 (29.7)	32 (35.2)	
higher-level vocational training	13 (28.3)	16 (34.8)	17 (37.0)	
university	49 (42.2)	37 (31.9)	30 (25.9)	
Education of the father				
primary	6 (42.9)	5 (35.7)	3 (21.4)	0.209
secondary	49 (34.3)	41 (28.7)	53 (37.1)	
higher-level vocational training	6 (20.0)	11 (36.7)	13 (43.3)	
university	35 (42.2)	28 (33.7)	20 (24.1)	
Marital status				
single	3 (33.3)	3 (33.3)	3 (33.3)	0.982
in relationship	97 (36.5)	84 (31.6)	85 (32.0)	
Residence				
county town	42 (34.1)	44 (35.8)	37 (30.1)	0.547
city	31 (36.0)	27 (31.4)	28 (32.6)	
village	27 (39.7)	16 (23.5)	25 (36.8)	
Planned pregnancy				
yes	89 (40.6)	62 (28.3)	68 (31.1)	**0.004**
no	9 (17.0)	24 (45.3)	20 (37.7)	

PMM: Prenatal multiple micronutrient supplements

Combined Micronutrient Intake

To provide a more comprehensive view, micronutrient intake was also analyzed in terms of appropriateness and combined use. *Figure 1* illustrates adherence for each nutrient individually, showing that although supplementation was common, only a minority of women followed recommendations precisely. The highest adherence rate was observed for VD (41.1%), whereas FA showed the lowest (31.0%). Inappropriate use was most prevalent for FA (58.0%), while complete non-use was notable for O3, reported by more than 40% of the women. To integrate these findings across nutrients, a composite adherence score was developed, as displayed in *Figure 2*. This analysis revealed that 30.4% of participants achieved high adherence (score 5–6), indicating appropriate intake of at least two or all three micronutrients. Conversely, 19.4% of women were classified as non-users or very low adherers, while just over half (50.2%) fell into the moderate category, demonstrating partial but inconsistent supplementation practices. The sociodemographic correlates of combined intake are presented in *Table 9.* Younger mothers, particularly those under 29 years of age, were significantly less likely to achieve appropriate combined intake, whereas higher adherence was observed among women aged 30 years or older (p=0.032). Educational attainment exerted a strong effect: university-educated mothers reported the highest rates of appropriate combined intake, in contrast to women with only primary or secondary schooling (p=0.005). Residence also played a role, with women living in county towns showing somewhat higher adherence compared to those in smaller cities or villages, although without achieving the level of significance. Finally, pregnancy planning emerged as a powerful determinant, as women with planned pregnancies were far more likely to supplement all three micronutrients correctly than those with unplanned pregnancies (p=0.004).

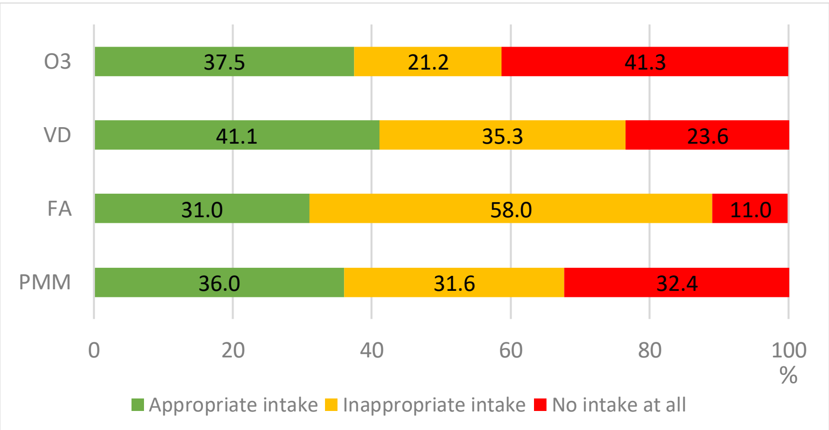

Figure 1. *Micronutrient intake appropriateness, adherence to guidelines*
O3: Omega-3 fatty acids VD: vitamin D, FA: folic acid, PMM: Prenatal multiple micronutrient supplements

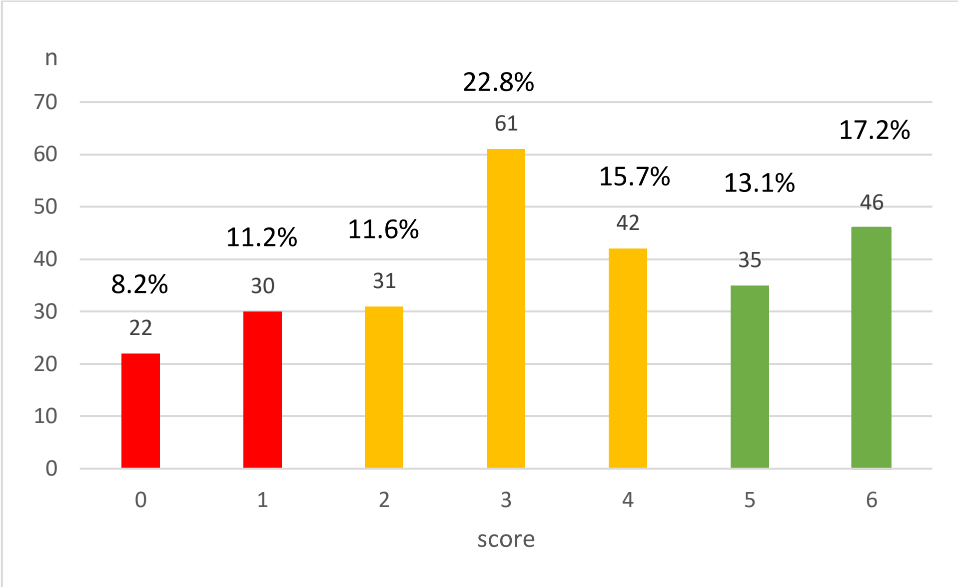

Figure 2. *Distribution of the composite adherence score values for combined micronutrient intake (FA+VD+O3)*

Red: almost non-users, yellow: inappropriate users, green: appropriate users. n=number of cases
O3: Omega-3 fatty acids VD: vitamin D, FA: folic acid

Table 9. *Characteristics of women taking combined micronutrients according to different adherence levels of supplementation*

	Combined intake (FA, VD, O3) (correctly used) n (%)	Combined intake (FA, VD, O3) (incorrectly used) n (%)	Combined intake (FA, VD, O3) (non-users) n (%)	*p*
Age group (years)				
–29	13 (17.8)	23 (31.5)	17 (23.3)	**0.032**
30–34	29 (29.0)	30 (30.0)	13 (13.0)	
35–	40 (31.5)	24 (18.9)	27 (21.3)	
Education of the mother				
primary	2 (8.0)	7 (28.0)	9 (36.0)	**0.005**
secondary	21 (21.6)	24 (24.7)	20 (20.6)	
higher-level vocational training	10 (20.0)	16 (32.0)	12 (24.0)	
university	48 (39.3)	16 (32.0)	15 (12.3)	
Education of the father				
primary	3 (18.8)	5 (31.3)	3 (18.8)	0.641
secondary	42 (27.1)	33 (21.3)	34 (21.9)	
higher-level vocational training	6 (19.4)	11 (35.5)	7 (22.6)	
university	31 (34.4)	25 (27.8)	12 (13.3)	
Marital status				
single	2 (20.0)	3 (30.0)	3 (30.0)	0.793
in relationship	80 (27.9)	73 (25.4)	53 (18.5)	

Residence				
county town	41 (30.6)	40 (29.9)	19 (14.2)	0.184
city	21 (23.6)	22 (24.7)	19 (21.3)	
village	20 (26.7)	14 (18.7)	19 (25.3)	
Planned pregnancy				
yes	74 (31.5)	54 (23.0)	39 (16.6)	**0.004**
no	8 (14.3)	21 (37.5)	17 (30.4)	

FA: folic acid, VD: vitamin D, O3: Omega-3 fatty acids

4.4. Total Vitamin D Intake and Serum Levels

Total VD intake, combining dietary and supplemental sources, averaged 19.27 µg/day (SD 22.44). While 44.5% of women reached the international recommendation of 15 µg/day, only 11% met the Hungarian lower threshold of 50 µg/day. Higher intake was associated with higher education (p=0.026), contraceptive use prior to conception (p=0.007), and conception by ART (p=0.034), as shown in *Table 10*.

Table 10. *Influencing factors of total VD intake (µg/day)*

Characteristics	Total VD intake (µg/day)	
	median (IQR)	***p* Value***
Individual characteristics		
Age group (years)		0.116
–24	7.98 (2.38-18.51)	
25–34	13.53 (5.67-24.27)	
35–	12.69 (4.38-22.60)	
Education		**0.026**
primary	10.04 (3.99-17.87)	
secondary	11.73 (3.13-20.45)	
higher-level vocational training	5.74 (1.49-25.30)	
university	15.25 (7.82-24.26)	
Relationship status		0.476
single	21.12 (17.00-22.51)	
in relationship	11.85 (3.52-21.96)	
Residence		0.073
capital city, county town	13.01 (5.61-23.29)	
city	12.31 (3.74-22.21)	
village	10.89 (2.60-21.08)	
Conception related characteristics		
Use of contraceptives		**0.007**
yes	12.76 (2.72-24.49)	
no	11.85 (4.72-21.08)	
Infertility treatment		0.257
yes	16.80 (9.55-22.83)	
no	11.6 (2.78-21.46)	

Mode of conception		**0.034**
spontaneous	11.85 (3.36-21.12)	
assisted reproductive techniques	26.43 (13.16-67.53)	
Pregnancy related characteristics		
Planned pregnancy		0.075
yes	13.26 (3.87-22.60)	
no	9.03 (3.17-20.56)	
First pregnancy		0.124
yes	14.89 (6.08-23.84)	
no	11.68 (3.45-22.52)	
Timing of first visit at pregnancy care		0.134
≤12 weeks	12.76 (3.96-22.68)	
>12 weeks	8.23 (2.58-14.10)	
Advice regarding pregnancy		0.455
yes	11.96 (3.75-22.02)	
no	13.26 (3.34-24.62)	
Previous miscarriage		0.314
yes	12.09 (3.91-23.24)	
no	12.07 (3.36-21.08)	
Previous preterm delivery		0.607
yes	11.73 (2.60-22.6)	
no	12.76 (20.52-6.32)	

VD: Vitamin D, *Results based on Mann-Whitney U or Kruskal-Wallis tests.

The mean maternal serum 25(OH)D concentration was 52.81 nmol/L (median 52.4 nmol/L). In total, 13.1% of women were classified as deficient (<30 nmol/L), 55.6% as sufficient (≥50 nmol/L), and only 12.1% achieved the optimal threshold of ≥75 nmol/L (*Figure 3*). Serum levels were significantly higher in women who initiated antenatal care early, conceived with ART, or received advice from their gynecologist. No other sociodemographic or obstetric parameters were associated with serum VD. Importantly, serum concentrations correlated with prenatal vitamin intake and total supplemental intake (Spearman's $r = 0.258$ and 0.274, respectively, both $p < 0.001$), but not with dietary VD intake (*Table 11*).

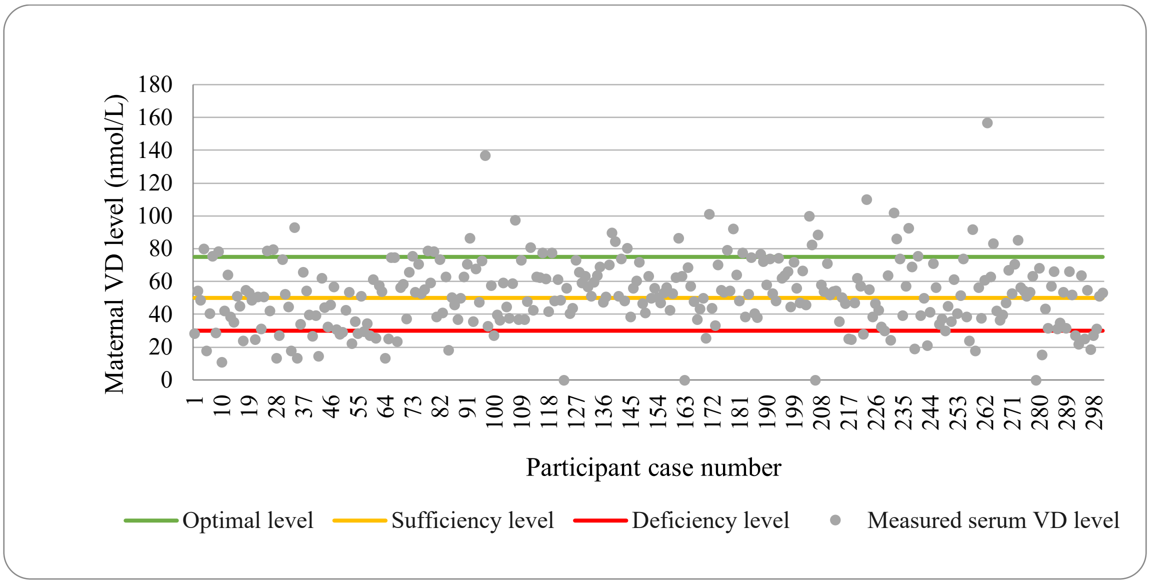

Figure 3. *Serum maternal vitamin D (VD) level among included women*

Table 11. *Correlations between maternal serum VD levels and its sources*

Source of VD	**Correlational coefficients**	
	Spearman's r	***p* Value**
Dietary VD intake	-0.098	0.090
Prenatal VD intake	0.258	**<0.001**
Other VD supplement	0.154	**0.008**
Total VD intake	0.274	**<0.001**

VD: vitamin D

4.5. Predictors of Adherence

To better understand which maternal and pregnancy-related characteristics influenced appropriate supplementation practices, multinomial logistic regression analyses were conducted for each micronutrient and for combined intake.

For PMM, parity emerged as a borderline significant predictor. Primiparous women had over twice the odds of being appropriate PMM users compared to non-users, although this association did not reach conventional statistical significance (AOR 2.10, $p = 0.053$). None of the other examined factors, including previous spontaneous abortion, timing of first antenatal visit, advice from a medical professional, or dietary attention, were significantly associated with PMM adherence. Predictors of adherence regarding PMM use are shown in *Table 12*.

Table 12. Predictors of appropriately/inappropriately using PMM by multinomial logistic regression

Predictors	*n*	Inappropriate PMM users (vs. non-users) AOR (95% CI)	*p*	Appropriate PMM users (vs. non-users) AOR (95% CI)	*p*
Parity					
first	106	1.03 (0.50-2.13)	0.938	2.10 (0.99-4.45)	0.053
second or more	143	1		1	
Previous spontaneous abortion					
yes	59	0.51 (0.22-1.19)	0.118	1.22 (0.54-2.76)	0.634
no	190	1		1	
First appearance at prenatal care					
≤12 weeks	208	1.28 (0.56-2.90)	0.560	2.12 (0.89-5.02)	0.088
>12 weeks	41	1		1	
Advice from a medical professional					
yes	183	1.55 (0.76-3.17)	0.226	1.52 (0.75-3.09)	0.242
no	66	1		1	
More attention on diet during pregnancy					
yes	195	1.02 (0.48-2.18)	0.956	1.27 (0.59-2.74)	0.540
no	54	1		1	
Body weight gain during pregnancy					
more than optimal	96	1.34 (0.62-2.90)	0.452	1.10 (0.52-2.33)	0.809
normal	75	1.40 (0.62-3.18)	0.423	1.29 (0.58-2.85)	0.532
less than optimal	78	1		1	

AOR: adjusted odds ratio, CI: confidence interval, PMM: prenatal multiple micronutrient supplements

Regarding VD, primiparity significantly increased the likelihood of correct intake (AOR 3.37, $p = 0.004$). Moreover, women who presented at antenatal care before the twelfth week of gestation were more likely to report both appropriate (AOR 2.75, $p = 0.023$) and inappropriate (AOR 2.53, $p = 0.039$) use, compared to non-users. No associations were observed with history of spontaneous abortion, medical advice, or attention to diet. Predictors of adherence regarding VD use are shown in *Table 13*.

In the case of O3**,** both primiparity (AOR 2.66, $p = 0.005$) and a history of spontaneous abortion (AOR 2.21, $p = 0.043$) were associated with significantly higher odds of appropriate use compared to non-use. Early initiation of antenatal care and professional advice did not reach statistical significance, although trends suggested a potential positive influence. Predictors of adherence regarding O3 use are shown in *Table 14*.

Table 13. *Predictors of appropriately/inappropriately using VD by multinomial logistic regression*

Predictors	***n***	**Inappropriate VD users (vs. non-users)**		**Appropriate VD users (vs. non-users)**	
		AOR (95% CI)	***p***	**AOR (95% CI)**	***p***
Parity					
first	107	1.57 (0.71-3.48)	0.269	3.37 (1.49-7.63)	**0.004**
second or more	145	1		1	
Previous spontaneous abortion					
yes	61	0.82 (0.34-1.96)	0.655	1.71 (0.72-4.09)	0.226
no	191	1		1	
First appearance at prenatal care					
≤12 weeks	211	2.53 (1.05-6.11)	**0.039**	2.75 (1.15-6.56)	**0.023**
>12 weeks	41	1		1	
Advice from a medical professional					
yes	185	1.27 (0.60-2.68)	0.530	1.60 (0.75-3.41)	0.226
no	67	1		1	
More attention on diet during pregnancy					
yes	197	1.84 (0.83-4.06)	0.134	1.70 (0.77-3.74)	0.189
no	55	1		1	
Body weight gain during pregnancy					
more than optimal	99	1.54 (0.69-3.44)	0.298	1.03 (0.46-2.29)	0.944
normal	75	2.13 (0.86-5.29)	0.104	2.01 (0.83-4.87)	0.120
less than optimal	78	1		1	

AOR: adjusted odds ratio, CI: confidence interval, VD: vitamin D

Table 14. *Predictors of appropriately/inappropriately using O3 by multinomial logistic regression*

Predictors	***n***	**Inappropriate O3 users (vs. non-users)**		**Appropriate O3 users (vs. non-users)**	
		AOR (95% CI)	***p***	**AOR (95% CI)**	***p***
Parity					
first	108	0.98 (0.47-2.08)	0.966	2.66 (1.35-5.28)	**0.005**
second or more	150	1		1	
Previous spontaneous abortion					
yes	61	0.90 (0.37-2.18)	0.818	2.21 (1.03-4.76)	**0.043**
no	197	1		1	
First appearance at prenatal care					
≤12 weeks	215	1.25 (0.51-3.04)	0.622	1.80 (0.82-3.94)	0.143
>12 weeks	43	1		1	
Advice from a medical professional					
yes	189	0.95 (0.46-1.98)	0.896	1.53 (0.78-2.97)	0.214
no	69	1		1	
More attention on diet during pregnancy					
yes	201	0.65 (0.30-1.41)	0.272	0.72 (0.36-1.47)	0.371
no	57	1		1	
Body weight gain during pregnancy					
more than optimal	100	1.66 (0.77-3.61)	0.198	1.21 (0.60-2.46)	0.590
normal	79	0.72 (0.29-1.79)	0.475	1.54 (0.75-3.14)	0.239
less than optimal	79	1		1	

AOR: adjusted odds ratio, CI: confidence interval, O3: omega-3 fatty acids

For FA**,** the analyses confirmed that parity and early antenatal care strongly predicted appropriate use. First-time mothers were over three times more likely to take FA correctly compared to non-users (AOR 3.16, $p = 0.040$). Similarly, women who began antenatal care by week twelve had nearly five times the odds of appropriate FA intake (AOR 4.70, $p = 0.009$). Interestingly, early care initiation also increased the likelihood of inappropriate FA use, suggesting that although early counseling encouraged supplementation, not all women adhered fully to recommendations. Predictors of adherence regarding PMM use are shown in *Table 15*.

Table 15. *Predictors of appropriately/inappropriately using FA by multinomial logistic regression*

Predictors	*n*	Inappropriate FA users (vs. non-users)		Appropriate FA users (vs. non-users)	
		AOR (95% CI)	*p*	AOR (95% CI)	*p*
Parity					
first	106	1.32 (0.48-3.63)	0.596	3.16 (1.05-9.46)	**0.040**
second or more	141	1		1	
Previous spontaneous abortion					
yes	60	1.40 (0.43-4.52)	0.575	1.67 (0.46-6.03)	0.432
no	187	1		1	
First appearance at prenatal care					
≤12 weeks	208	2.65 (0.97-7.25)	0.057	4.70 (1.48-14.99)	**0.009**
>12 weeks	39	1		1	
Advice from a medical professional					
yes	181	1.54 (0.60-3.94)	0.366	1.57 (0.57-4.37)	0.386
no	66	1		1	
More attention on diet during pregnancy					
yes	195	1.09 (0.39-3.07)	0.874	1.40 (0.45-4.36)	0.562
no	52	1		1	
Body weight gain during pregnancy					
more than optimal	95	1.05 (0.37-2.97)	0.935	0.74 (0.24-2.25)	0.589
normal	74	1.42 (0.44-4.58)	0.554	1.24 (0.36-4.27)	0.731
less than optimal	78	1		1	

AOR: adjusted odds ratio, CI: confidence interval, FA: folic acid

Finally, for combined micronutrient adherence (FA, VD, O3 together), parity and timing of antenatal care visits were the most consistent predictors. Primiparous women had over five times the odds of being classified as appropriate combined users compared to multiparas (AOR 5.23, $p = 0.001$). Early antenatal care also predicted both inappropriate (AOR 3.57, $p = 0.006$) and appropriate (AOR 3.75, $p = 0.012$) combined adherence. In addition, women with normal gestational weight gain were significantly more likely to be in the appropriate (AOR 2.93, p=0.044) or near-appropriate adherence groups (AOR 3.18, p= 0.020), compared with those whose weight gain was below recommended levels. Predictors of adherence regarding combined micronutrient use are shown in *Table 16.*

***Table 16.** Predictors of appropriately/inappropriately using overall micronutrients by multinomial logistic regression.*

Predictors	*n*	Inappropriate combined supplement users (vs. non-users)		Appropriate combined supplement users (vs. non-users)	
		AOR (95% CI)	***p***	**AOR (95% CI)**	***p***
Parity					
first	103	1.99 (0.83-4.79)	0.126	5.23 (1.92-14.23)	**0.001**
second or more	138	1		1	
Previous spontaneous abortion					
yes	58	0.61 (0.25-1.49)	0.278	1.63 (0.59-4.51)	0.346
no	183	1		1	
First appearance at prenatal care					
≤12 weeks	203	3.57 (1.45-8.84)	**0.006**	3.75 (1.33-10.58)	**0.012**
>12 weeks	38	1		1	
Advice from a medical professional					
yes	177	0.62 (0.27-1.43)	0.260	1.53 (0.57-4.11)	0.394
no	64	1		1	
More attention on diet during pregnancy					
yes	190	1.56 (0.66-3.72)	0.315	1.22 (0.47-3.16)	0.689
no	51	1		1	
Body weight gain during pregnancy					
more than optimal	92	1.79 (0.78-4.11)	0.168	1.18 (0.47-2.96)	0.727
normal	73	3.18 (1.20-8.47)	**0.020**	2.93 (1.03-8.31)	**0.044**
less than optimal	76	1		1	

AOR: adjusted odds ratio, CI: confidence interval

Taken together, these findings underline the role of parity and early contact with antenatal services as the strongest determinants of correct micronutrient use. In particular, primiparous women and those who initiated care before the twelfth week were consistently more likely to follow supplementation recommendations appropriately.

4.6. Pregnancy and Delivery Outcomes

Analyses of micronutrient adherence in relation to pregnancy and delivery outcomes revealed several important associations. Detailed results are shown in *Table 17* and *Table 18.* Neither VD nor PMM supplementation showed significant associations with GDM, gestational hypertension, or delivery outcomes. However, if dietary plus supplemental VD intake together achieved 15 µg/day, then it significantly reduced the likelihood of gestational hypertension (OR0.44, p=0.043). Insufficient maternal serum VD level increased the chance for inadequate uterine contraction and abnormal rupture of membranes, by 2.95 (p=0.030) and 3.21 (p=0.019) times higher, respectively; however, if the maternal serum VD level was higher than 75 nmol/L, then the occurrence of abnormal membrane rupture was also significantly elevated with a 5.59-fold probability (p=0.002).

Appropriate O3 supplementation was associated with a markedly lower risk of GDM (OR 0.06, p=0.047). In contrast, inappropriate O3 supplementation was linked to a 4.24-fold increased likelihood of inadequate uterine contractions (p=0.005). FA intake showed a consistent association with delivery outcomes. Both inappropriate and appropriate FA supplementation were associated with a reduced risk of cesarean section, by 69% (p=0.038) and 75% (p=0.036), respectively. No significant associations were found between FA supplementation and other outcomes. Combined micronutrient adherence did not reveal statistically significant associations with most pregnancy outcomes. However, women with higher composite adherence were more likely to achieve weight gain within the recommended range, although this did not translate into higher birth weights.

Table 17. *The association of micronutrient supplementation with different adherence levels in pregnancy*

	GDM		**Gestational hypertension**	
	OR (95% CI)	***p***	**OR (95% CI)**	***p***
PMM				
non-users	ref.		ref.	
inappropriate users	2.04 (0.31-13.30)	0.456	0.71 (0.14-3.61)	0.682
appropriate users	3.03 (0.41-22.21)	0.276	1.35 (0.24-7.42)	0.734
VD				
non-users	ref.		ref.	
inappropriate users	0.47 (0.05-4.99)	0.533	1.12 (0.13-9.42)	0.917
appropriate users	0.50 (0.04-6.86)	0.603	1.06 (0.09-12.35)	0.964
FA				
non-users	ref.		ref.	
inappropriate users	2.80 (0.62-12.66)	0.182	0.52 (0.07-3.70)	0.514
appropriate users	3.62 (0.61-21.38)	0.155	0.21 (0.02-1.96)	0.169
O3				
non-users	ref.		ref.	
inappropriate users	0.76 (0.21-2.78)	0.682	1.16 (0.31-4.29)	0.826
appropriate users	0.06 (0.003-0.97)	**0.047**	0.59 (0.11-3.24)	0.543
Combined supplement intake				
non-users	ref.		ref.	
inappropriate users	0.39 (0.05-3.19)	0.381	2.99 (0.23-38.30)	0.400
appropriate users	5.36 (0.12-249.78)	0.392	4.28 (0.10-188.20)	0.451
Maternal serum VD level				
deficient	ref.		ref.	
insufficient	1.91 (0.51-7.14)	0.338	0.71 (0.24-2.10)	0.542
sufficient	2.51 (0.71-8.88)	0.155	0.44 (0.15-1.30)	0.138
optimal	1.77 (0.39-8.06)	0.458	0.81 (0.22-2.93)	0.744
Total VD intake (dietary + supplemental)				
below rec.	ref.		ref.	
above rec.	0.56 (0.29-1.08)	0.083	0.44 (0.19-0.98)	**0.043**

OR: odds ratio, CI: confidence interval, rec: recommendation, PMM: Prenatal multiple micronutrient supplements, FA: folic acid, VD: vitamin D, O3: Omega-3 fatty acids. GDM: Gestational Diabetes Mellitus

Table 18. *The association of micronutrient supplementation with different adherence levels on delivery and birth*

	Preterm birth		High birth weight		Inadequate uterine contraction		Cephalopelvic disproportion		Abnormal rupture of membranes		Caesarean section	
	OR (95% CI)	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***
PMM												
non-users	ref.		ref.		ref.		ref.		ref.		ref.	
inappropriate users	0.64 (0.19-2.11)	0.463	3.34 (0.35-31.56)	0.292	1.14 (0.29-4.45)	0.855	3.06 (0.30-31.46)	0.348	0.88 (0.27-2.86)	0.834	1.49 (0.51-4.35)	0.470
appropriate users	1.37 (0.41-4.54)	0.610	4.06 (0.30-55.50)	0.293	2.52 (0.63-10.10)	0.192	2.52 (0.17-36.97)	0.500	1.14 (0.34-3.81)	0.829	2.04 (0.65-6.41)	0.223
VD												
non-users	ref.		ref.		ref.		ref.		ref.		ref.	
inappropriate users	1.18 (0.27-5.13)	0.824	0.45 (0.03-7.29)	0.562	0.42 (0.09-2.05)	0.281	1.71 (0.05-54.91)	0.763	0.47 (0.11-1.96)	0.297	1.11 (0.28-4.33)	0.886
appropriate users	2.47 (0.46-13.24)	0.291	0.19 (0.01-5.56)	0.337	0.40 (0.06-2.46)	0.322	0.60 (0.01-34.61)	0.807	0.77 (0.15-3.94)	0.754	1.01 (0.21-4.88)	0.990
FA												
non-users	ref.		ref.		ref.		ref.		ref.		ref.	
inappropriate users	1.61 (0.51-5.07)	0.414	5.22 (0.52-52.89)	0.162	0.80 (0.22-2.95)	0.733	4.02 (0.34-47.61)	0.270	0.87 (0.27-2.79)	0.820	0.31 (0.10-0.94)	**0.038**
appropriate users	1.56 (0.41-6.00)	0.519	6.44 (0.47-88.43)	0.163	1.32 (0.30-5.90)	0.716	4.88 (0.30-79.78)	0.266	1.92 (0.49-7.46)	0.349	0.25 (0.07-0.92)	**0.036**
O3												
non-users	ref.		ref.		ref.		ref.		ref.		ref.	
inappropriate users	1.25 (0.47-3.36)	0.652	0.63 (0.17-2.35)	0.489	4.24 (1.55-11.62)	**0.005**	0.31 (0.05-2.00)	0.219	1.77 (0.70-4.48)	0.227	0.55 (0.23-1.30)	0.175
appropriate users	1.30 (0.40-4.18)	0.666	0.30 (0.04-2.36)	0.253	2.90 (0.89-9.49)	0.078	0.49 (0.06-4.34)	0.528	1.32 (0.43-4.10)	0.631	0.42 (0.15-1.21)	0.107
Combined supplement intake												
non-users	ref.		ref.		ref.		ref.		ref.		ref.	
inappropriate users	0.57 (0.12-2.74)	0.484	0.63 (0.06-7.02)	0.708	1.25 (0.24-6.55)	0.794	0.19 (0.01-5.53)	0.335	1.58 (0.34-7.31)	0.560	1.46 (0.34-6.25)	0.610
appropriate users	0.25 (0.02-3.05)	0.279	1.08 (0.02-56.37)	0.970	0.67 (0.05-8.85)	0.759	0.99 (0.01-104.97)	0.996	0.73 (0.06-8.34)	0.797	2.59 (0.27-24.94)	0.411

Table 18. *cont. The association of micronutrient supplementation with different adherence levels on delivery and birth*

	Preterm birth		**High birth weight**		**Inadequate uterine contraction**		**Cephalopelvic disproportion**		**Abnormal rupture of membranes**		**Caesarean section**	
	OR (95% CI)	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***
Maternal serum VD level												
deficient	ref.		ref.		ref.		ref.		ref.		ref.	
insufficient	0.89 (0.39-2.03)	0.787	1.25 (0.31-5.01)	0.753	2.95 (1.11-7.87)	**0.030**	2.13 (0.24-18.94)	0.496	3.21 (1.21-8.52)	**0.019**	0.98 (0.45-2.14)	0.959
sufficient	0.89 (0.40-1.95)	0.764	0.92 (0.23-3.58)	0.899	2.22 (0.85-5.78)	0.103	3.78 (0.48-30.14)	0.209	2.29 (0.88-5.96)	0.088	0.91 (0.43-1.92)	0.805
optimal	1.86 (0.72-4.82)	0.199	0.69 (0.11-4.53)	0.703	2.42 (0.79-7.40)	0.122	4.38 (0.46-41.23)	0.197	5.59 (1.87-16.69)	**0.002**	1.12 (0.44-2.85)	0.812
Total VD intake (dietary + supplemental)												
below rec.	ref.		ref.		ref.		ref.		ref.		ref.	
above rec.	1.02 (0.63-1.65)	0.935	1.07 (0.47-2.45)	0.878	1.43 (0.87-2.34)	0.158	1.80 (0.75-4.36)	0.191	1.03 (0.64-1.66)	0.909	0.89 (0.56-1.40)	0.607

OR: odds ratio, CI: confidence interval, rec.: recommendation, PMM: Prenatal multiple micronutrient supplements, FA: folic acid, VD: vitamin D, O3: Omega-3 fatty acids

5. Discussion

This dissertation provides a comprehensive assessment of micronutrient supplementation among Hungarian pregnant women, focusing on both self-reported intake and biological validation through maternal serum VD measurements. The results highlight several critical issues: widespread but often inappropriate supplement use, insufficient dietary VD intake, low rates of adherence to evidence-based recommendations, and suboptimal maternal VD serum concentrations. In addition, the analyses identified sociodemographic and obstetric predictors of adherence and revealed meaningful associations between supplementation practices and maternal or neonatal outcomes. Together, these findings underscore the urgent need for more effective nutritional counseling and structured antenatal guidelines in Hungary.

5.1. Micronutrient Intake Patterns and Adherence

Consistent with international studies, supplementation during pregnancy was widespread in the study population, with the majority of women reporting the use of FA, VD, and PMM products. However, correct adherence to recommendations regarding timing and duration was markedly lower. Sources of supplementation varied widely: 69% of participants consumed PMM, 8–21% supplemented only from other sources (mainly single-component products, not PMM), and 10–23% supplemented both from PMM and other sources.

For FA, although nearly nine in ten women reported use, only about one-third initiated supplementation before conception and continued through the first trimester, as recommended. FA supplementation has shown some improvement over the past two decades. In our cohort, 89.0% of pregnant women reported FA use, whereas earlier Hungarian studies found much lower rates, at around 40% and 69% (Bognár et al., 2008; Paulik et al., 2009). Although directly comparable adherence data are not available, those earlier investigations indicated that only 7–30% of women began FA supplementation before conception (Bognár et al., 2008; Paulik et al. 2009). If this group is considered equivalent to the “appropriate users” in our study, then the situation has not improved substantially, as in our cohort only 31% of women-initiated supplementation prior to conception. Similar trends have been observed internationally, with adherence rates of 27–36% in Australia and Germany (Malek et al., 2016; Doru et al., 2023). These findings highlight a persistent gap between knowledge and practice. Population-based data from Canada and the United States confirm the same issue: although overall supplement use is high, only a minority of women initiate FA at the recommended preconceptional stage (Plumptre et al., 2013; Branum et al., 2012).

Every three out of four women supplemented VD during pregnancy. Adherence to VD supplementation was the highest among the studied micronutrients, but still suboptimal, with less than half of participants categorized as appropriate users (41%). Similarly high prevalence (68%) with much lower correct use (37%) of VD intake was experienced by Jensen et al. (2012) among the Danish pregnant women. In addition, awareness of VD content in supplements was strikingly low in our findings, with only a quarter of women recognizing it. Comparable results have been reported from Ireland, where over half of women incorrectly believed that they were not supplementing with VD despite using prenatal vitamins that contained it (Windrim et al., 2018). These results suggest that women often lack detailed knowledge of supplement composition and may not make informed choices about their intake. Similar inconsistencies have been observed in Asian and Middle Eastern contexts: in Japan, 75% of pregnant women reported supplement use, but often started too late (Sato et al., 2013); in Saudi Arabia, prevalence reached 71.5% with marked differences in timing and dosage (Alfawaz et al., 2017); and in China, nearly 95% reported supplement intake, though correct adherence varied (Xiang et al., 2022).

O3 supplementation showed the lowest prevalence and adherence, with fewer than two in five women following recommendations. Although supplementation is generally advised from the 20th gestational week, many women either did not take O3 at all or used it inconsistently. This result aligns with data from Sweden, where only 25% of pregnant women reported O3 use (Bärebring et al., 2018b). Despite strong evidence linking O3 intake to fetal neurodevelopment and reduced risk of adverse outcomes (Coletta et al., 2010; Middleton et al., 2018), its use remains overlooked in many populations, including Hungary. Additional studies from Iran also reported high supplement use (69%) but poor adherence to proper dosage and timing, further illustrating that the gap between prevalence and effective use is global (Talank et al., 2019).

International cohort studies indicate that most pregnant women in high-income countries rely on PMM, though usage patterns are not uniform. In the United States, Jun et al. (2020) reported that 77% of pregnant women used dietary supplements, mainly multivitamins, while 53% additionally consumed FA as a separate product. A comparable trend was seen in Canada, where more than 80% of women reported supplement use and about 60% took single FA products (Green et al., 2011). In Sweden, however, Bärebring et al. (2018b) found that although 78% of pregnant women used some form of supplementation, only 43% specifically took VD and 25% consumed O3. This corresponds with our findings, where O3 intake remains underutilized despite increasing evidence of its importance for fetal brain development (Bernardi et al., 2012).

In our study, PMM use was widespread, but the consumption of individual micronutrients varied considerably. Only a small proportion of women used single-nutrient supplements: 8.8% relied solely on VD, and 13.5% combined PMM with an additional vitamin D–containing preparation. These patterns suggest that although most women report taking supplements, reliance on multivitamins alone does not ensure adequate intake of all required nutrients, particularly when dosages may be insufficient or the product composition is not fully understood by users.

When micronutrient intake was evaluated jointly, fewer than one-third of women achieved high adherence across FA, VD, and O3. More than half of participants demonstrated moderate adherence, characterized by partial or inconsistent intake, while nearly one-fifth either did not use these supplements or used them incorrectly. Sociodemographic factors were important determinants: older age, higher education, urban residence, and planned pregnancy were associated with more appropriate combined intake. Similar patterns have been described in Norway, Germany, and the UK, where higher educational attainment and planned conception were positively associated with adherence (Arkkola et al., 2006; Aronsson et al., 2013; Mathews, 2000).

Logistic regression analyses confirmed that parity and early initiation of antenatal care were the most consistent predictors of appropriate supplementation. Primiparous women were significantly more likely to follow recommendations for VD, FA, O3, and combined use, compared to multiparas. This finding suggests that first-time mothers may be more motivated or better targeted by health professionals during pregnancy care. Previous miscarriage also increased the likelihood of appropriate O3 supplementation, possibly reflecting heightened awareness of risks and greater health consciousness after adverse outcomes. These findings resonate with international evidence linking parity and reproductive history to supplementation behaviors (Moser et al., 2019; Yang et al., 2021). Similar associations were also noted among women with obesity, where maternal age and parity strongly influenced supplement use (Redfern et al., 2022).

Education and age emerged as robust determinants of correct supplementation. Younger women and those with lower educational attainment were significantly less likely to follow recommended supplementation practices. In particular, women under 29 years of age were less likely to use FA correctly compared to women over 35. This finding is consistent with evidence from the United Kingdom, where younger maternal age was associated with poorer adherence to supplementation (Mathews et al., 2000). Previous studies have also demonstrated that lower maternal age is often linked with reduced health literacy, irregular antenatal care attendance, and limited awareness of dietary guidelines (Yee et al., 2021). Education exerted a similarly strong influence in our study: women with university-level education were far more likely to use dietary supplements correctly during pregnancy. This aligns with the findings of Haugen et al. (2008), who reported that supplement use in Norway was positively correlated with maternal education and income. Similarly, de Paula et al. (2023) demonstrated that higher education is strongly associated with micronutrient awareness and intake, highlighting that greater educational attainment translates into improved nutritional knowledge and adherence during pregnancy. Interestingly, paternal education did not appear to affect maternal supplementation practices, indicating that pregnant women assume primary responsibility for their own health behaviors. These findings underscore the importance of targeted educational interventions for younger and less-educated women.

Planned pregnancy was another highly influential factor shaping supplementation behavior. Women with planned pregnancies were significantly more likely to correctly use each of the studied supplements. This is consistent with the results of Bodnar et al. (2007a), who found that women planning their pregnancies were more likely to engage in positive health behaviors, including appropriate nutrient intake, higher PMM use, and earlier initiation of prenatal care in the United States.

Early presentation at antenatal care visits, typically before the 12th gestational week, was strongly associated with correct and incorrect supplementation compared to non users. It increased the likelihood of VD intake (both appropriately and inappropriately), FA intake (appropriately), and combined intake (both appropriately and inappropriately). This association applied across PMM and in the composite score, indicating that timely access to counseling and care plays a critical role in shaping supplementation practices. Comparable findings were reported in Vietnamese and European studies, where health literacy and early antenatal advice were linked to higher supplement use (Le et al., 2023; Bombas et al., 2024). Emphasizing the importance of pregnancy counselling, Polanek et al. (2022) demonstrated that early attendance at prenatal care is associated with a significantly higher maternal health-promoting behavior index and, consequently, greater overall health consciousness. Le et al. (2023) reported that limited health literacy was strongly linked to the lowest levels of supplement use in their study population. Previous research has shown that recommendations from healthcare professionals during pregnancy are positively associated with supplement use (Bombas et al., 2024); however, the appropriateness of intake has been less frequently evaluated. In contrast, our results indicate that receiving advice from a medical professional on healthy lifestyle habits or paying more attention to diet during pregnancy did not predict correct use of the micronutrients examined, despite the fact that three-quarters of participants reported receiving such information. This raises concerns about the effectiveness of current communication strategies in pregnancy counselling. Supporting this interpretation, a systematic review by Gomes et al. (2021) identified several effective interventions—such as education-based programs, supplement monitoring, SMS reminders, and free provision of supplements—that could also be adapted for the Hungarian context to improve adherence to prenatal micronutrient supplementation. The Hungarian antenatal decree does stipulate attention only to FA and VD (Ministry of Human Resources, 2014), but the effectiveness of counseling appears inconsistent, as inappropriate use was still common even among early attenders. Findings from the Netherlands further emphasize these gaps, where Willemse et al. (2020) showed that even in high-income countries, specific micronutrient intake during pregnancy often falls short despite widespread supplement use.

Our findings also highlight another shortcoming of Hungarian antenatal care: in smaller settlements outside of county towns such as Szeged, FA supplementation was used less appropriately. This points to an unequal implementation of national recommendations on maternal FA supplementation. The underlying reasons for this discrepancy remain unclear and warrant further investigation.

The non-adherence observed in our study can partly be explained by sociodemographic and pregnancy-related characteristics. However, additional determinants—such as cultural influences or broader health policy factors—should also be explored in future Hungarian research. International evidence has pointed to several behavioral and systemic barriers beyond sociodemographic ones, including lack of time, forgetfulness, financial cost, fear of side effects, limited awareness of importance, difficulty swallowing tablets, poor access to prenatal care, and inadequate counselling (Gomes et al., 2021; Jasti et al., 2005; Nechitilo et al., 2016.). Moreover, Doru et al. (2023) found that adherence was more likely among women who followed a vegetarian diet, intended to breastfeed, or reported regular use of medications.

In our study, healthier weight gain during pregnancy was associated with the combined supplementation of FA, VD, and O3. This finding challenges a common preconception among pregnant women that dietary supplementation contributes to excessive maternal weight gain and larger fetal size. This perception was also reflected in our results, as women whose weight gain exceeded the recommended levels were not more likely to consume micronutrients. Tabrizi et al. (2019) similarly found that dietary supplementation reduced the risk of inadequate gestational weight gain, whereas Alwan et al. (2010) reported no association between supplement use and birth size. Consistent with these findings, our results did not demonstrate any link between supplement use and high birth weight, further refuting the assumption that supplementation promotes excessive fetal growth.

5.2 Vitamin D Intake and Serum Concentrations

Dietary VD intake in this pregnant population was negligible, averaging only about 2 µg per day; equal with that of the general population; despite 78% of the pregnant women reported more conscious attention on diet. This is consistent with international studies showing dietary intakes below 5 µg/day in most countries (Spiro & Buttriss, 2014). In Hungary, such low intakes reflect limited consumption of VD-rich food and the absence of food fortification (National Institute of Pharmacy and Nutrition, 2019). Comparable findings were documented in other populations: Wang et al. (2010) in China, Kazemi et al. (2009) in Iran, and Bodnar et al. (2007b) in the United States all reported widespread insufficiency among pregnants. The average total VD intake (19.27 µg/day) was slightly higher than identified by other studies (Jensen et al., 2012), although only 44.5% and 11% of the pregnant women reached the international (15 µg/day) and the Hungarian (50 µg/day) recommendations, respectively. From the detected influencing factors of elevated total VD intake, apart from desired pregnancy and history of spontaneous abortion, the positive association with higher educational level was confirmed by other studies (Camargo et al., 2007; Mathews et al., 2000).

Despite high rates of reported supplementation, maternal serum VD concentrations remained inadequate for most women. Only 12% achieved the optimal threshold of 75 nmol/L, and more than 40% failed to reach the sufficiency cut-off of 50 nmol/L. These findings are notable given the established role of VD in reproduction and fetal well-being, with reviews highlighting its impact not only on skeletal development but also on placental function and pregnancy outcomes (Heyden & Wimalawansa, 2018). Similar prevalence rates of insufficiency (35-45%) have been documented in Switzerland (Christoph et al., 2020), Belgium, the Netherlands, and the UK (Mansur et al., 2022). Data from Qatar (Al Emadi & Hammoudeh, 2013) and Shanghai (Yang et al., 2021) further highlight that insufficiency is widespread even in sunny climates. Correlation analyses confirmed that supplemental, but not dietary, VD intake was associated with higher serum levels, reinforcing the need for supplementation as the primary source.

Considering the total average daily VD intake (19.27 µg) and the average serum VD levels 52.81 nmol/L) our findings support international evidence that current recommendations of 10–15 µg/day are insufficient to achieve optimal (75 nmol/L) maternal VD levels. EFSA calculations suggest that 15 µg/day enables most individuals to reach 50 nmol/L, but higher intakes of 37.5–50 µg/day may be necessary to attain 75 nmol/L (EFSA NDA Panel, 2016; Holick et al., 2011). In line with this, the Hungarian consensus recommends 2000 IU (50 µg) daily during the UV-B radiation-free period (Takács et al., 2022). However, only a minority of women in this study reached that intake level. Randomized controlled trials provide support for higher-dose regimens: Hollis et al. (2011) demonstrated safety and efficacy of 4000 IU/day in U.S. women, while Enkhmaa et al. (2019) found that higher doses effectively reduced deficiency in Mongolian pregnancies.

5.3. Associations with Maternal and Neonatal Outcomes

The analysis of maternal and neonatal outcomes demonstrated that adherence is not only a theoretical concern but also has tangible clinical implications. When examining pregnancy-related outcomes, the findings revealed that maternal serum VD status was not significantly associated with either GDM or gestational hypertension. Compared to VD-deficient women, those with insufficient, sufficient, or optimal levels did not exhibit significantly different risks for these conditions. This is somewhat unexpected, as prior studies have often identified low VD status as a risk factor for GDM and hypertensive disorders in pregnancy (de Souza & Pisani, 2020; Rostami et al., 2018). Conversely, analysis of total VD intake yielded more suggestive results. Women who achieved intake above the recommended level demonstrated a protective effect against gestational hypertension, while for GDM, there was a non-significant trend toward reduced odds. These results highlight the importance of evaluating both intake and serum levels: while serum concentrations may not have shown clear associations in this dataset, consistent supplementation leading to higher intake levels appears to have protective benefits against hypertensive disorders of pregnancy. The analyses exploring maternal serum VD levels in relation to delivery outcomes provided new insights. Interestingly, women with insufficient or optimal VD levels had higher odds of certain labor complications compared to those classified as deficient. Specifically, insufficiency was associated with a nearly threefold increase in the risk of inadequate uterine contractions, and a more than fivefold higher risk of abnormal rupture of membranes, while optimal VD levels were linked to a more than threefold increased likelihood of the latter. These findings suggest that higher serum VD concentrations may not uniformly confer protection and, under certain conditions, could even be associated with adverse intrapartum outcomes. However, studies raise explanations: Ulu et al. (2019) demonstrated that O3 derived resolvins can influence placental vascular and myometrial activity, suggesting that bioactive lipid–VD interactions might alter uterine contractility. Prevailing literature, however, generally describes beneficial or neutral associations between

VD sufficiency and labor parameters (Christoph et al., 2020; Tous et al., 2020). In contrast, total VD intake above the recommended levels did not show statistically significant associations with preterm birth, cesarean section, or other delivery complications.

O3 supplementation, when appropriately used, was associated with a significantly lower risk of GDM. This finding is consistent with randomized controlled trials demonstrating that O3 can improve insulin sensitivity and reduce inflammatory responses in pregnant women (Gao et al., 2020). Conversely, inappropriate O3 use was associated with an increased risk of inadequate uterine contractions, which may be explained by the physiological effects of O3-derived lipids on prostaglandin production and on trophoblast functions within the placenta, finally leading to reduced myometrial contractility (Ulu et al., 2019). This can be beneficial to prevent premature contractions and to prolong the pregnancy but can be unwanted during labor (Mu et al., 2023).

FA supplementation also showed important associations with delivery outcomes. Both appropriate and inappropriate use were linked to a reduced likelihood of cesarean section. Although the mechanism is less clear, possible explanations include improved placental function, reduced risk of complications such as preeclampsia, and better fetal development, all of which may reduce the need for surgical delivery (Cheng et al., 2019). Still, the literature is mixed: Meena et al. (2023) found no significant association between serum FA levels and delivery mode, whereas several cohort studies support indirect benefits. For example, Cheng et al. (2019) reported that prolonged FA supplementation attenuates the effect of GDM on macrosomia, thereby not elevating the risk of cesarean delivery; while Guo et al. (2020) demonstrated that folate sufficiency lowered the risk of small-for-gestational-age infants. In Hungary, Bánhidy et al. (2011) observed that FA supplementation reduced adverse outcomes in preeclampsia, reinforcing its multifaceted protective role.

No significant associations were observed for VD supplementation, which may reflect the generally insufficient dosages consumed or the difficulty of achieving optimal serum concentrations in this population. Nevertheless, evidence from randomized controlled trials suggests that proactive screening and supplementation can reduce adverse outcomes such as preeclampsia, GDM, and preterm birth (Rostami et al., 2018).

5.4. Strengths and Limitations

A major strength of this dissertation is the integration of both self-reported supplementation data and objective biomarker assessment of VD status. This approach allows for cross-validation of intake and biological adequacy, which is rarely done in Hungarian studies. Moreover, the analyses encompassed not only prevalence and adherence but also predictors of behavior and associations with pregnancy outcomes, providing a comprehensive picture of micronutrient use during pregnancy. Finally, a great value of this research is that – to our best knowledge – recently this is the only one available comprehensive examination in Hungary that analyzes the micronutrient intake habits among pregnant women.

However, several limitations must be acknowledged. First, the retrospective design and reliance on self-reported data introduce the possibility of recall and social desirability bias, particularly in relation to supplement use. Second, the study was conducted at a single institution, which may limit the generalizability of findings to the broader Hungarian population, nevertheless, it has regional responsibility, potentially enhancing the applicability of the findings. Third, dietary intake of FA and O3 was not assessed, precluding estimates of total nutrient exposure for these micronutrients. Participation in the study was offered to all eligible women, but enrollment was ultimately determined by the participants themselves, which may have introduced selection bias. Furthermore, pregnancy-related data were collected retrospectively after delivery, and the questionnaire used had not undergone formal validation. Finally, the sample size, though substantial, may have limited power to detect associations with relatively rare outcomes.

6. Conclusion

This dissertation investigated the micronutrient supplementation practices of pregnant women in Hungary, focusing specifically on FA, VD, O3, and PMM. Using a retrospective case–control dataset of 300 women who delivered at the University of Szeged, the study integrated multiple sources of data: self-administered questionnaires, medical documentation, dietary assessment, and laboratory measurement of maternal serum 25-hydroxyvitamin D concentrations. This multifaceted design allowed for a detailed exploration of intake patterns, adherence to guidelines, predictors of appropriate supplementation, and associations with maternal and neonatal outcomes. By combining intake and adherence data with biomarker evidence, this research provides a unique and comprehensive contribution to the understanding of prenatal nutrition in Hungary.

The findings demonstrate that while the majority of Hungarian pregnant women report taking dietary supplements, adherence to evidence-based recommendations is far from optimal, despite the fact that majority of pregnancies was planned. The results regarding FA supplementation suggest that although the prevalence of supplementation is high, correct usage that aligns with scientific recommendations remains limited. Similarly, findings regarding VD supplementation highlight a persistent gap between supplement use and biological adequacy.

Sociodemographic and obstetric factors strongly influenced supplementation practices. These findings align with international evidence linking education, health literacy, parity, and reproductive history to supplementation behaviors. Finally, associations between supplementation and maternal or neonatal outcomes were identified. Appropriate O3 intake was associated with a significantly reduced risk of GDM mellitus, while inappropriate intake increased the likelihood of inadequate uterine contractions. FA supplementation, whether appropriate or inappropriate, was associated with reduced odds of cesarean section. No significant associations were detected between VD supplementation and outcomes, likely reflecting insufficient dosages and low serum levels across the population.

The findings carry several important implications for public health and clinical practice in Hungary. High prevalence of supplement use indicates that most women are aware of the importance of prenatal nutrition. However, the low adherence to guidelines reveals a critical gap in knowledge translation. Interventions should therefore focus not merely on encouraging supplement use but on ensuring that women understand when and how to take these products. The results underscore the pivotal role of antenatal care. Women who initiated care early were consistently more likely to adhere to recommendations. This highlights the importance of timely access to health services and effective counseling during the first trimester, or ideally even before conception. Strengthening preconception counseling services and integrating micronutrient education into family planning programs could improve adherence rates. Associations between adherence and outcomes emphasize the clinical importance of correct supplementation. The protective effect of O3 against GDM suggests that its routine recommendation should be considered, particularly for women at elevated risk. Similarly, the association of FA with reduced cesarean deliveries supports continued emphasis on its use, though attention should be paid to initiating supplementation prior to conception.

Several avenues for future research emerge from this work:

- larger, multicenter studies are needed to confirm these findings and ensure generalizability across Hungary;
- prospective cohort studies beginning in the preconception period would provide more accurate data on supplementation timing and allow for assessment of causal relationships with outcomes;
- intervention studies could test strategies for improving adherence, such as digital reminders, free supplement provision, or enhanced counseling protocols;
- further biomarker studies should be conducted, not only for VD but also for folate, O3, and other nutrients, to provide objective evidence of nutritional status.
- qualitative research exploring women's knowledge, attitudes, and barriers to supplementation would provide valuable insights for designing more effective interventions.

In conclusion, this dissertation demonstrates that achieving optimal maternal and neonatal outcomes requires more than supplement use alone—it requires appropriate, timely, and sustained adherence. The evidence presented here should inform both clinical practice and policy, guiding efforts to ensure that future generations of Hungarian mothers and children can benefit fully from the well-established advantages of adequate micronutrient nutrition.

7. Original Findings

1. As per our knowledge, it is the first Hungarian study to provide a comprehensive analysis of FA, VD, O3, and PMM intake simultaneously, with detailed evaluation of both prevalence and adherence. This study provides the first evidence among Hungarian population that, although supplementation prevalence is high (60-89%), adherence to recommendations (correct use) is low, particularly for FA and O3 (30-40%).
2. The study integrates self-reported intake data with laboratory measurement of VD status, providing rare biomarker validation of supplementation practices. The results demonstrated that dietary intake was negligible, supplementation was essential, and yet serum sufficiency remained rare. Only 12% of women achieved the optimal Hungarian consensus threshold of 75 nmol/L, even though over three-quarters reported supplement use. This discrepancy between reported intake and biological adequacy is an original observation for Hungary, underscoring that mere supplementation prevalence does not guarantee effective outcomes.
3. The third originality of this work is the detailed assessment of adherence, defined by appropriate timing and duration of use, rather than intake alone. By distinguishing between appropriate, inappropriate, and non-use, and by developing a composite adherence score across FA, VD, and O3, this study advances the methodology of prenatal nutrition research. The finding that only 30% of Hungarian women achieved high combined adherence, despite high prevalence of use, represents a novel contribution to the understanding of supplementation behaviors and offering important insights for targeted interventions.
4. The identification of predictors of adherence in a Hungarian population is another important and original finding of the study. Multinomial logistic regression analyses revealed that primiparity and early initiation of antenatal care were the strongest and most consistent determinants of correct supplementation. These findings provide actionable targets for intervention, suggesting that multiparas, younger women, and those who initiate antenatal care late are at highest risk of inadequate supplementation.
5. The fifth contribution lies in the demonstration of clinically relevant associations between supplementation adherence and maternal outcomes. Specifically, appropriate O3 supplementation was linked to a markedly lower risk of GDM, while inappropriate intake increased the likelihood of inadequate uterine contractions. FA supplementation, whether appropriate or inappropriate, was associated with reduced odds of cesarean

delivery. These associations are rarely reported in Central and Eastern Europe and provide new evidence supporting the clinical relevance of adherence beyond nutrient sufficiency alone.

6. Another original insight lies in the distinction between serum status and total VD intake. While serum levels showed no significant association with GDM or hypertension, women with total intake above recommendations had significantly lower odds of gestational hypertension and a borderline reduction in GDM risk. This divergence highlights that intake patterns may capture protective behavioral practices better than serum levels alone, and underscores the value of analyzing both measures together. These findings provide new evidence to inform Hungarian antenatal care guidelines by emphasizing the importance of consistent supplementation behaviors alongside biological monitoring.
7. Finally, the study contributes to international debates by highlighting the inadequacy of current VD recommendations. Despite relatively high supplementation rates, maternal serum sufficiency remained low, suggesting that dosages typically consumed by Hungarian women are insufficient to achieve optimal concentrations. This finding supports international calls for revising VD intake guidelines during pregnancy and demonstrates the importance of biomarker validation in nutrition research.

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