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Micronutrient supplementation among pregnant women: effects on maternal anemia and neonatal outcomes

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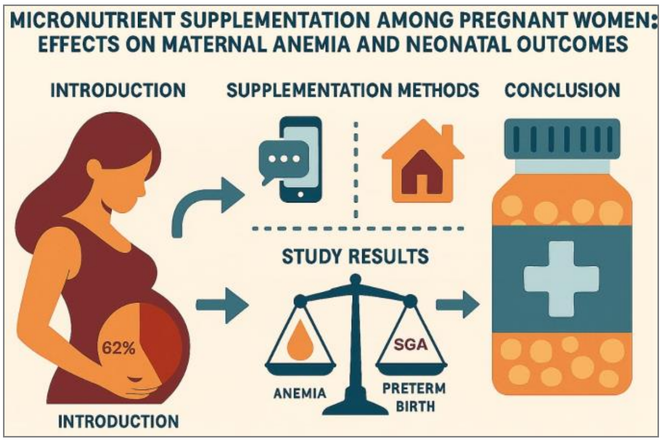
Abstract

Background: Synonymous with low- and middle-income countries (LMICs), micronutrient deficiencies during pregnancy is a serious public health issue. It is estimated that 38% of pregnant women around the world are anaemic and this is mainly due to iron deficiencies but other risks are posed by poor consumption of folate and vitamin B twelve. These shortcomings are a reason of poor maternal and neonatal outcomes, including preterm birth, low birth weight and fetal growth restriction. Multivitamin minerals (MMS) have been an attractive alternative to the conventional iron and folic acid (IFA) program. **Objective:** The purpose of this review is to examine barriers to implementation of supplementation programs, and to examine strategies including simulation frameworks, and real time data analytics, to enhance these interventions. **Methods:** Systematic literature review using scientific databases namely; PubMed, Scopus, and Google Scholar to identify studies targeting clinical subjects published between 2020 and 2025 was conducted. Qualitative thematic analysis approach was used for synthesizing the findings on maternal health, neonatal outcomes, as well as the program implementation challenges. The selected and included studies were based on the PRISMA framework. **Results:** MMS has been found to offer broader benefits than IFA in that it appears to reduce risks for preterm birth, low birth weight, and small-for-gestational-age, with the benefits accumulated when folate is also fortified. Although IFA continues to be an effective measure for tackling the problem of maternal anaemia and reducing neonatal mortality rates, as evidenced by its proven results in a host of observed cases, the nutritional support it provides is not comprehensive enough, unlike its counterpart MMS. The poor adherence, limited accessibility, socioeconomic barriers, and insufficient education were identified to be multiple barriers for implementation. We suggested strategies including SMS reminders, homebased support, and free provision of supplement. Cost benefit analyses also indicate that MMS would be a viable investment for maternal and child health programs. **Conclusions:** It is possible to reduce the possibility of improvement in maternal and neonatal health outcomes in LMICs with micronutrient supplementation, particularly with MMS. However, tailored interventions, better education, use of data driven approaches are what are needed to overcome the implementation barriers. The long term impacts and the best time and way of delivering the optimal gestational nutrition need to be studied or refined to achieve maternal and child health global targets.

Keywords: Micronutrient Supplementation. Maternal Anemia. Neonatal Outcomes. Multiple Micronutrient Supplements (MMS). Iron-Folic Acid (IFA).

Graphical Abstract



Introduction

Prenatal micronutrient deficiencies are one of the most significant global health issues and estimates show that up to 38 percent of pregnant women in low- and middle-income countries (LMICs) experience anemia **[1]**. Maternal undernutrition is a cause of poor pregnancy outcomes in sub-Saharan Africa and South Asia, such as premature birth, birth weight, and neonatal deaths **[2]**. The main causes of anemia are iron deficiency that influences the health of both the woman and the unborn child, putting them at risk of contracting perinatal complications and experiencing delayed development in the long run **[3]**.

The most popular, successful public health measure taken to address them has been the supplementation of micronutrients, most often with iron-folic acid (IFA). Nevertheless, there are new indications that supplements containing multiple micronutrients (MMS) including iron and folate and other vital vitamins and minerals could be more advantageous and have more lasting effects such as birth weight and the number of small-for-gestational-age (SGA) babies **[4]**. However, MMS programs are covered and effective irregularly because of poor adherence, lack of access, and poor implementation plans.

One of the crucial information gaps is related to realistic obstacles to implementation and optimization approaches of MMS interventions required to scale them up in LMICs. The biological benefits of MMS are still well-documented, but overall, there is little systems-level incorporation of data analytics and simulation frameworks to enhance uptake and effects. There are a number of studies which support this gap. They also highlighted how there was no clarity in the operations of incorporating MMS into the antenatal care programs **[5]**. A study emphasized that there were no tools to help decide how to implement the costs in the context of policy development **[6]**. Likewise, another study did not observe the use of specific intervention strategies in any systematic reviews focusing on the problem of maternal nutrition in LMICs **[7]**. All these findings are indicative of the necessity of evidence-based scalable methods to help in getting through the implementation and optimization issues.

Vulnerable populations, such as pregnant women, are seriously affected by micronutrient deficiencies, which are a considerable public health challenge. The physiological demand of maternal body during pregnancy increases substantially and as a result the need for essential vitamins and minerals increase to maintain maternal health as well as protect fetal development **[8]**. Despite the critical importance of adequate micronutrient intake, many pregnant women worldwide experience deficiencies in key nutrients such as iron, folic acid, vitamin D, iodine, and zinc **[9]**. The existence of these deficiencies can cause adverse health outcomes for both the mother and the developing fetus, which emphasize the importance for efficient nutritional intervention. Of these interventions, micronutrient supplementation is one of the most important strategies to fill in such dietary intake gaps and mitigate potential health risks **[10]**. Given the access to nutrient rich foods may be constrained, due to economic, social, and environmental factors, in low- and middle-income countries (LMICs), this is particularly relevant.

Amongst all the consequences of inadequate micronutrient intake during pregnancy, maternal anemia is one of the most prevalent and worrisome problems. Anemia is characterized by a reduction in red blood cells count or Hemoglobin levels and occurs in about 38% of pregnant women worldwide, and up to higher rates in LMICs **[11]**. The leading cause of anemia in pregnancy is iron deficiency but other causes include deficiency in folate, vitamin B12 and vitamin A **[12]**. Maternal anemia has long term implications which extends beyond the immediate health of the mother, increased risk of preterm birth, low birth weight, intrauterine growth restriction and perinatal mortality are associated with it. Additionally, maternal anemia can also impair a mother's ability to endure labour and recovery in the postpartum period and can increase the risk to both the mother and the offspring of complications such as hemorrhage and infections **[13]**. With this, there is therefore need to address anemia by targeted micronutrient supplementation to achieve improved maternal health and also for optimal neonatal outcomes.

The deficiency of micronutrients in pregnant woman has far reaching effects on neonatal health and development besides anemia. For example, NTDs, a type of severe congenital anomaly which can cause lifelong disability, or death, are quite well known to be associated with insufficient intake of folic acid at early stages of pregnancy **[14]**. Iodine deficiency during pregnancy also has adverse effects on fetal brain development, resulting in children impaired at cognition and having lower intellectual capacity **[15]**. Poor fetal growth has been associated with zinc deficiency and vitamin D insufficiency is associated with increased risk of bone or immune dysfunction in newborn. Taken together, these findings reveal the integrated relationship of maternal nutrition with neonatal health, and in particular illustrate the developmental importance of the maternal contribution during gestation for shaping long term developmental trajectories. Therefore, micronutrient supplementation is a strong tool to break the intergenerational cycle of malnutritioned and its allied health burdens.

Over the past decades, many studies have been conducted aiming to evaluate the effectiveness of different micronutrient supplementation strategies for correction of maternal anemia and associated neonatal outcomes **[16]**. Currently, iron and folic supplementation are the backbone of the antenatal care program in all parts of the world; however, there are wide and increasing considerations for the benefits of multiple micronutrient supplements (MMS) that incorporate several significant nutrients form the single formula **[17]**. Although there is evidence that MMS has additional advantages compared to standard regimens of iron-folic acid, this may be especially true in areas where there is more than one deficiency **[18]**. However, many barriers exist for the implementation of supplementation programs in that many individuals don't adhere, it is not accessible and it is not cost effective. There are cultural beliefs, socioeconomic barriers and logistical constraints that complicate the effort to make coverage consistent and equitable. Such complexities need to be understood in order to design scientifically sound and contextually appropriate interventions.

Maternal micronutrient deficiencies have become increasingly important in the global health community as part of the campaigns to reach Sustainable Development Goals (SDGs) with regard to maternal and child health **[19]**. SDG Target 3.1 aspiringly intends to reduce the global maternal mortality ratio to less than 70 per 100,000 live births by 2030 and in a similar vein Target 3.2 aspires to end preventable deaths of newborns and children under five years of age by 2030 **[20]**. To reach these targets, a comprehensive approach will be needed which would include ways to improve access to a balanced nutrition, upgrading infrastructure for health care providers, education, and equality of gender in all areas of life. Within the framework, micronutrient supplementation is a cost effective and scalable intervention with the potential to make a large impact on (mother and infant) morbidity and mortality. Given these benefits, however, they are contingent on strong research, policy informed by that research, and sustained government, international organisation and local community involvement.

There is a vast body of evidence supporting the use of micronutrient supplement during pregnancy, but there are also important knowledge gaps and controversy. For example, it is still not clear when the supplements should be administered, at what dose or what composition without compromising their safety or efficacy in a variety of populations. However, a few studies have reported some concerns about the possibility of its negative impact, for example, that the possibility of overloading with iron may be the cause of oxidative stress or upset to the gastrointestinal tract **[21]**. It may not be justified to supplement universally in settings with low pre-existing rates of deficiency, according to others. Furthermore, micronutrient supplementation and other nutritional interventions including food fortification and dietary diversification seem to interact.

Thus, this study aims to summarise existing evidence of micronutrient supplementation, especially MMS, during pregnancy, potential barriers to the implementation, and assess the potential of novel ways of addressing micronutrient supplementation, including simulation models and real-time data analytics in the enhancement of maternal and neonatal health outcomes. Understanding these uncertainties in how the patterns affect intervention outcomes is necessary to improve current guidelines and apply recommendations specific to given contexts, to optimize the effect of supplementation programs. The research objectives include;

- To determine if micronutrient supplementation can reduce maternal anemia as well as improve neonatal health outcomes.
- To research the barriers and challenges against the implementation of micronutrient supplementation programs among pregnant women in varied setting.
- To evaluate role in solving such optimization challenges to improve maternal and neonatal resilience via simulation frameworks and real time data analytics.

Methodology

Research Design

According to the JAND Author Guidelines for systematic reviews, a systematic literature review was done to determine the effects of micronutrient supplementation on maternal anemia and neonatal outcomes. By doing so it would enable a synthetic approach to synthesizing existing research, and identify patterns, knowledge gaps and trends in the field. The review follows the transparency, the reproducibility, and the methodological rigor as defined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. This way of proceeding makes it possible to conduct a very complete review of existing research, so that there are common patterns that can be found, gaps that can be detected and trends appearing in the field that may be shown. The systematic review synthesizes findings from a number of studies to offer a strong empirical basis for understanding what role micronutrient supplementation has in improving maternal and neonatal health. The findings are compared between methodologies, outcomes and frameworks across studies, identify best practices, and provide some guidance as to where future research can proceed.

Research Approach

A qualitative methodology is taken, in which thematic analysis was used to look at the multiple impacts of micronutrient supplementation. Hereby, results from empirical studies have been adopted to detect recurrent patterns indicating advantages of some micronutrients (e.g., iron, folic acid, vitamin D), implementation hurdles (e.g., adherence, accessibility), and means by which supplementation impacts maternal anemia and neonatal results. Thematic analysis also explains the relationship between supplementation strategies and broader public health outcomes like maternal mortality reduction and child health.

Quality Assessment

Included studies were appraised for methodological quality on the basis of the CASP (Critical Appraisal Skills Programme) checklist for cohort and randomized controlled trials. Each eligible study was evaluated for risk of bias across established domains, by two independent reviewers (Authors A and B), including selection, performance, detection, attrition and reporting biases. Consensus or a third reviewer was consulted to resolve discrepancies. A ranking of each domain as "Low Risk," "Unclear," or "High Risk" was given based on predefined criteria. Appendix A provides a summary table of the quality appraisal results.

Study Selection and Data Extraction

Two investigators (Authors A and B) performed independently all studies selected at all stages and data extraction. Disagreements were discussed and (if need be) settled by involving a third investigator. Inclusion criteria were maternal micronutrient supplementation, impact on maternal anemia, and neonatal health outcomes in low and middle-income countries (LMICs) and the full text was screened.

Research Method

The method of systematic literature review covers the extensive search made of the scientific databases such as, PubMed, Scopus, IEEE Xplore, Google scholar among others. The following is required to be included:

- **Publication Year:** The studies published between 2020 and 2025 in order to provide relevance to the current technological and healthcare domain.
- **Research Areas:** Micronutrient supplementation in pregnant women, empirical studies, a case study, and simulation base research.
- **Geographic Scope:** Provides insights globally from a number of areas.
-

Data Collection

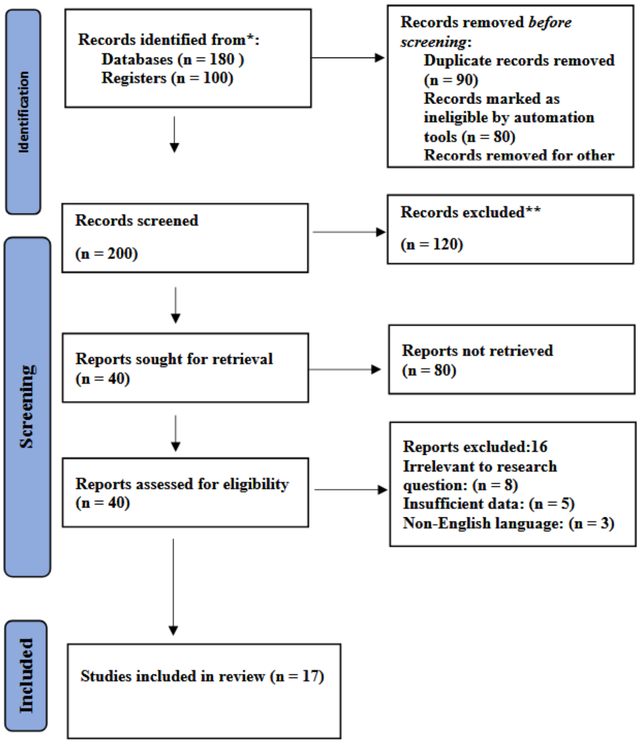
Data is then collected following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) framework to guarantee systematic transparency of the research. The keywords used for identification are "micronutrient supplementation," "maternal anemia," "neonatal outcomes," "pregnancy". Exclusion based on titles and abstracts to reduce studies not applicable to the research question. The inclusion criteria are applied on full-text articles to determine the eligibility. Data extracted from the supplementation on maternal health, neonatal health, challenges of implementation and outcomes on resilience and adaptability of health systems are covered.

Data Analysis

Thematic Analysis lists broad categories like 'micronutrient deficiency prevention,' 'real time monitoring of maternal health', and 'barriers to supplementation', and organizes the synthesized findings in themes like 'germfree testing, control of water wave in water channel photonic integrated device,' and 'choice mutation screening.' Thematic analysis suits the research objective, by empowering a link between the findings and practical applications of micronutrient supplementation in maternal and neonatal health.

Results

Figure 1. PRISMA flow diagram.



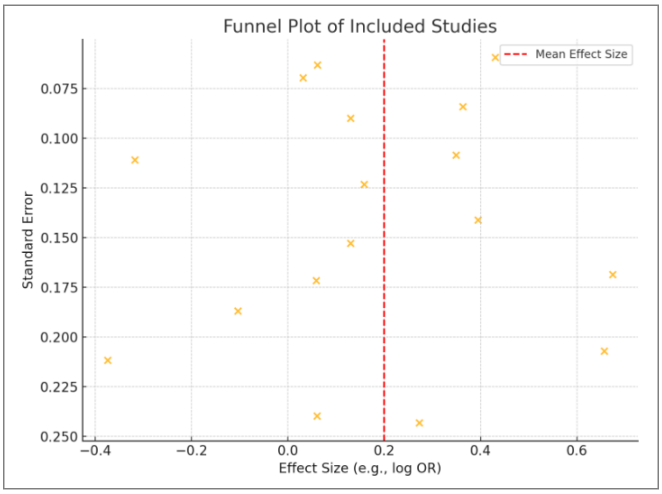
Source: Own authorship.

Risk of Bias Testing

Funnel plot was created to evaluate the possibility of a publication bias in 17 analyzed studies (Figure 2). The distribution of effect sizes against the standard errors is shown on the plot. The general symmetry indicates that it is not very likely that there is a prominent publication bias. Minor scatter can be regarded as an expression of homogeneity of the intervention effects or study sample sizes.

Symmetrical distribution of effect sizes on standard errors seems to show low publication bias of the included studies in the review.

Figure 2. Funnel plot with Risk of Bias plot on Inclusion Studies.



Source: Own authorship.

Impact of Micronutrient Supplementation on Maternal Anemia and Neonatal Health

There is positive evidence on the effects of Micronutrient supplementation during pregnancy on maternal and neonatal health outcomes from low and middle income countries. In addition, several maternal birth outcomes have improved with multiple micronutrient (MMN) supplementation over iron-folic acid (IFA) supplementation: decreased preterm birth, small-for-gestational-age, and low birth weight **[22]**. Consequently, iron and folic acid supplementation has been shown to reduce neonatal mortality and maternal anemia **[23]**. However, calcium supplementation is thought to reduce pre-eclampsia/eclampsia rates **[24]**.

Low body mass index and mid upper arm circumference have been associated to adverse fetal and neonatal outcomes of maternal undernutrition **[25]**. Single micronutrient supplementation has multiple benefits for specific outcomes, but MMN supplementation seems to present the most comprehensive positive effect on maternal and child health **[24]**. But more research is needed to understand the long term effects of these interventions in terms of child development and health outcomes.

This causes adverse health outcomes, which persist in children of low and middle income countries **[26]**. Multiple micronutrient (MMN) supplementation has also been proposed as a potential avenue of addressing these deficiencies as it alleviates some of the nutritional deficiencies and poor physical health problems. According to studies, MMN can be supplemented in pregnant mothers who will lead to high hemoglobin levels and decrease in children anemia **[27]**. Among lipid supplements, especially lipid-based nutrient supplements (LNS) have been particularly effective in reducing anemia prevalence by about 40%, and iron deficiency by 25%, in young children **[28]**. In addition to this, LNS has also been implicated in more favorable pregnancy outcomes like lower incidence of current low birth weight (LBW) and small for gestational age (SGA) infants **[27]**. Despite the effects of micronutrient supplementation on maternal and infant nutritional status in low and middle income countries being still studied, existing evidence supports the place of micronutrient supplementation in combatting micronutrient malnutrition in children **[29]**.

Barriers of Micronutrient Supplementation Programs for Pregnant Women

Various challenges in the implementation of micronutrient supplementation programs for pregnant women have been identified. A poor adherence is a main barrier, which needs for interventions on supplement consumption **[30]**. Factors that affect adherence are family support, accessing supplements, and benefit belief **[31]**. Studies also noted that the implementation is also affected by resources available, organizational structure, knowledge of providers and users **[32]**. Their implementation can be facilitated with the help of external gui delines, as well as regular monitoring of their performance and engagement of private sectors **[32]**. Numerous pregnant women still have insufficient intake of some micronutrients, even when using supplements, like choline, magnesium, and potassium **[33]**. Some women go on to exceed the tolerable upper limit of folate and iron **[33]**. Taken together, these findings underscore the importance of interventions aimed at specific gaps, better education, and individualized supplementation to provide optimal nutrition for pregnant women.

Pregnancy associated with micronutrient deficiencies is common among low and middle income countries with adverse maternal and child health outcomes **[12]**. Multiple micronutrient (MMN) supplementation has provided beneficial effects for many outcomes such as maternal anemia, low birth weight and preterm birth **[12]**. But maternal diets in India, for instance, remain suboptimal for a number of supply and demand side reasons **[34]**. Several effective strategies to improve adherence of prenatal micronutrient supplementation include education based interventions, consumption monitoring, SMS reminders and provision of free supplements **[30]**. In Ethiopia, women displayed high motivation to adhere to antenatal calcium supplementation regimens with strategies involving elements of home-based and family support, which are reported to improve adherence **[35]**. The results of these findings suggest institution of tailored intervention and supportive counseling in order to help increase the effectiveness of micronutrient supplementation programs during pregnancy.

Optimizing Micronutrient Supplementation Strategies

In low and middle income countries, micrionutrient deficiency is prevalent especially among pregnant women and children **[22]**. The evidence indicates that multiple micronutrient supplementation (MMS) during pregnancy can lead to better birth outcomes such as decreased preterm births and low birth weight, when compared to iron-folic acid supplementation (IFA) **[22]**. Cost benefit analyses show that it is a viable, good value for money intervention compared to IFA **[36]**. Furthermore, providing undernourished pregnant women with targeted BEP in combination with MMS is a cost effective strategy to maximize benefit **[37]**. Yet, inconsistent effects of micronutrient supplementation on maternal and infant nutritional status in the context of poor countries still require further research **[29]**. The findings support the consideration of MMS and supported BEP in maternal nutrition policies and programs for improving maternal and child health outcomes in resource limited settings.

Micronutrient supplementation for maternal and infant health, has recently been shown to be of great importance in low and middle income countries. In Ghana, an integrated simulation training on emergency obstetric care and respectful maternity care also improved providers' knowledge, self eficiency, and patient provider communication **[38]**. Optimal MMN supplementation requires that the women take it daily for three months prior to conception and during the entire first trimester and has thus has been shown to prevent these maternal and fetal complications **[39]**. The review protocol in this systematic review seeks to determine the effects of a variety of micronutrient tonics on nutritional status of both the mother and the infant in low and middle income countries **[29]**. A large observational study in Botswana found that those women with HIV or those aged 35 and over who received MMN had lower adverse birth outcomes compared to women who only received iron and folic acid **[15]**.

Discussion

Results from the study suggest that micronutrient supplementation during pregnancy will be an important potential tool to address widespread maternal and neonatal health problems in low- and middle- income countries (LMICs). Additionally, the associations found with reduced preterm birth and small, for gestational age and improved birth weight after multiple micronutrient supplementation (MMN), in contrast to the standard iron-folic acid (IFA) supplementation, lend support for a broader benefit of this combination of additional and complimentary actions of micronutrients in relation to birth outcomes with favourable outcomes of reduced preterm birth rates, small, for gestational age and low birth weight. It is clear that iron and folic acid supplementation are still important in the reduction of neonatal mortality and maternal anemia; and calcium supplementation might have a role in reducing the rates of pre-eclampsia/eclampsia, but MMN addresses a broader range of deficiencies.

In addition, lipid based nutrient supplements (LNS) have been found very effective in addressing micronutrient deficiencies in young children, resulting in increased maternal hemoglobin levels, and less risk of anemia and iron deficiency with their offspring as well as better pregnancy outcomes, including lower rates of low weight birth and small for gestational age infants.

While single micronutrient supplementation may confer specific benefits, supplementation with MMN appears to have the most far reaching positive effects on the health of both the mother and her child. While there is some mixed evidence regarding the long term effects of these interventions on child development and the exact effect these interventions will have on maternal and infant nutritional status in LMICs remains to be investigated. This recommendation is additionally supported by an observational study in Botswana that indicates thatMMN is associated with decreased risk for adverse birth outcomes in comparison with IFA alone, especially among women who are HIV infected or older than age 35 years. In addition, maximum benefits from MMN in preventing the maternal and fetal complications could be realized by daily intake beginning 3 months prior to conception until the first trimester.

Although seen to be highly beneficial, introduction of micronutrient supplementation programs for pregnant women is fraught with significant barriers. The major challenge is low adherence and interventions should be targeted to enhance consistent supplement intake. Factors for adherence include family support, accessibility of the supplements, and perceived benefit by the women. Besides resources available, implementation is also dependent on the structure of the organization to which the health system belongs, and the level of knowledge such implementation elicits on providers and users. However, a worrying proportion of pregnant women in LMICs continue to have deficiency or inadequate intakes even with supplementation of some crucial micronutrients including choline, magnesium, and potassium, while others may ingest above upper levels of tolerable intake for folic acid and iron. Thus, there is a need for tailored supplements strategies and better nutritional education. There continue to be supply and demand side limitations that maintain suboptimal maternal diets in e.g. India. Nonetheless, constructing effective strategies to enhance adherence to prenatal micronutrient supplementation is possible through education based interventions, monitoring of consumption, SMS reminder and free supplements. Home based and family support strategies helped in improvements of adherence to antenatal calcium supplementation in Ethiopia.

Additionally, the role of simulation frameworks and real time data analytics is explored to refine micronutrient supplementation strategies is also explored. The specific results regarding this aspect are not discussed in the provided excerpts, but there is an ongoing research on this aspect which is one of the objectives of the main research. Overall, the application of integrated simulation training in Ghana to improve emergency obstetric care and respectful maternity care demonstrates the potential for simulation the improving the delivery of care important of maternal and neonatal welfare. In addition, due to cost benefit analyses, MMN supplementation is a comparatively more cost effective intervention than IFA. A second approach of combining MMN with targeted supplementation of balanced energy protein for undernourished pregnant women is also proposed as a cost effective method to achieve optimal outcomes. This indicates that data analysis, including cost effectiveness evaluation, is an essential part in guiding the optimization of the supplementation programs and maternal nutrition policy in resource limited settings. Overall, micronutrient supplementation, in particular MMN, significantly contributes positively to maternal and neonatal health in LMICs, but innovative approaches to address implementation barriers and leveraging of data driven approaches can contribute substantially to maximize benefits and provide best possible gestational nutritional status in pregnancy.

Conclusion

Micronutrient supplementation, especially in the form of multiple micronutrient supplements (MMN), has the potential to improve the maternal and neonatal health outcomes in the low and mid income countries, reducing maternal anemia and improving birth outcomes. Despite this, they can only be accomplished with effective solutions to implementation barriers, including low adherence, which require newly developed interventions and greater accessibility. In addition, the ongoing requirement for further research is confirmed, including what the long term effects of such interventions will be, and how simulations can be used to improve upon, and cost effectively implement, supplementation programs in these resource limited settings. Achieving global health targets for maternal and child wellbeing, therefore, requires a tedious process to increase the efficacy of micronutrient supplementation and the practical delivery of the supplement.

CRediT

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No additional data are available.

Conflict of Interest

The authors declare no conflict of interest.

Similarity Check

It was applied by Ithenticate®.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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