

Impact of postbiotics on inflammatory markers in high risk pregnancies

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<https://doi.org/10.5281/zenodo.16885230>

Article Received: 06-July-2025, Revised: 26-July-2025, Accepted: 16-August-2025

ABSTRACT:

High-risk pregnancies tend to have increased inflammatory responses, which may lead to poor maternal and neonatal outcomes. Postbiotics, non-viable microbial products with bioactivity, have been identified as an exciting intervention for immune function regulation and anti-inflammation. The qualitative study examines the effect of postbiotics on inflammatory markers during high-risk pregnancies, with the secondary data being retrieved from 10 peer-reviewed journals and obtained through the PRISMA sequence. Thematic analysis is to be used to organise results on the impact of postbiotic interventions on maternal and fetal inflammatory responses, especially in preeclampsia and gestational diabetes. This study seeks to summarise the available evidence, describe principal benign mechanisms of action, and determine areas of research deserts. The results will allow the in-depth characterisation of the potential of postbiotics as a safe and effective supplementary treatment to control inflammation status, propose a non-pharmaceutical alternative to support better pregnancy outcomes, and mitigate related risks.

Keywords: *Postbiotics, Inflammatory Markers, High-Risk Pregnancy, Maternal Health, Prenatal Care, Immune Modulation, Pregnancy Outcome*

1. INTRODUCTION:

1.1 Background and Context:

High-risk pregnancies are known to be an issue of global health concern; they are defined as pregnancies that have or develop conditions that cause risks to maternal and fetal health. Conditions such as preeclampsia, gestational diabetes mellitus (GDM), and intrauterine growth restriction (IUGR) tend to be similar to chronic, low-grade inflammation. Associated with this are boosted levels of inflammatory factors such as C-reactive protein (CRP) and various cytokines (such as IL-6, TNF- α), which can add to endothelial dysfunction, insulin resistance, and the pathology of the placenta (Xuan Nguyen et al. 2023). The microbiome of the gut has proven to be a major

regulator of systemic inflammation, and a fair amount of data has established that a dysbiotic state can trigger an augmentation of inflammatory processes. The recent focus in the study has changed to using probiotics, prebiotics, and, in the new turn, postbiotics to regulate the gut microbiome, its pro-inflammatory effects. The problem is that the reduction of inflammation using stimulation with some live microorganism also implies the danger of having these microorganisms active in our organism; postbiotics, which include dead cells of the microorganism and their remains and metabolites, provide a more stable, safe, perhaps more specific solution to the issue of inflammation reduction.

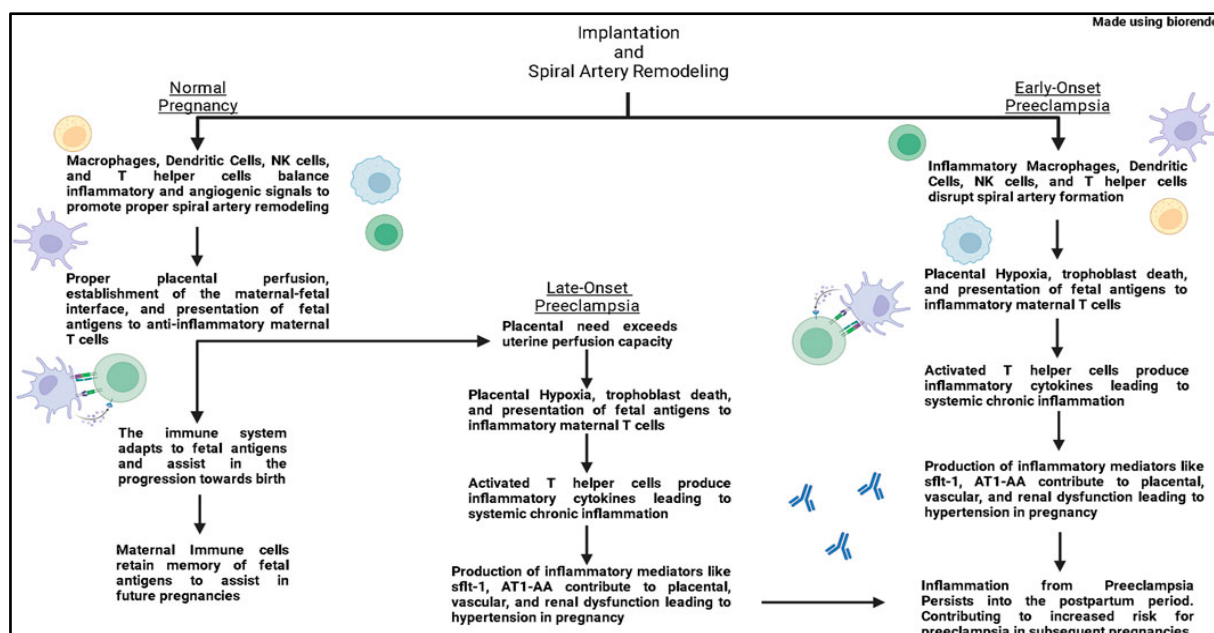


Figure 1: Immune Dysregulation and Inflammation in Preeclampsia
(Source: Herrock, Deer & LaMarca, 2023)

1.2 Problem Statement:

It has been acknowledged that systemic inflammation is associated with discouraging results in the pregnancy of the high-risk population; qualitative data have yet to be consolidated on the domains and effectiveness of postbiotics in addressing these inflammatory pathways. Although some individual studies are available, there is no comprehensive, systematic synthesis of the qualitative data, as is available in peer-reviewed studies. Such a lack of understanding poses challenges for healthcare providers to fully comprehend the therapeutic potential of postbiotics, thereby inhibiting the development of safe and effective adjunct therapies. The issue is that the situation with the existing evidence was fragmented.

1.3 Aim and Objectives:

Aim:

This research would mainly intend to conduct a qualitative review of the available literature in a bid to establish the effects of postbiotics on inflammatory markers in high-risk pregnancies.

Objectives:

- To evaluate the effect of postbiotic supplementation on key inflammatory markers
- To assess the association between changes in inflammatory markers and maternal pregnancy outcomes
- To assess the potential role of postbiotics in improving maternal and fetal health outcomes

by modulating inflammatory responses during high-risk pregnancies

1.4 Purpose of this Research:

This study is conducted with the aim of ensuring a synthesised evidence-based knowledge of how postbiotics help in alleviating inflammation in high-risk pregnancies. The combination of a qualitative strategy, high-quality selection, and significant evidence of a rigorous selection process will collect fragmented information into an integrated story, which will support the clinical practice and future research. The study will be a key reference point to clinicians, researchers, and policymakers.

2. LITERATURE REVIEW:

2.1 High-Risk Pregnancy and Inflammation:

A state of chronic and low-grade inflammation is commonly experienced in high-risk pregnancies. Such inflammatory reactions are not only a symptom but also an important pathogenic mechanism in the case of preeclampsia and gestational diabetes mellitus (GDM). Large-scale endothelial dysfunction is a hallmark of preeclampsia, which is amplified through a pro-inflammatory cascade that entails an elevated cytokine such as IL-6 and TNF- α . On the same note, GDM is characterised by insulin resistance that is directly connected with systemic inflammation (Ray et al. 2024). Higher inflammatory markers are frequent biomarkers in these conditions, and their level may be correlated with the severity of the outcome and poor fetal and maternal outcomes.

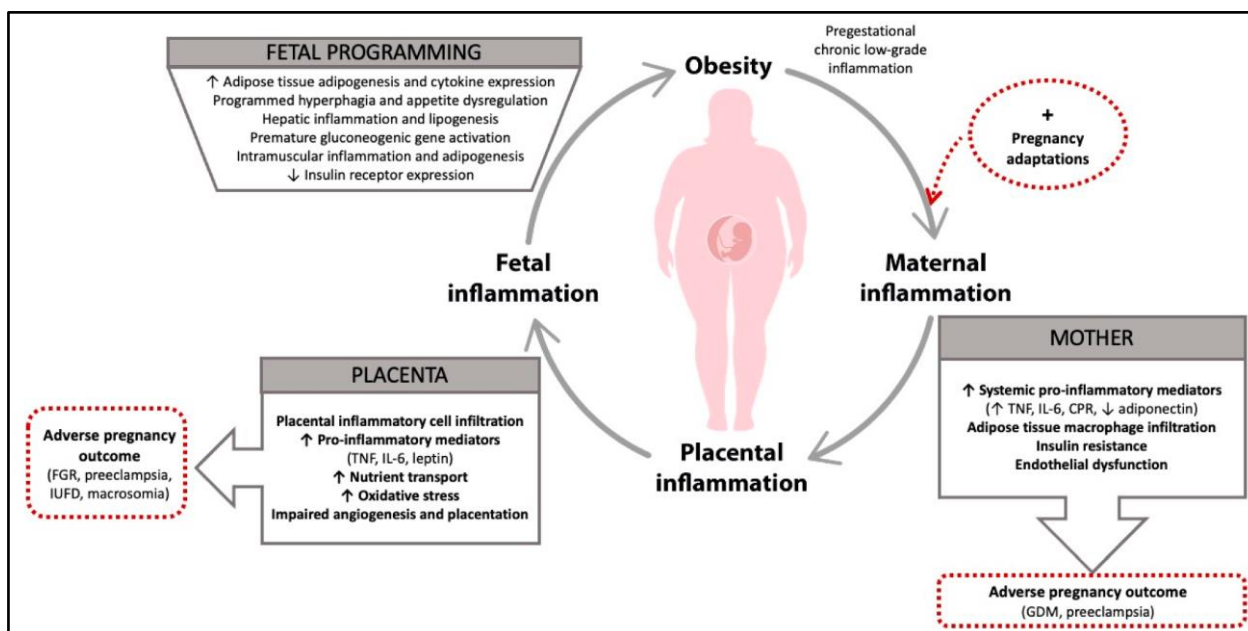


Figure 2: Transmitted Across Generations, Metabolic Diseases Via Maternal Low-Grade Chronic Inflammation (Source: Parisi et al. 2021)

2.2 Gut Microbiome in Pregnancy:

The microbiome of the gut changes profoundly during pregnancy and is critical in the metabolic and immune modulation of the mother. A healthy, balanced microbiome, called eubiosis, allows healthy immune and nutrient acquisition functions to help sustain healthy pregnancies. On the other hand, an imbalance

in the microbial community, called dysbiosis, has been attributed to an induced systemic inflammation (de Oliveira et al. 2021). In such a dysbiotic state, the integrity of the gut barrier may be breached, and products derived from the microbiome may enter the blood circulation, thus initiating a pro-inflammatory process.

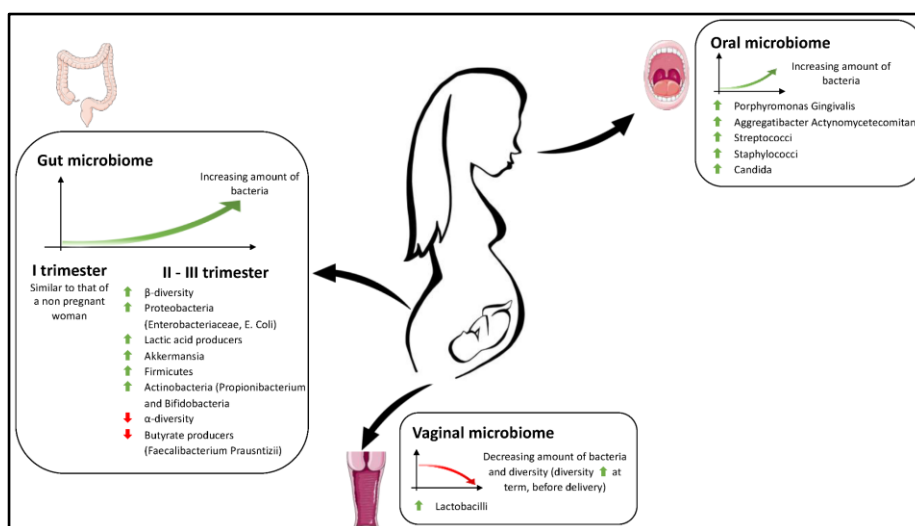


Figure 3: Changes in Maternal Microbiome Physiology During Pregnancy (Source: Giannella et al. 2023)

2.3 Probiotics, Prebiotics, and Postbiotics:

Definition and Difference:

- Probiotics are live microorganisms that exert health effects upon the application of a sufficient quantity (Latif et al. 2023).
- Prebiotics are non-food elements that stimulate the germination of advantageous microorganisms (Jadhav et al. 2023).

- Postbiotics are bioactive compounds generated during the fermentation of microorganisms such as cell wall materials, enzymes, peptides, and SCFAs, but lack viable bacteria (Scott, De Paepe & Van de Wiele, 2022).

Mechanisms of action of Postbiotics:

- Immune modulation: balancing of T cells and cytokines.
- Strengthening the intestinal epithelial particle barrier operations.
- Anti-inflammatory signalling-SCFAs suppress NF- κ B activation and suppress pro-inflammatory cytokine transcription.

- Glucose and lipid metabolic control (Fang et al. 2025).

Uses and advantages of Probiotics:

- Stability: Stable to storage and gastric acid.
- Safety: No possibility of translocation of live bacteria (Moradi et al. 2020).
- Standardisation: Bioactive composition.

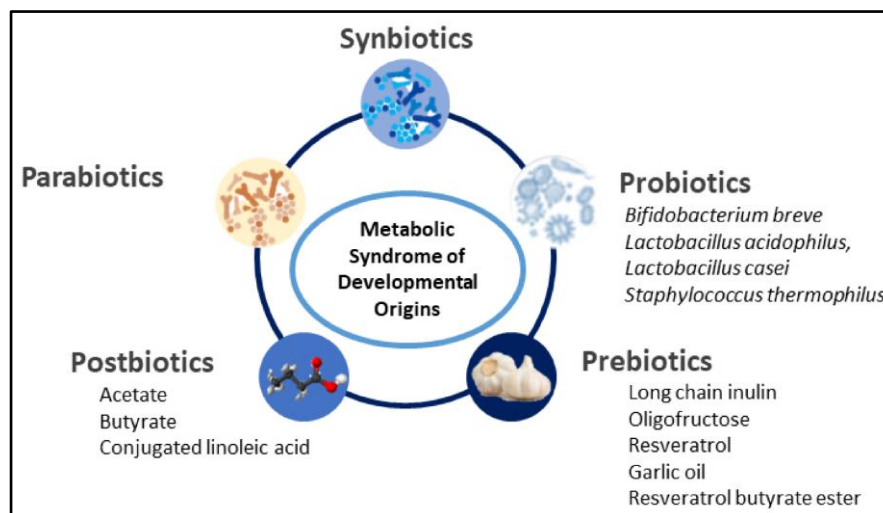


Figure 4: Maternal Supplementation of Probiotics, Prebiotics, and Postbiotics
(Source: Huang, Tain & Hsu, 2022)

2.4 Evidence of Postbiotics in Inflammation:

Postbiotics have been found to reduce IL-6, TNF- α , and CRP and raise IL-10 and TGF- β , according to studies. In prepartum settings, they could enhance endothelial performance, reduce oxidative stress, and boost the perfusion of the placenta (Saha, Samadder & Nandi, 2023). Non-pregnant incidence figures prove their safety based on clinical trials; however, anyone carrying a pregnancy will have limited information. Postbiotic supplementation in animals lowers placental inflammation and increases fetal growth.

2.5 Research Gap:

Although some literature exists about the overall anti-inflammatory effects of postbiotics, no truly comprehensive qualitative review exists yet on the potential influence of the tested on inflammatory markers in at-risk pregnancies. The existing literature remains scattered, and a systematic combination is required in order to integrate the discovered findings and locate evident treatment potentials.

3. METHODOLOGY:

The *interpretivist philosophy* of this research uses an *inductive* and *exploratory research design* (Casula,

Rangarajan & Shields, 2021), to explain how postbiotics affect the inflammatory markers of high-risk pregnancies.

The *PRISMA framework* was used to collect *secondary qualitative data* from 10 peer-reviewed journals that have been systematically identified, thus ensuring the relevance to the postbiotics, inflammation, and conditions of high-risk pregnancy. The criteria of inclusion and exclusion guaranteed the selection of the studies, with a high methodological quality and strong thematic congruence with the topic of the research.

The *thematic analysis* was used with regard to the chosen studies. Identification of the key concepts, similar patterns were coded and sorted into the generalised themes (Christou, 2022). This approach assisted in the synthesis of qualitative data to further understand the mechanisms and consequences of postbiotic interventions in high-risk pregnancies.

PRISMA Framework

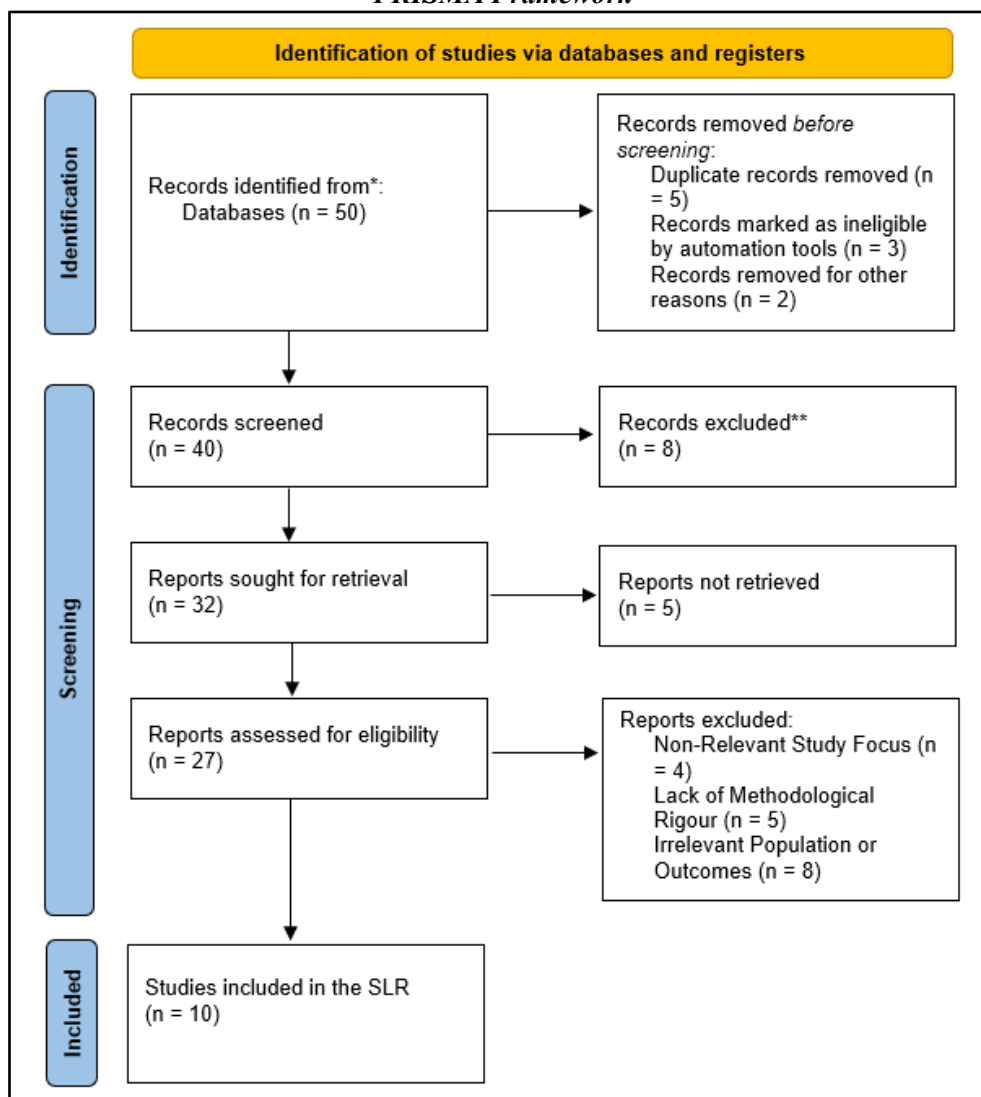


Figure 5: PRISMA Framework
(Source: Self-Developed)

This PRISMA flow diagram describes systematic study selection for the SLR. 10 duplicates or ineligible records have been excluded prior to screening from 50 records initially identified in databases. Following the

screening of 40 records and the retrieval of 32 reports, 27 have been evaluated for eligibility. After exclusion on grounds of relevance, methodological rigour, and population outcomes, 10 studies have been ultimately included in the review.

4. RESULTS:

4.1 Systematic Literature Review Table

Author(s) , Year	Title	Methodology	Type of High-Risk Pregnancy	Postbiotic Intervention (Type, Dose, Duration)	Comparator / Control	Inflammatory Markers Measured	Key Findings	Limitations
Huang, Tain & Hsu, (2022)	Maternalsupplementation of probiotics, prebiotics or postbiotics to prevent offspring metabolic syndrome: the gap between preclinical results and clinical translation	Literature Review	General	SCFAs (Butyrate)	Animal model	IL-6, TNF- α	Animal studies have found promise in the use of postbiotic metabolites such as butyrate as a preventive of inflammation and metabolic problems	Limited clinical data
Paul et al. (2022)	The promising	Systematic Literature Review	Type 2 Diabetes	General Postbiotics	-	CRP, TNF- α	There is also a parallel of GDM with	Lack of focus on GDM

	role of micro biome therap y on bioma rkers of inflam mation and oxidati ve stress in type 2 diabet es: a system atic and narrati ve review						T2D: microbiome-based therapies, postbiotics included, also succeed in lowering inflammatory markers in T2D	
Akanda & Mehjabin , (2024)	Potent ial Role of Probio tics, Prebio tics, and Synbi otics in Manag ement of	SLR & Meta analysis	General	Probiotics, Prebiotics, and Synbiotics	-	Biomarkers, immunological markers	Probiotics have beneficial effects on metabolic disorders	Lack of specification of inflammatory markers

	Metabolic Syndrome and Chronic Metabolic Disease							
Lu et al. (2024)	Maternal gut microbiota in the health of mothers and offspring: From the perspective of immunology	SLR	GDM, HDP	SCFAs, Butyrate	-	IL-1beta, IL-6, and TGFbeta	Gut microbiota and maternal gut health	Maternal-fetal interface data are limited
Zdybel et al. (2025)	Postbiotics Formulation and Therapeutic Effect in Inflammation	SLR	General	SCFA, <i>Lactobacillus</i> , <i>Bifidobacterium</i>	Mice model	IL-6, TNF-α	Therapeutic effect on postbiotics formulation	Risk of bias requires cautious interpretation

	mation : A Syste matic Revie w							
Mills et al. (2025)	Mater nal gut micro biome interve ntions to impro ve matern al and perinat al health outco mes: Target produc t profile expert consen sus and pipelin e analys is	Mixed-method	Maternal EED	Probiotics and LC- PUFA, Microbial interventions	Human model	-	Pipeline analysis on maternal gut health	Availability of limited prevalence data
Morales-Ferré et al. (2021)	Effect s of a postbi otic and	Mixed-method	General	SCFA, scGOS, lcFOS	Rat model	-	Examine the effects of the supplementati on with a postbiotic	Perform a lack of comparison data analysis

	prebio tic mixtur e on suckli ng rats’ micro biota and immu nity							
Miller et al. (2024)	Effect s of Dietar y Qualit y on Vagina l Micro biome Comp osition Throu ghout Pregna ncy in a Multi- Ethnic Cohort	Cohort Study	General	Probiotics	Human model	-	Dietary quality effects on maternal gut health	Limited data about the vaginal microbiome during pregnancy and reproduction
Mogoş et al. (2025)	Intesti nal Micro biota in Early Life:	SLR	General	SCFAs	-	IL-10	Dysbiosis treatment approaches regarding the role	Limited data survey

	Latest Findings Regarding the Role of Probiotics as a Treatment Approach for Dysbiosis							
Doroftei et al. (2022)	An updated narrative mini-review on the microbiota changes in antenatal and postpartum depression	Mini Literature Review	General	SCFA	-	Inflammatory markers	AND and PPD influenced the gut microbes	Lack of a survey model

4.2 Thematic Analysis:

4.2.1 The Effect of Postbiotic Supplementation on Key Inflammatory Markers:

According to Paul et al. (2022), postbiotic metabolites, particularly SCFA, are consistently linked with pro-inflammatory cytokine (IL-6, TNF- α) and CRP reductions. With the growth of anti-inflammatory regulators (IL-10, Treg induction) through GPCR signalling and HDAC inhibition, across reviews (Mogoş et al. 2025). There is little human interventional data in pregnancy.

4.2.2 The Association between Changes in Inflammatory Markers and Maternal Pregnancy Outcomes:

Reduced pro-inflammatory factors were associated with more favourable endothelial function, blood pressure, and glycaemic profiles in observational studies. The effects of postprandial elevation of SCFA-rich dietary patterns are associated with a lower risk of PE and GDM, but well-designed trials are needed to identify causality (Morales-Ferré et al. 2021).

4.2.3 The Role of Postbiotics in Improving Maternal and Fetal Health Outcomes by Modulating Inflammatory Responses During High-Risk Pregnancies:

According to Lu et al. (2024), postbiotics can prevent placental inflammation, TGF-beta lowers the risk of preterm birth, and improves fetal growth by modulating immune balance and enhancing the barrier function. The evidence in current literature is encouraging in a mechanistic sense, but still requires pregnancy-specific RCTs to support clinical utility and regimens.

4.3 DISCUSSION:

This SLR of recent literature has high levels of mechanistic support toward postbiotics, particularly SCFAs, in reducing endothelial effects and the mechanisms controlling metabolism in lowering systemic and placental inflammation. Most of the evidence, however, is comprised of reviews, animal models, or observational human studies; there are few pregnancy-specific interventional trials of specific products of defined postbiotics.

5. CONCLUSION AND RECOMMENDATIONS:

5.1 Conclusion:

This study emphasised the possibilities of postbiotics in regulating the inflammatory markers during high-risk pregnancies. It is indicated that there are advantages associated with lowering CRP, IL-6, and TNF- α to enhance maternal and fetal outcomes. Nevertheless, the small number of clinical studies

presents a necessity for further studies that are required to prove efficacy and safety.

5.2 Recommendations:

• Higher Usage of Postbiotics

According to Goley & Garg (2025), clinical professionals are advised to take note of the growing postbiotics evidence as an adjunctive treatment in salvaging high-risk pregnancies.

• Randomised Controlled Trials

Well-designed randomised controlled trials to find out best dosages, safety profile, and long-term effects should be a priority among policymakers and researchers on the one hand; integrating multidisciplinary strategies to maternal care that address inflammation-related pregnancy complications on the other.

5.3 Future Outlook:

Further research needs to focus on the molecular aspects of postbiotic effects during pregnancy, different populations, and combination treatment with probiotics/prebiotics. Further developments in microbiome research and individualised food may improve personalised interventions (Matusheski et al. 2021), providing more secure and effective methods of curing inflammation in the maternal settings with high risks.

REFERENCES:

1. Akanda, M. K. M., & Mehjabin, S. (2024). Potential Role of Probiotics, Prebiotics, and Synbiotics in Management of Metabolic Syndrome and Chronic Metabolic Disease. In *Synbiotics in Metabolic Disorders* (pp. 39-54). CRC Press. <https://www.taylorfrancis.com/chapters/edit/10.1201/9781032702438-3/potential-role-probiotics-prebiotics-synbiotics-management-metabolic-syndrome-chronic-metabolic-disease-md-khokon-miah-akanda-sanzia-mehjabin>
2. Casula, M., Rangarajan, N., & Shields, P. (2021). The potential of working hypotheses for deductive exploratory research. *Quality & Quantity*, 55(5), 1703-1725. <https://link.springer.com/article/10.1007/s11135-020-01072-9>
3. Christou, P. A. (2022). How to use thematic analysis in qualitative research. *Journal of Qualitative Research in Tourism*, 3(2), 79-95. <https://www.elgaronline.com/view/journals/jqr/3/2/article-p79.xml>
4. de Oliveira, G. L. V., Cardoso, C. R. D. B., Taneja, V., & Fasano, A. (2021). Intestinal

- dysbiosis in inflammatory diseases. *Frontiers in immunology*, 12, 727485. <https://www.frontiersin.org/journals/immunology/articles/10.3389/fimmu.2021.727485/full>
5. Doroftei, B., Ilie, O. D., Diaconu, R., Hutanu, D., Stoian, I., & Ilea, C. (2022). An updated narrative mini-review on the microbiota changes in antenatal and post-partum depression. *Diagnostics*, 12(7), 1576. <https://www.mdpi.com/2075-4418/12/7/1576>
 6. Fang, H., Rodrigues e-Lacerda, R., Barra, N. G., Kukje Zada, D., Robin, N., Mehra, A., & Schertzer, J. D. (2025). Postbiotic impact on host metabolism and immunity provides therapeutic potential in metabolic disease. *Endocrine Reviews*, 46(1), 60-79. <https://journals.aai.org/edrv/article/46/1/60/7749916>
 7. Giannella, L., Grelloni, C., Quintili, D., Fiorelli, A., Montironi, R., Alia, S., ... & Ciavattini, A. (2023). Microbiome changes in pregnancy disorders. *Antioxidants*, 12(2), 463. <https://www.mdpi.com/2076-3921/12/2/463>
 8. Goley, R., & Garg, A. P. (2025). Child Health Management using Probiotics. *Journal of International Pediatrics and Child Health*, 1(01-2025). https://www.biotory.org/publisharticles_uploads/Child%20Health%20Management%20using%20Probiotics.pdf
 9. Herrock, O., Deer, E., & LaMarca, B. (2023). Setting a stage: Inflammation during preeclampsia and postpartum. *Frontiers in Physiology*, 14, 1130116. <https://www.frontiersin.org/articles/10.3389/fphys.2023.1130116/full>
 10. Huang, Y. H., Tain, Y. L., & Hsu, C. N. (2022). Maternal supplementation of probiotics, prebiotics or postbiotics to prevent offspring metabolic syndrome: the gap between preclinical results and clinical translation. *International Journal of Molecular Sciences*, 23(17), 10173. <https://www.mdpi.com/1422-0067/23/17/10173>
 11. Jadhav, A., Jagtap, S., Vyavahare, S., Sharbidre, A., & Kunchiraman, B. (2023). Reviewing the potential of probiotics, prebiotics and synbiotics: advancements in treatment of ulcerative colitis. *Frontiers in Cellular and Infection Microbiology*, 13, 1268041. https://www.frontiersin.org/journals/cellular-and-infection-microbiology/articles/10.3389/fcimb.2023.1268041/full?utm_campaign=HI_mejores-suplementos-de-sailberry
 12. Latif, A., Shehzad, A., Niazi, S., Zahid, A., Ashraf, W., Iqbal, M. W., ... & Korma, S. A. (2023). Probiotics: mechanism of action, health benefits and their application in food industries. *Frontiers in microbiology*, 14, 1216674. https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2023.1216674/full?utm_campaign=CHD_gi-advantage-review
 13. Lu, X., Shi, Z., Jiang, L., & Zhang, S. (2024). Maternal gut microbiota in the health of mothers and offspring: From the perspective of immunology. *Frontiers in Immunology*, 15, 1362784. <https://www.frontiersin.org/journals/immunology/articles/10.3389/fimmu.2024.1362784/full>
 14. Matusheski, N. V., Caffrey, A., Christensen, L., Mezgec, S., Surendran, S., Hjorth, M. F., ... & Péter, S. (2021). Diets, nutrients, genes and the microbiome: recent advances in personalised nutrition. *British Journal of Nutrition*, 126(10), 1489-1497. <https://www.cambridge.org/core/journals/british-journal-of-nutrition/article/diets-nutrients-genes-and-the-microbiome-recent-advances-in-personalised-nutrition/8D623DF612071485B4AD712F4D59EA33>
 15. Miller, C., Morikawa, K., Benny, P., Riel, J., Fialkowski, M. K., Qin, Y., ... & Lee, M. J. (2024). Effects of Dietary Quality on Vaginal Microbiome Composition Throughout Pregnancy in a Multi-Ethnic Cohort. *Nutrients*, 16(19), 3405. <https://www.mdpi.com/2072-6643/16/19/3405>
 16. Mills, K., Tan, J., Guneratne, T., Keir, L., Goldstein, M., Ventola, C., ... & McDougall, A. R. (2025). Maternal gut microbiome interventions to improve maternal and perinatal health outcomes: Target product profile expert consensus and pipeline analysis. *PloS one*, 20(7), e0321543. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0321543>
 17. Mogoş, G. F. R., Manciulea, M., Enache, R. M., Pavelescu, L. A., Popescu, O. A., Cretoiu, S. M., & Marinescu, I. (2025). Intestinal Microbiota in Early Life: Latest Findings Regarding the Role of Probiotics as a Treatment Approach for Dysbiosis. *Nutrients*, 17(13), 2071. <https://www.mdpi.com/2072-6643/17/13/2071>

18. Moradi, M., Kousheh, S. A., Almasi, H., Alizadeh, A., Guimarães, J. T., Yilmaz, N., & Lotfi, A. (2020). Postbiotics produced by lactic acid bacteria: The next frontier in food safety. *Comprehensive reviews in food science and food safety*, 19(6), 3390-3415. <https://ift.onlinelibrary.wiley.com/doi/abs/10.1111/1541-4337.12613>
19. Morales-Ferré, C., Azagra-Boronat, I., Massot-Cladera, M., Tims, S., Knipping, K., Garssen, J., ... & Pérez-Cano, F. J. (2021). Effects of a postbiotic and prebiotic mixture on suckling rats' microbiota and immunity. *Nutrients*, 13(9), 2975. <https://www.mdpi.com/2072-6643/13/9/2975>
20. Parisi, F., Milazzo, R., Savasi, V. M., & Cetin, I. (2021). Maternal low-grade chronic inflammation and intrauterine programming of health and disease. *International journal of molecular sciences*, 22(4), 1732. <https://www.mdpi.com/1422-0067/22/4/1732>
21. Paul, P., Kaul, R., Abdellatif, B., Arabi, M., Upadhyay, R., Saliba, R., ... & Chaari, A. (2022). The promising role of microbiome therapy on biomarkers of inflammation and oxidative stress in type 2 diabetes: a systematic and narrative review. *Frontiers in Nutrition*, 9, 906243. <https://www.frontiersin.org/articles/10.3389/fnut.2022.906243/full>
22. Ray, G. W., Zeng, Q., Kusi, P., Zhang, H., Shao, T., Yang, T., ... & Guo, R. (2024). Genetic and inflammatory factors underlying gestational diabetes mellitus: a review. *Frontiers in endocrinology*, 15, 1399694. <https://www.frontiersin.org/journals/endocrinology/articles/10.3389/fendo.2024.1399694/full>
23. Saha, A., Samadder, A., & Nandi, S. (2023). Stem cell therapy in combination with naturopathy: Current progressive management of diabetes and associated complications. *Current Topics in Medicinal Chemistry*, 23(8), 649-689. <https://www.benthamdirect.com/content/journals/ctmc/10.2174/1568026623666221201150933>
24. Scott, E., De Paepe, K., & Van de Wiele, T. (2022). Postbiotics and their health modulatory biomolecules. *Biomolecules*, 12(11), 1640. <https://www.mdpi.com/2218-273X/12/11/1640>
25. Xuan Nguyen, K., Bui Minh, T., Dinh, H. T., Viet Tran, T., Dinh Le, T., Phi Thi Nguyen, N., ... & Tien Nguyen, S. (2023). Low-grade inflammation in gestational diabetes mellitus and its correlation with maternal insulin resistance and fetal growth indices. *International Journal of General Medicine*, 1429-1436. <https://www.tandfonline.com/doi/abs/10.2147/IJGM.S408856>
26. Zdybel, K., Śliwka, A., Polak-Berecka, M., Polak, P., & Waśko, A. (2025). Postbiotics Formulation and Therapeutic Effect in Inflammation: A Systematic Review. *Nutrients*, 17(13), 2187. <https://www.mdpi.com/2072-6643/17/13/2187>