

Review

Not peer-reviewed version

---

# Birth Mode and the Early-Life Microbiome: Strategies to Improve Health Outcomes for Cesarean-Born Infants

---

[Trishita Samanta](#)\*

Posted Date: 3 November 2025

doi: 10.20944/preprints202510.2496.v1

Keywords: microbiome; cesarean birth; neonatal health; vaccine; immunisation; nutrition; antibiotic stewardship



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

# Birth Mode and the Early-Life Microbiome: Strategies to Improve Health Outcomes for Cesarean-Born Infants

Trishita Samanta

Independent Researcher, formerly at Sri Ramachandra Institute of Higher Education and Research, Chennai, India; trishitabioinfo@gmail.com

## Abstract

Mode of delivery plays a significant role in shaping the initial microbiome development of newborns. Cesarean section often disrupts the natural microbial transfer that occurs during vaginal birth, potentially affecting immune maturation, vaccine responsiveness, and increasing the risk of gut-related disorders. This issue is particularly concerning in low- and middle-income countries (LMICs), where C-section rates continue to rise alongside challenges such as maternal and neonatal morbidity, mortality, and limited healthcare infrastructure. This article reviews global evidence on how birth mode influences the establishment of the early-life microbiome and outlines context-specific interventions such as personalized maternal-infant nutrition, improved antibiotic stewardship, optimized vaccine scheduling, enhanced childbirth education, and professional training. Integrating microbiome-informed birth practices into national maternal child health programs could help reduce unnecessary C-sections and promote equitable approaches to improve long-term health and well-being among cesarean-born infants.

**Keywords:** microbiome; cesarean birth; neonatal health; vaccine; immunisation; nutrition; antibiotic stewardship

---

## Introduction

Our lives depend on the vast variety of microorganisms that are present within us. According to recent studies suggest that the number of bacterial cells and human cells in the body is roughly equal, and the total mass of bacteria is about 0.2 kilos [1]. Although the collective microbial genome, or microbiome, consists of about ten times more genes than the human genome does and there is only around 10% of genetic similarity shared between any two individuals. Microbiome research studies explore how microbial communities influence human health and physiology. Large-scale initiatives like the American Gut Project have leveraged citizen science to map the diversity of the human gut microbiome across thousands of participants worldwide, revealing how lifestyle, diet, and geography shape microbial communities [2]. In general, the human microbiome consists of three major categories (bacteria, fungi, and archaea), each associated with different organs and body sites [3]. At birth, infants acquire their initial microbiota from their mother, and this microbial transmission varies significantly depending on the mode of delivery, such as vaginal delivery or C-section. These early microbial exposures can influence the baby's immune development and may affect long-term health outcomes. The global rate of cesarean births is steadily increasing. According to the World Health Organisation (WHO), the global rate of caesarean section births has risen significantly, from 6% in 1990 to 21% by 2018, and is projected to reach 30% by 2030 with indication of 38 million women will give birth through c-section annually and 88% of these incidents are expected to occur in low- and middle-income countries (LMICs) [4] underscoring this growing dependency on surgical births in regions that often face limited healthcare infrastructure.

Although caesarean section can be a vital and life-saving procedure, if it is done when there is no medical necessity, it may cause babies and mothers unnecessary health risks that can last a lifetime. Although the recent advancements in microbiome studies, scientifically revealed that infants, who born via cesarean section are predominantly colonized by skin-oral-hospital associated microbes, with lower diversity of beneficial bacteria, which is potentially impacting the infant's overall health outcomes, whereas those delivered vaginally, acquired necessity microbiota primarily from the mother via vaginally and exposes diverse maternal microbes, including beneficial bacteria such as *Lactobacillus* and *Bifidobacteria*, which play a significant roles in immune system development and gut health [5]. Adhering to the recommended antibiotic schedule during an infant's first year of life can impair the functionality of beneficial gut bacteria, although this effect largely depends on external factors such as the regional health care system and socioeconomic level. Some research indicates that amoxicillin is one of the most commonly prescribed antibiotics in paediatric care, which can significantly alter the composition of the infant microbiota. This disruption may persist for up to two years and potentially affect immune system development and increase susceptibility to allergic reactions [6]. Although adequate amounts of probiotic food supplements, known for their potent antibacterial properties, may significantly enhance infant gut health, particularly when combined with certain vaccines [7].

Currently, caesarean births are becoming more common and routine. As a result, there is an increasing need for policy awareness and targeted maternal-infant health care strategies that emphasise safe procedures to minimize long-term impacts, especially concerning the disruption of early-life microbiome development. WHO investigated that at present, there is no globally standardized, evidence-based protocol that exists, which can govern the specific steps to follow during a cesarean section [8]. Practices may vary widely across surgeons, hospital settings, and countries, leading to inconsistent early-life exposures that may influence infant microbiome development. Addressing this variation, it is crucial to think on new strategy to explain the development or refinement of existing rules to promote microbiome-friendly equitable birth practices globally.

In this manuscript, I aim to synthesize current scientific evidence from existing literature on how birth mode affects the infant microbiome, considering various factors, and to explore its policy-relevant implications and practices for optimizing caesarean section deliveries. In order to reduce infant mortality and improve health, it will cover both clinical and non-clinical interventions, such as designing vaccine only for c-section babies, work on antibiotic stewardship program, precision nutrition, childbirth education, nurse-led training, smart medical management, especially in low- and middle-income countries (LMICs). My main objective in writing this article is to protect every child who deserves to be safe and well.

## Implementation Barriers and Strategies

Nevertheless, Multiple factors influence the rate of ceaserean section birth outcome; many of them are still poorly understood or inadequately addressed in current healthcare systems. Such as Clinical reasons, including the increased incidence of maternal obesity, gestational diabetes, multiple pregnancy and a higher maternal age at birth [9], which are not enough to fully explain by medical needs alone. Their wide variation across hospitals, healthcare providers, and regions, as well as the fear of legal action, and various organizational, social, and cultural influences, play a significant role [10]. A newborn baby desired to be safe and Healthy, by making such programmes is crucial for proper management of c-section birth practice. Immunization scheduling, awareness programme, choosing right Nutrition, childbirth education, and nurse-led practice may further influence maternal-infant health outcomes and integrating genetic understanding is practically equally important for infant microbiome colonization and long-term health benefits. Despite growing global awareness, the implementation of microbiome-informed strategies in low- and middle-income countries (LMICs) remains limited due to several factors, including (i) infrastructural limitations [11], (ii)inconsistent policy adoption [12] (iii) insufficient provider training or lack of awareness regarding

microbiome-informed care and solution [13]. Monitoring and evaluating during implementation are crucial for infant health outcomes. Therefore, these structural gaps should be addressed through coordinated, consistent, and proactive measures. The following section outlines these key challenges and proposes context-sensitive strategies to strengthen maternal and infant health, with a focus on microbiome-dependent delivery practices.

## **Interconnected Pathways: Antibiotics, Vaccination, and Nutrition in Shaping the Cesarean-Born Infant Microbiome**

The child mortality of a cesarean section has been steadily increasing every day due to vulnerable healthcare systems in LMICs. In 2019, a comprehensive study presented that there were overall 56.6 stillbirths for every 1000 caesarean section newborns, with sub-Saharan Africa having the highest rate (82.5 per 1000), and the perinatal death rate was 84.7 per 1000, observed most in the Middle East and North Africa at 354.6 per 1000, followed by sub-Saharan Africa at 100.4 per 1000 [14]. To reduce this mortality rate and improve pregnancy outcomes, healthcare systems must implement coordinated strategies across clinical, nutritional, and immunisation sectors to support microbiome-informed birth practices.

There is strong evidence that microorganisms are associated with vaccine response, antibiotic exposure, and maternal-infant diet. While genetic and environmental factors also have a greater relationship between the immune system and microbiota, based on this, it is possible to develop individual-specific vaccine-induced immunological responses [15]. Considering these often raises the core question: Can early antibiotic use influence the baby's immune system? An antibiotic is a type of medicine that is used to kill or stop the growth of bacteria to treat infections, such as strep throat, urinary tract infections, or pneumonia, and certain types of infant diarrhoea [16]. Recent studies have investigated how antibiotic-mediated microbial depletion affects the infant immune system's response to tetanus, influenza, polio, rotavirus, and BCG vaccination (Only the polio study used newborns, for ethical reasons) [17]. Antibiotic use, microbiota disruptions, and a rise in immune-mediated disorder are all negatively correlated with either no improvement or significantly decreased vaccination immunogenicity. Studies revealed that HIV-infected mothers and their children show alterations in gut microbiome composition, suggesting that immune-related diseases like HIV are associated with disrupted microbial transmission [18]. Another example, autism spectrum disorder (ASD), unlike neurodegenerative diseases such as Parkinson's and Alzheimer's disease, is a neurodevelopmental disorder influenced by aberrant gut microbial colonisation during early life. Evidence suggests that disruptions in the maternal microbiota, mode of delivery, and early antibiotic exposure can impair a healthy microbial ecosystem, potentially modulating neurodevelopmental trajectories through the microbiota-gut-brain axis and contributing to ASD pathophysiology [19].

Overriding these issues, can diet influence the baby's immune system? Since the WHO supports Breast milk [20] should be initiated within an hour of delivery (colostrum), and maintaining exclusive breastfeeding till 6 months, especially it is crucial and critical for C-section births, where it is not only the ideal food for infants but also provides a complete source of nutrition and numerous health benefits. In a study, feeding IF containing *B. lactis* to C-section full-term infants predominantly enhanced responses to polio and rotavirus vaccines over the six-week intervention period [21]. Although a balanced maternal diet during pregnancy may influence the initial colonization of the infant gut microbiome, especially rich in green leafy vegetables, fruits [22] a high dietary fibre and low-fat diet may help infants' early colonization. Timely nutrition should be prioritized. Usually, probiotics and prebiotics, along with supplemented food, may have some beneficial effects, but it does not appear to have a long-term impact on an infant's gut microbiota [23]. The preterm babies who are born via c-section before 32 weeks of pregnancy have an unusual start in life. Such conditions often require sterile incubators, the use of antibiotics, and the inability to breastfeed, and complicated nutritional supplements that avoid the gastrointestinal tract [24]. Antibiotic use during the first year of life has been linked with several factors and an increased risk of allergic, asthma, eczema, hay

fever, wheeze, and atopy [25], and inflammatory bowel disease [26,27]. Addressing these issues, this paper emphasizes microbiota-based antibiotic planning during and after cesarean delivery, along with maternal-infant nutrition programmes that can be accessible and culturally adapted to reduce unnecessary disruption of the infant gut microbiome. Along with integrating microbiome awareness into vaccination planning is equally important, as early-life microbiota influences immune development and vaccine responsiveness, particularly for oral vaccines [28]. Therefore, including these components in national maternal-child health policies enables evidence-based, equitable treatment that has an extended impact on global health.

## Non-Clinical and Community-Based Practices

A mother and the family member play a significant role in developing their child's growth. Sharing appropriate education, conducting such motivational microbial workshops, seminars are crucial to understanding microbial importance for prospective parents to make informed decisions about their potential delivery methods. Until now, there have been no global guidelines on Microbiome-based Strategies to Improve Caesarean Birth. Although in 2018 WHO published non-clinical interventions to reduce unnecessary caesarean sections, they're nowhere talking about microbiome-friendly awareness or practices. Addressing this gap, the new recommended strategy of community-level microbial knowledge is needed to provide long-term health benefits to the cesarean birth. It has the potential to follow advised practices. Locally relevant information, education, and available communication resources like flowcharts, videos, pamphlets, and activities should be used to share understandable and consistent manner.

## Engagement of Medical Professionals in Clinical Practice

Effective implementation of microbiome-based clinical practices requires addressing multiple barriers within healthcare systems. Resistance among healthcare providers, often due to limited awareness, inadequate training, or unwillingness to alter established routines, can hinder the adoption of evidence-based approaches. Integrating broad aspects of microbiome-related modules into midwifery, nursing, and obstetric curricula is essential to enhance provider competence and understanding of how birth mode influences infant microbial colonization and long-term health outcomes.

Successful integration of microbiome-based strategies, such as guiding timely vaccination and boosters, supporting breastfeeding, optimizing antibiotic use, and promoting diet-based interventions should work collaboratively. Implementation often requires the involvement of technical experts for microbial sampling and sequencing, and bioinformaticians for data interpretation. Clinical checklists that include microbiome awareness during cesarean decision-making can prompt clinicians to consider microbial consequences alongside medical indications.

Standardizing postnatal protocols, such as early skin-to-skin contact, delayed bathing, exclusive breastfeeding, and colostrum feeding, can further support microbiome restoration in cesarean-born infants. Strengthening implementation efforts requires local clinical champions, updated pre-service and in-service training, and team-based care models with well-defined roles.

Structural and logistical barriers, such as workforce shortages or limited opportunities for second opinions before surgical births, underscore the need for multidisciplinary coordination and locally adapted guidelines. Additionally, culturally sensitive education and counselling should address maternal preferences for cesarean birth, which may stem from fear, misconceptions, or social pressures. Financial incentives that inadvertently promote unnecessary surgical deliveries should also be reevaluated through collaboration between healthcare providers and policymakers. Finally, documenting and sharing successful implementation models can facilitate broader adoption of microbiome-informed practices across comparable healthcare settings.

## Future Research:

This article synthesizes current global evidence linking mode of delivery to early neonatal microbiome colonization, highlighting key determinants such as vaccination, antibiotic exposure, and nutrition. Microbiomics is a branch of microbiology and systems biology that explores the composition, diversity, and functional role of microbial communities and their genomes [29]. The development of this field began around three decades ago, during the era of the Human Genome Project and the initiation of the Human Microbiome Project. If we think in a genetic perspective, the human genome lacks 16S rRNA V3 or V4 region, which is present in microbial cells in prokaryotic ribosomes (bacteria and archaea); researchers are actively targeting this region to amplify and identify microbial strains, thereby understanding their functions. A study by Linda Wampach et al. analysed microbial differences in neonates by delivery mode using 16S rRNA-based advanced sequencing tools [30]. They found that vaginally delivered (VD) infants showed higher expression of immune-related microbial genes. Lipopolysaccharide from early stool samples of Vaginal Delivery neonates triggered increased production of TNF- $\alpha$  and IL-18 in immune cells and plasma. In contrast, caesarean section delivery (CSD) disrupted maternal microbial transmission, reducing functional microbial traits and early immune stimulation. Another study used Shotgun metagenomic sequencing of stool samples from 98 mothers and their neonates revealed significant differences in infant gut microbiota based on delivery mode. C-section-delivered infants showed early enrichment of skin, oral, and environmental microbes such as *Staphylococcus*, *Haemophilus*, *Enterobacter*, and *Veillonella*, while vaginally delivered infants had higher abundances of gut-associated genera like *Bacteroides*, *Bifidobacterium*, *Parabacteroides*, and *Escherichia/Shigella*. Temporal sampling differences partly explained variations in *Escherichia/Shigella* abundance. Although microbial differences between delivery modes diminished by 4 and 12 months, C-section infants maintained greater microbiota heterogeneity and reduced prevalence of key *Bacteroides* species [31]. In this context, a study by Garcia Mantrana et al. [32] examined the specific relationship between maternal diet during pregnancy and the composition of both maternal and neonatal gut microbiota, employing 16S rRNA gene sequencing. This study revealed that particular clusters of gut microbiota in mothers and their offspring were associated with dietary elements like fibre, lipids, and proteins. Studies examining the function of vitamin D during pregnancy have produced a sizable body of evidence. Using data from the same group of the Vitamin D Antenatal Asthma Reduction Trial (VDAART), it was found that a higher alpha diversity in the gut microbiota of newborns was linked to prenatal dietary practices categorized as "healthy", characterized by a high intake of vegetables and a low intake of processed meats and deep-fried foods [33]. Nevertheless, region-specific population studies that integrate gene sequencing approaches could play a pivotal role in shaping future vaccines specifically reformulated for C-section infants, representing a major step toward equitable and globally effective immunization strategies. In implication with antibiotics and diet, leveraging the microbial genetic makeup in a standardized manner could maximize the benefits for cesarean infants worldwide. For instance, probiotic supplementation has shown potential to restore microbial and immune balance. A pilot study demonstrated that infant formula containing a low dose of *Bifidobacterium lactis* CNCM I-3446 supported immune and gut functions in C-section-delivered infants, producing outcomes broadly similar to those of breastfed infant [34]. Similarly, emerging evidence from a scoping review suggests that vaginal seeding exposing C-section newborns to maternal vaginal microbiota can partially restore early microbial colonization patterns, although standardized safety protocols and larger clinical trials are still required before implementation [35]. In addition, sustainable technical investment is crucial for developing next-generation genetic tools that can enhance recovery outcomes in clinical practice and drive personalised healthcare innovations across the biopharmaceutical and nutrition sectors. To ensure the responsible application of both clinical and community-based microbiome interventions, policymakers should emphasise strategies that uphold the principles of equity, ethics, and public health integrity. Moreover, robust community participation frameworks can strengthen this approach by ensuring that societal values and cultural contexts are meaningfully incorporated into microbiome-informed health programs and policy development.

## Conclusion

The mode of birth has a vital and greater impact on the composition and function of the infant microbiome, influencing subsequent health where cesarean deliveries are increasing alongside challenges like unnecessary death, malnutrition, and infectious disease burden, integrating microbiome-aware practices into pregnant mothers and newborn care is both timely and necessary. Evidence-based protocol, influence on the field of precision vaccinology, antenatal education, responsible antibiotic use, early breastfeeding support, Nutrition alteration, and policy frameworks, can help to reduce the unexpected health effects of surgical births. Strengthening health systems to support these interventions and investing in context-specific implementation research will be essential to improving neonatal outcomes globally.

## References

1. Sender R, Fuchs S, Milo R. Revised Estimates for the Number of Human and Bacteria Cells in the Body. *PLoS Biol.* 2016 Aug 19;14(8):e1002533.
2. McDonald D, Hyde E, Debelius JW, Morton JT, Gonzalez A, Ackermann G, et al. American Gut: an Open Platform for Citizen Science Microbiome Research. *mSystems.* 2018 Jun 26;3(3).
3. Leonard JM, Toro D Del. Defining the Microbiome Components (Bacteria, Viruses, Fungi) and Microbiome Geodiversity. *Surg Infect (Larchmt).* 2023 Apr 1;24(3):208–12.
4. WHO publishes surgical sub-group membership for caesarean section recommendations [Internet]. [cited 2025 Jul 14]. Available from: <https://www.who.int/news/item/13-05-2025-who-publishes-surgical-sub-group-membership-for-caesarean-section-recommendations>
5. Rinne M, Kalliomaki M, Arvilommi H, Salminen S, Isolauri E. Effect of Probiotics and Breastfeeding on the Bifidobacterium and Lactobacillus/Enterococcus Microbiota and Humoral Immune Responses. *J Pediatr.* 2005 Aug;147(2):186–91.
6. Korpela K, Salonen A, Saxen H, Nikkonen A, Peltola V, Jaakkola T, et al. Antibiotics in early life associate with specific gut microbiota signatures in a prospective longitudinal infant cohort. *Pediatr Res.* 2020 Sep 18;88(3):438–43.
7. Zimmermann P, Curtis N. The influence of probiotics on vaccine responses – A systematic review. *Vaccine.* 2018 Jan;36(2):207–13.
8. WHO publishes surgical sub-group membership for caesarean section recommendations [Internet]. [cited 2025 Aug 7]. Available from: <https://www.who.int/news/item/13-05-2025-who-publishes-surgical-sub-group-membership-for-caesarean-section-recommendations>
9. Smith GCS, Cordeaux Y, White IR, Pasupathy D, Missfelder-Lobos H, Pell JP, et al. The Effect of Delaying Childbirth on Primary Cesarean Section Rates. *PLoS Med.* 2008 Jul 1;5(7):e144.
10. Lin HC, Xirasagar S. Institutional Factors in Cesarean Delivery Rates: Policy and Research Implications. *Obstetrics & Gynecology.* 2004 Jan;103(1):128–36.
11. Trends in maternal mortality 2000 to 2020: estimates by WHO, UNICEF, UNFPA, World Bank Group and UNDESA/Population Division [Internet]. [cited 2025 Jul 25]. Available from: <https://www.who.int/publications/i/item/9789240068759>
12. Global strategy on human resources for health: Workforce 2030.
13. WHO recommendations non-clinical interventions to reduce unnecessary caesarean sections.
14. Sobhy S, Arroyo-Manzano D, Murugesu N, Karthikeyan G, Kumar V, Kaur I, et al. Maternal and perinatal mortality and complications associated with caesarean section in low-income and middle-income countries: a systematic review and meta-analysis. *The Lancet.* 2019 May;393(10184):1973–82.
15. Ciabattini A, Olivieri R, Lazzeri E, Medaglini D. Role of the Microbiota in the Modulation of Vaccine Immune Responses. *Front Microbiol.* 2019 Jul 3;10.
16. Traa BS, Walker CLF, Munos M, Black RE. Antibiotics for the treatment of dysentery in children. *Int J Epidemiol.* 2010 Apr 1;39(Supplement 1):i70–4.
17. Harris V, Ali A, Fuentes S, Korpela K, Kazi M, Tate J, et al. Rotavirus vaccine response correlates with the infant gut microbiota composition in Pakistan. *Gut Microbes.* 2018 Mar 4;9(2):93–101.

18. Machiavelli A, Duarte RTD, Pires MM de S, Zárata-Bladés CR, Pinto AR. The impact of in utero HIV exposure on gut microbiota, inflammation, and microbial translocation. *Gut Microbes*. 2019 Sep 3;10(5):599–614.
19. Taniya MA, Chung HJ, Al Mamun A, Alam S, Aziz MdA, Emon NU, et al. Role of Gut Microbiome in Autism Spectrum Disorder and Its Therapeutic Regulation. *Front Cell Infect Microbiol*. 2022 Jul 22;12.
20. Breastfeeding [Internet]. [cited 2025 Aug 2]. Available from: [https://www.who.int/health-topics/breastfeeding#tab=tab\\_1](https://www.who.int/health-topics/breastfeeding#tab=tab_1)
21. Holscher HD, Czerkies LA, Cekola P, Litov R, Benbow M, Santema S, et al. *Bifidobacterium lactis* Bb12 Enhances Intestinal Antibody Response in Formula-Fed Infants. *Journal of Parenteral and Enteral Nutrition*. 2012 Jan 11;36(1S).
22. Al Rubaye H, Adamson CC, Jadavji NM. The role of maternal diet on offspring gut microbiota development: A review. *J Neurosci Res*. 2021 Jan 28;99(1):284–93.
23. Catassi G, Aloï M, Giorgio V, Gasbarrini A, Cammarota G, Ianiro G. The Role of Diet and Nutritional Interventions for the Infant Gut Microbiome. *Nutrients*. 2024 Jan 30;16(3):400.
24. Bin-Nun A, Kassirer Y, Jarallah Y, Barg M, Mimouni FB, Hammerman C, et al. Early breast expression for very low birth infants admitted to neonatal intensive care unit: the challenges of cesarean deliveries. *The Journal of Maternal-Fetal & Neonatal Medicine*. 2022 Nov 30;35(25):8249–56.
25. Kusel MMH, De Klerk N, Holt PG, Sly PD. Antibiotic use in the first year of life and risk of atopic disease in early childhood. *Clinical & Experimental Allergy*. 2008 Dec 19;38(12):1921–8.
26. Yamamoto-Hanada K, Yang L, Narita M, Saito H, Ohya Y. Influence of antibiotic use in early childhood on asthma and allergic diseases at age 5. *Annals of Allergy, Asthma & Immunology*. 2017 Jul;119(1):54–8.
27. Kronman MP, Zaoutis TE, Haynes K, Feng R, Coffin SE. Antibiotic Exposure and IBD Development Among Children: A Population-Based Cohort Study. *Pediatrics*. 2012 Oct 1;130(4):e794–803.
28. Huda MN, Lewis Z, Kalanetra KM, Rashid M, Ahmad SM, Raqib R, et al. Stool Microbiota and Vaccine Responses of Infants. *Pediatrics*. 2014 Aug 1;134(2):e362–72.
29. Miyashita H, Kato S, Sicklick JK. Precision clinical genomics and single subject studies of multi-omics data. In: *Comprehensive Precision Medicine*. Elsevier; 2024. p. 41–56.
30. Wampach L, Heintz-Buschart A, Fritz J V., Ramiro-Garcia J, Habier J, Herold M, et al. Birth mode is associated with earliest strain-conferred gut microbiome functions and immunostimulatory potential. *Nat Commun*. 2018 Nov 30;9(1):5091.
31. Bäckhed F, Roswall J, Peng Y, Feng Q, Jia H, Kovatcheva-Datchary P, et al. Dynamics and Stabilization of the Human Gut Microbiome during the First Year of Life. *Cell Host Microbe*. 2015 May;17(5):690–703.
32. García-Mantrana I, Selma-Royo M, González S, Parra-Llorca A, Martínez-Costa C, Collado MC. Distinct maternal microbiota clusters are associated with diet during pregnancy: impact on neonatal microbiota and infant growth during the first 18 months of life. *Gut Microbes*. 2020 Jul 3;11(4):962–78.
33. Litonjua AA, Lange NE, Carey VJ, Brown S, Laranjo N, Harshfield BJ, et al. The Vitamin D Antenatal Asthma Reduction Trial (VDAART): Rationale, design, and methods of a randomized, controlled trial of vitamin D supplementation in pregnancy for the primary prevention of asthma and allergies in children. *Contemp Clin Trials*. 2014 May;38(1):37–50.
34. Baglatzi L, Gavrili S, Stamouli K, Zachaki S, Favre L, Pecquet S, et al. Effect of Infant Formula Containing a Low Dose of the Probiotic *Bifidobacterium lactis* CNCM I-3446 on Immune and Gut Functions in C-Section Delivered Babies: A Pilot Study. *Clin Med Insights Pediatr*. 2016 Jan 13;10.
35. LaPoint P, Banks K, Bacorn M, Prasad R, Romero-Soto HN, Namasivayam S, et al. Can Vaginal Seeding at Birth Improve Health Outcomes of Cesarean Section-Delivered Infants? A Scoping Review. *Microorganisms*. 2025 May 28;13(6):1236.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.