

Review Article

Cost Effectiveness of Micronutrient Supplementation in India: A Scoping Review

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Abstract

Background: Micronutrient deficiencies decrease cognitive capacity, economic productivity, and quality of life. Micronutrient deficiencies, also called hidden hunger, may contribute to 2-12% of the total DALYs in high-burden countries. However, despite the growing burden, the evidence on the cost-effectiveness of the interventions to prevent or control micronutrient deficiencies is limited and varies. Hence, we conducted a scoping review of the published literature to assess the cost-effectiveness of the micronutrient interventions in India. **Methods:** We searched four electronic databases, including PubMed/MEDLINE, Web of Science, EBSCO, and Applied Social Sciences Index and Abstracts. We used the search strategy using the keywords ("micronutrient" OR "micronutrient supplementation") AND ("cost-effectiveness" OR "cost utility" OR "economic evaluation" OR "cost benefit") AND India. Our searches were limited to literature published until 07 August 2025. The initial search for this scoping review yielded 72 records. **Results:** Our review comprised 14 studies in total, which were conducted mostly in India and other high-burden Asian and African nations, and concentrated on the impact and cost-effectiveness of several micronutrient therapies. Evidence on micronutrient supplementation and food fortification in India was synthesized in this scoping review from 14 diverse studies, including economic modeling, social cost-benefit analysis, *ex ante* assessments, systematic reviews, and RCT, confirming that these are highly cost-effective strategies for combating hidden hunger and its related disease burden. Similarly, biofortification of staple crops like rice and wheat at large-scale with essential nutrients such as iron and zinc, fortification of regularly consumed products such as double-fortified salts and wheat flour, deliver significant health benefits at a relatively low cost per DALY averted. **Conclusions:** To meet national nutrition targets and eventually improve the health and well-being of India's people, it is imperative and economically reasonable to prioritize the scale-up of MMS and large-scale or universal food fortification projects.

Keywords

Cost-effectiveness, Cost-benefit Analysis, Micronutrient Supplementation, Disability-adjusted Life-years (DALY), Iron and Folic Acid

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1. Introduction

Micronutrients are defined as nutrients that are required in minute quantities, i.e., less than 100 mg per day, by the World Health Organization. Micronutrients are essential for the normal growth and development of the body. Their deficiencies, such as vitamin B12, C, D, and A deficiencies, goiter, anemia, hypocalcemia, etc., are public health problems [1]. Globally, 1.91 billion people are suffering from anemia, and 190 million school-age children and 19 million mothers are deficient in vitamin A [1, 2]. Likewise, 1.9 billion people exhibit inadequate iodine intake (urinary iodine concentration below 100 µg/L) and 50 million people show clinical signs of iodine deficiency, such as goiter and hypothyroidism [3].

Micronutrient deficiencies, also known as hidden hunger, are associated with reduced quality of life, cognitive capacity, and economic productivity. It has been estimated that the total global disability adjusted life years (DALY) burden from hidden hunger spans tens of millions annually. Furthermore, Susler *et al.* suggested that the total chronic and hidden hunger DALYs may increase by over 30 million by 2050 compared with 2010 globally [4]. Micronutrient deficiencies, especially iron, vitamin A, and zinc, contribute to 2-12% of the total DALYs in high-burden countries. India, the most populous country in the world, is estimated to have 1000 DALYs per 100,000 population attributable to micronutrient deficiencies [5].

Micronutrient supplementation is an effective strategy to reduce deficiencies and improve health outcomes. Studies found a reduced risk of low-birth-weight babies, premature birth, maternal anemia, and stillbirths with the intake of multiple micronutrient powder during pregnancy [6, 7]. Similarly, zinc supplementation during diarrheal management, vitamin A supplementation during routine immunization, and universal iodization of salt are other effective public health strategies to reduce DALYs [8, 9]. Besides, micronutrient supplementation has also been suggested as a cost-effective strategy to reduce the burden of hidden hunger and mortality. It is imperative to understand that health systems are always under budget constraints. Prioritizing cost-effective interventions is essential to ensure an equitable distribution of resources and reach of services to more people.

Micronutrient supplementation has been advocated across various life stages due to its burgeoning need. The World Health Organization (WHO) suggested iron-folic acid supplementation for pregnant women [10]. Likewise, multiple micronutrient supplements (MMS) that include iron, folic acid, vitamins A, C, D, E, B-6, and B-12, thiamine, riboflavin, niacin, zinc, copper, selenium, and iodine have also been recommended [6]. Iodine is critical for fetal brain development, and its deficiency during pregnancy can lead to irreversible mental impairment, with an average IQ loss of 10-15 points in children [11].

Cost-effectiveness helps policy-makers assess public health interventions' optimal impact per dollar spent, their scalability and sustainability, evidence-based allocation of scarce re-

sources, and ultimately, improved health equity and population well-being [12]. Cost-effectiveness assessment can help us compare different food supplementation strategies (e.g., fortified blended foods, take-home rations, ready-to-use foods) and decide the best option based on DALYs averted or health outcomes achieved per one USD spent. Furthermore, cost-effectiveness can identify program components (e.g., delivery mechanism, targeting strategy, dosage, frequency) that are driving costs without proportional benefits [12, 13]. Hence, we conducted a review of the published literature to assess the cost-effectiveness of the micronutrient interventions.

The introduction plays an important role in providing background information (including relevant references), emphasizing the importance of the study, and outlining its objectives. It is crucial to conduct a thorough review of the current state of the research field and incorporate key publications into your work. By referencing other research papers, you can provide context and position your own work within the broader research landscape. The final paragraph should provide a concise summary of the main findings and conclusions, which will be helpful to the readers.

2. Materials and Methods

Our scoping review mapped the available literature on micronutrient supplementation and its cost-effectiveness in India. We used the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) checklist to ensure transparency and methodological rigor.

2.1. Databases and Sources

We searched four electronic databases, including PubMed/MEDLINE, Web of Science, EBSCO, and Applied Social Sciences Index and Abstracts.

2.2. Search Strategy

We employed a comprehensive and iterative search strategy and used keywords:

("micronutrient" OR "micronutrient supplementation") AND ("cost-effectiveness" OR "cost utility" OR "economic evaluation" OR "cost benefit") AND India.

Our searches were limited to literature published until 07 August 2025. We limited our search to literature published only in English. We excluded conference abstracts, commentaries, editorials, protocols without results, and non-peer-reviewed literature, such as anecdotal reports.

A two-staged screening process was followed:

- 1) Title and abstract screening: Two independent reviewers (AS and RR) screened all citations. Disagreements were resolved through discussion or by a third reviewer

(SS).

- 2) Full-text review: Full texts of potentially eligible studies were retrieved and assessed against the inclusion criteria.

The data extraction was done based on the table created *a priori*. The information was extracted, including the bibliographic information: author, year, title, journal, economic evaluation type: cost-effectiveness, cost-utility, etc., cost components included, effectiveness outcomes: e.g., cases averted, DALYs/QALYs gained, summary measures: ICER, cost per DALY averted, etc., and the key findings and conclusions. All data were independently extracted by two reviewers and cross-verified for accuracy.

Thematic synthesis was used to group findings under domains such as: cost drivers, effectiveness outcomes used, modeling vs. trial-based evaluations, and equity considerations. Where available, cost-effectiveness thresholds (such as WHO-CHOICE or country-specific WTP thresholds) were compared to study findings to interpret whether interventions were “cost-effective” or not.

3. Results

3.1. Literature Section and Study Selection

The initial search for this scoping review yielded 72 records from PubMed, Web of Science, ASSIA, and EBSCO. Title and abstract screening were performed on 61 articles following the removal of 11 duplicates. Among the full-text articles screened, 17 articles were excluded due to not being related to cost-effectiveness ($n = 13$) and not having focus on Indian context ($n = 4$).

As a result, this scoping review comprised 14 studies in total, which were conducted mostly in India and other high-burden Asian and African nations, and concentrated on the impact and cost-effectiveness of several micronutrient therapies. The included studies were microsimulation models, cost-effectiveness models, systematic reviews, costing studies, economic modeling, and mixed-methods evaluations. This selection process is summarized in a flow diagram in Figure 1, which details the number of records at each stage of the review.

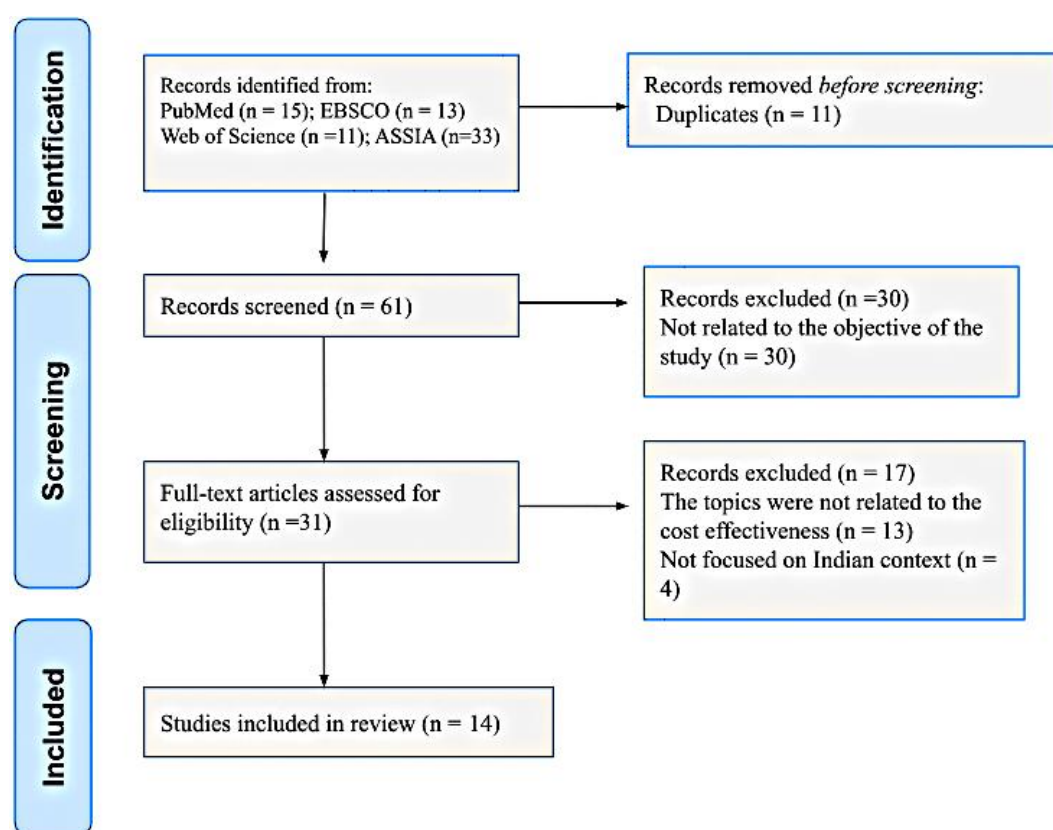


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) flow diagram of study selection.

3.2. Characteristics of Included Studies

The focus and methodology of the included studies varied.

Nine studies in all used economic modeling as they utilize mathematical or computational frameworks to estimate health and economic implications, and simulate outcomes to evaluate the effectiveness of interventions [6, 14-17, 22-25], as

shown in Table 1. Two of the studies were systematic reviews [18, 19], one was a costing study [20], one was a randomized controlled trial with economic evaluation [26], and one study was cross-sectional that used mixed-methods program evaluation approaches [21].

The interventions assessed covered both supplementation and fortification strategies. A major theme, examined in three cost-effectiveness models and tools [6, 14, 22] and a systematic review [18] was the comparison of Iron and Folic Acid (IFA) with MMS. Five studies focused on food fortification and biofortification, such as fortified wheat flour [17], dou-

ble-fortified salt [16], and zinc and Iron biofortification [15, 23, 24]. One study by Menon *et al.* (2016) used population data to analyze the costs of a larger collection of 14 direct nutrition interventions, with an emphasis on 10 Scaling Up Nutrition (SUN) programs [20]. While another study by Sethi *et al.* (2019) assessed a particular maternal spot feeding program [21]. One study assessed a Social Cost-Benefit Analysis (SCBA) of millets [25], one study worked on an evaluation of zinc and copper supplementation with oral rehydration solution (ORS) [26], and one systematic review presented broader perspectives on scaling up maternal nutrition programs [19].

Table 1. Description of the included studies and their findings.

No.	Authors	Year	Study Type	Intervention	Area/Location	Population Studied	Objective	Main Findings	Cost-Effectiveness
1	Young <i>et al.</i> [14]	2022	Microsimulation model	MMS + BEP vs IFA supplementation	India, Pakistan, Mali, and Tanzania	Dynamic microsimulation of national populations (pregnant women)	Compare DALYs and cost	MMS + BEP averted more DALYs than IFA	USD 70 (MMS), USD 83 (MMS + BEP)
2	Kashi <i>et al.</i> [6]	2019	Cost-effectiveness model	MMS vs IFA supplementation	Pakistan, India, and Bangladesh	Modeling based on meta-analyses; applied to national populations	Model DALYs from meta-analysis	MMS more cost-effective than IFA	For India: USD 31.62 (Cochrane), USD 14.99 (Lancet)
3	Alfiani <i>et al.</i> [18]	2025	Systematic review	MMS vs IFA supplementation	Global (including India)	Synthesizing 5 studies involving pregnant women	Review MMS vs IFA studies	All studies showed MMS cost-effective	USD 3.62-USD 1,024 per DALY
4	Menon <i>et al.</i> [20]	2016	Costing (not CEA)	14 Direct Nutrition Interventions	India	Estimates for national and subnational target populations	Estimate annual program cost	IFA among cheapest (~USD140/c hild/year)	Not applicable
5	Stein <i>et al.</i> [15]	2007	Modeling study	Zinc biofortification	India	Modeling based on national household food consumption survey data; applied to Indian population	Estimate DALYs and cost	0.6-1.4M DALYs saved annually	USD 0.73-USD 7.31 per DALY
6	Sethi <i>et al.</i> [21]	2019	Evaluation (mixed methods)	Maternal spot feeding	Andhra Pradesh and Telangana, India	360 pregnant and lactating women per state (Total 720 women)	Evaluate coverage, uptake	High diet diversity, counseling uptake	No ICER; evaluation only
7	Victora <i>et al.</i> [19]	2012	Systematic review	Scaling up maternal nutrition programs	Global (including India)	Synthesizing studies on populations benefiting from large-scale maternal nutrition programs	Review large-scale program scale-up	Fortification and CCT promising; variable impact	No ICER; enabling conditions
8	Horton <i>et al.</i> [16]	2011	Economic modeling	Double-fortified salt (DFS)	India	Economic modeling based on literature survey and existing algorithms for India	Estimate benefit: cost ratio (BCR)	DFS reduces anemia; good alternative	BCR = 2.4:1 to 5:1

No.	Authors	Year	Study Type	Intervention	Area/Location	Population Studied	Objective	Main Findings	Cost-Effectiveness
9	Fiedler <i>et al.</i> [17]	2012	Case study & modeling	Wheat flour fortification	Gujarat, India	Analysis using India's 2004/05 National Sample Survey data (beneficiaries of SSNPs in Gujarat)	Evaluate coverage and cost	Significant micronutrient gains in SSNPs	Highly cost-effective
10	Stein <i>et al.</i> [24]	2008	<i>Ex-ante</i> impact assessment	Iron Biofortification of rice and wheat	India	<i>Ex-ante</i> impact assessment on rural Indian populations	Assess the potential impacts of iron biofortification, building of the DALYs framework.	Iron biofortification could reduce the disease burden from ID by 19-58%. The cost-effectiveness was higher for rice alone than for the combined rice and wheat intervention.	Cost per DALY saved - USD 0.30 to USD 8.70. USD 0.46 (optimistic) and USD 5.39 (pessimistic) for Rice and wheat.
11	Patel <i>et al.</i> [26]	2003	RCT with Economic Evaluation	Zinc and copper supplementation added to ORS	Nagpur, India	Children (6-59 months) with acute diarrhea.	Evaluate cost of treating child with acute diarrhea in hospital, cost-effectiveness of Zinc and copper supplementation	The supplemented group had an 8% lower total treatment cost and a 24% lower cost per unit of health, making the intervention a cost-saving measure.	ICER: not statistically significant; DALYs lost 0.1 lower in the treatment group.
12	Singh <i>et al.</i> [25]	2024	Social cost-benefit analysis (SCBA) using mixed method and interdisciplinary approaches	Millet (nutri-cereals) as a nutritional supplement to rice	India	Not specified, focuses on national-level policy and value chain.	Conduct a SCBA of millets using a value chain analysis, and a nutrition and health analysis of Pearl, Sorghum and Finger millet.	Negative trend in returns for all crops considering social and environmental factors. Pearl millet was the most favorable, with the smallest negative difference between social and private returns.	The difference between social and private returns as a percentage is highest for finger millet at -111% and lowest for pearl millet at -14%.
13	Verney <i>et al.</i> [22]	2023	Cost-Benefit Tool	MMS vs IFAS supplementation	33 LMIC with data including India	Pregnant women	Describe methodology of MMS	MMS delivers substantial health benefits	Cost per DALY averted averages at

No.	Authors	Year	Study Type	Intervention	Area/Location	Population Studied	Objective	Main Findings	Cost-Effectiveness
14	Meenakshi <i>et al.</i> [23]	2009	<i>Ex ante</i> assessment	Biofortification of staple crops with iron, zinc, and vitamin A	India and 11 other countries in Asia, Africa, and Latin America	Target populations with micronutrient deficiencies in various countries including children <6 years	Cost-Benefit Tool; provide the findings of a hypothetical MMS scale-up for 4 focus countries and 29 countries with pre-loaded data; discuss how the Tool can help translate evidence into action.	while being far less expensive and better value for money than IFAS.	USD 23.61. Benefit-cost ratio ranges from USD 41 to USD 1304: USD1.0.
							Estimated costs and benefits of biofortification of global staples with vitamin A, iron, and zinc.	Biofortification is cost-effective and can result in reduction in the burden of micronutrient deficiencies	For India: Cost per DALY averted for iron biofortified rice is USD 3, and USD 1 for zinc biofortified rice, iron biofortified wheat and rice under optimistic scenarios.

MMS: Multiple Micronutrient Supplementations; IFA: Iron and Folic Acid; BEP: Balanced Energy Protein; ICER: incremental cost-effectiveness ratios; DALY: Disability adjusted life year; CEA: cost-effectiveness assessment; CCT: Conditional Cash Transfers; DFS: Double fortified Salt; BCR: Benefit Cost Ratio; SSNPs: social safety net programs; ID: Iron Deficiency; RCT: Randomized Controlled Trial; ORS: Oral Rehydration Solution; ORT: Oral Rehydration Therapy; SCBA: Social cost-benefit analysis; IFAS: Iron folic acid supplementation; LMIC: Low-and Middle-Income-Countries

3.3. Cost-Effectiveness of Multiple Micronutrient Supplementation (MMS) vs. Iron and Folic Acid (IFA)

Economic evaluations highlight that Multiple Micronutrient Supplementation (MMS) during pregnancy is more cost-effective than the standard Iron and Folic Acid (IFA) supplementation, implying that these interventions can produce large health benefits for a given investment.

A dynamic microsimulation model that included India, Pakistan, Mali, and Tanzania provided strong evidence for this, demonstrating that both MMS alone and MMS with Balanced Energy Protein (BEP) averted more DALYs than IFA supplementations [14]. The study found incremental cost-effectiveness ratios (ICERs) of USD 70 per DALY averted for MMS and USD 83 for MMS + BEP. Further analysis in this study showed that a tailored strategy of supplying BEP (including MMS) to 90% of women attending Antenatal Care (ANC) with low body mass index, BMI

(<18.5 Kg/m²) and MMS to 90% of women with BMI >18.5 Kg/m², averted more DALYs than a universal MMS strategy. This differentiated strategy was also found to be cost-effective in comparison to present IFA practice, with ICERs of USD 54 per DALY averted for Pakistan, USD 73 for Mali, USD 83 for India, and USD 245 for Tanzania. Improving MMS coverage demonstrates greater cost-effectiveness for child health outcomes compared to current IFA practices. While universal BEP + MMS provided greater overall impact, a targeted strategy of BEP for undernourished women and MMS for those with adequate BMI is a more economically efficient approach providing better child health benefits than MMS alone.

Further supporting this, a cost-effectiveness model applied to India, Pakistan and Bangladesh similarly showed that MMS was more cost-effective than IFA. The study used data from both a Cochrane and Lancet meta-analysis with country specific results confirming the benefit. The ICERs for transitioning from IFA to MMS for India, was USD 31.62 per DALY averted when using data from Cochrane meta-analysis, and USD 14.99 per DALY averted when using data from The Lancet meta-analysis [6] reinforcing these findings on a broader scale, a systematic review of global studies including some from India consistently found that MMS was more cost-effective than IFA during pregnancy in all reviewed studies with ICERs ranging from USD 3.62 to USD 1,024 per DALY averted [18]. Another study found that switching to MMS from IFA supplementation provides significant health benefits. Verney *et al.* (2023) described for policymakers how MMS is considerably more cost-effective than IFA supplementation in 33 low- and middle-income countries (LMICs), including India. The study findings showed an average of USD 23.61 per DALY prevented and a benefit-cost ratio (BCR) ranging from USD 41 to USD 1304: USD 1.0, demonstrating the intervention's remarkable economic efficiency in meeting global nutrition targets [22].

3.4. Cost-Effectiveness of Food Fortification and Biofortification

Beyond just comparing two health interventions, some studies focused on the economic viability of fortification and biofortification programs. A modeling study specific to India by Stein *et al.* (2007) highlighted the significant public health burden, estimating that 2.8 million DALYs are lost annually due to zinc deficiency (ZnD). Considering this substantial health burden, their analysis estimated that implementing zinc biofortification of rice and wheat could save between 0.6 and 1.4 million DALYs annually. This intervention demonstrated a highly favorable cost-effectiveness ratio, ranging from USD 0.73 to USD 7.31 per DALY averted [15].

Similarly, economic modelling for India by Horton *et al.* (2011) revealed that double-fortified salt (DFS) effectively reduced anemia. This intervention had a benefit: cost ratio (BCR) of 2.4:1, which may increase to between 4:1 and 5:1 if

male anemia levels were also reduced [16]. Additionally, a case study and modeling analysis in Gujarat, India, on wheat flour fortification within social safety net programs (SSNPs), found this initiative to be highly cost-effective, leading to significant micronutrient gains among beneficiaries [17]. Based on an *ex-ante* assessment by Meenakshi *et al.* (2009), the cost-effectiveness analysis for biofortification in South Asia is extensive, presenting varying estimates for different scenarios and staple crops.

In India, iron biofortified rice and wheat are extremely cost-effective. The cost per DALY saved with iron biofortified rice and wheat was calculated to be USD 3 and USD 1 under an optimistic scenario, rising to between USD 17 and USD 10 under a pessimistic scenario. Iron-biofortified wheat had significantly lower costs. The study also discovered zinc biofortification to be particularly cost-effective in India. The cost per DALY avoided for both zinc-biofortified wheat and rice is extremely cheap, remaining below USD 11 even under the most pessimistic scenarios. Under optimistic scenarios, the costs are significantly lower, at USD 1 for India per averted DALY for both wheat & rice. The percent reduction in DALY burden of micronutrient deficiency was higher for iron biofortified wheat (39%) than rice (15%), and 56% for zinc biofortified rice and 48% for under optimistic scenarios [23]. As evident from these results, the study emphasizes that biofortification is a cost-effective technique. Stein *et al.* (2008) conducted another *ex-ante* impact assessment which focused on the potential of iron biofortification in India, concluding that it may lower the disease burden due to iron shortage by 19-58%. Its findings indicate that this intervention is cost-effective, with a cost per DALY averted ranging from USD 0.30 to USD 8.70, and compares favorably with other micronutrient therapies due to its low institutional costs [24]. Providing a national level perspective on millets in India, Singh *et al.* (2024) conducted a social cost benefit analysis. It indicated that while millets have great health benefits, the social returns for some varieties, such as finger millets showed a negative trend compared to their private returns. Pearl millet was the most favorable, with the smallest negative difference between social and private returns at -14%, highlighting a need for policy support to expand their production and capture their full social value [25].

3.5. Program Costs and Implementation Considerations

Without a direct cost-effectiveness comparison, some studies presented data on the costs and implementation challenges of micronutrient interventions. Menon *et al.* (2016) conducted a detailed costing analysis focusing on the resources required to deliver 14 key direct nutrition interventions at scale across India, including a specific focus on 10 Scaling Up Nutrition (SUN) interventions. This modeling study highlighted the considerable funding required, projecting an annual cost of USD 5.9 billion to deliver the full set of

nationally recommended interventions. Within this comprehensive framework, they also provided a "rule of thumb" average: an estimated USD 140 per child (0-24 months of age) per year as a budgeting figure for the entire package of interventions. Their findings indicated that while IFA supplementation and Behavior Change Communication (BCC) interventions were among the least expensive interventions in this large package, the total cost to deliver multiple nutrition programs on a wide scale is very significant [20].

Supplementing oral rehydrating solution (ORS) with zinc and copper for children with acute diarrhea was found to be cost-effective and dominant for both the government and the patients with an 8% less treatment cost and a 24% lower cost per unit of health compared to giving only ORS. However, the findings did not reach statistical significance. Moreover, the authors extended their study outcomes to the national context and projected that this intervention strategy may save USD 117.6 million annually for India [26].

An evaluation based on mixed-methods approach of maternal spot feeding programs in Andhra Pradesh and Telangana, India presented valuable implementation insights, demonstrating substantial dietary diversity and counseling uptake among a total of 720 pregnant and lactating women, despite not reporting an ICER [21]. Furthermore, a systematic review by Victora *et al.* (2012) on the scaling up of maternal nutrition programs included a variety of interventions and delivery systems. The study investigated the efficacy of micronutrient supplements, food fortification, food supplements, and nutrition education. It also identified Conditional Cash Transfers (CCTs) as a promising delivery platform. While food fortification demonstrated promise, its effectiveness was heavily dependent on execution and political will, resulting in varying outcomes in practice. The review could not provide cost-effectiveness ratios, but its main finding was that the success of these initiatives is heavily reliant on implementation variables including adequate funds and effective delivery systems [19].

4. Discussion

Micronutrients are vital for human life for normal growth and development. Their deficiencies are one of the rising health burdens that affect quality of life, cognition, as well as economic productivity [27]. Multiple studies have shown that adequate intake and supplementation of key micronutrients reduces the risk of their perilous consequences [6-9]. Micronutrient supplementation has been advocated by global health bodies such as the WHO and has also been promoted by the government of India through national programs like *Anemia Mukh Bharat*, Vitamin A supplementation, +F fortification programs, etc. Analyzing cost-effectiveness helps to provide a valuable framework for comparing food supplementation strategies and identifying which interventions may deliver the greatest health impact per dollar spent [12]. It also helps identify cost drivers that do not yield proportional benefits,

guiding more efficient and equitable program design [12, 13].

In this scoping review, the evidence reviewed across fourteen studies consistently highlights the cost-effectiveness of micronutrient supplementation and food fortification interventions. MMS was found to be more cost-effective than only IFA. Kashi *et al.* (2019) demonstrated that MMS had a lower cost per DALY averted than IFA in three high-burden Asian countries, including India, with estimates ranging from USD 21.26 to USD 31.62 per DALY [6]. Similarly, Young *et al.* (2022) found that combining MMS with balanced energy protein (BEP) supplementation yielded even greater DALY reductions, which indicates that integrating nutrition-based approaches can further strengthen micronutrient supplementation interventions [14]. These findings were further reinforced by Verney *et al.* (2023) with an MMS Cost-Benefit tool, indicating that for 33 LMICs, including India, MMS was substantially more cost-effective than IFA supplementation [22].

Fortification and biofortification strategies, including iron and zinc biofortification of staple crops, DFS [16], and wheat flour fortification, were also shown to be highly cost-effective, with zinc biofortification achieving DALY savings at very low cost (USD 0.73-USD 7.31) and DFS demonstrating favorable benefit-cost ratios (2.4:1 to 5:1) [15]. Fiedler *et al.* (2012) found that wheat flour fortification in Gujarat had notable coverage within social safety net programs, demonstrating that state-led, targeted initiatives can bring positive outcomes [17]. The two *ex-ante assessment* studies demonstrated that iron and zinc biofortification of our staple crops, rice and wheat, could be achieved at very low costs per DALY averted [23, 24]. A social cost-benefit analysis study on millets emphasized the necessity for national policy support to maximize their social value [25].

Another convincing piece of evidence was offered for the addition of zinc and copper to ORS for children with acute diarrhea, highlighting a dominating, cost-saving intervention, even though the findings could not reach statistical significance [26]. While some studies, such as maternal feeding program evaluations and costing analyses, did not report incremental cost-effectiveness ratios, they provided valuable insights into program implementation, coverage, and affordability [21]. Collectively, the evidence substantiates the prioritization of interventions such as multiple micronutrient supplementation and large-scale fortification, given their capacity to generate significant health improvements at relatively low financial investment.

Our scoping review offers many strengths that enhance its value and significance to the public health and nutrition sector in India. First, this review presents a complete synthesis of the current economic evidence on the cost-effectiveness of micronutrient interventions within the Indian context, thereby addressing a critical gap in the literature. By focusing on a particular high-burden country, India, the review presents a more context-specific and detailed analysis than larger global studies. This review follows a methodologically rigorous

approach to literature search and screening, minimizing bias and enhancing the reproducibility of our findings. A major strength of this review is that it covers a diverse range of studies, from economic modelling and trials to costing and program-level evaluations, this scoping review provides a holistic perspective that goes beyond simple cost-effectiveness ratios to address implementation and program-level aspects, essential for effective policy making.

Although the evidence supports cost-effectiveness, some limitations can be observed. The studies are widely variant in terms of design, methodology, and outcome measures, which makes it difficult to draw direct comparisons. Many studies were based on models, not real-life programs, so their results might not apply in all settings, especially in India. Only a few studies explored long-term sustainability and the impact of enabling conditions that might affect the success and scale-up of these interventions.

The synthesis of the included studies points to some topics that warrant further investigation. First, it is evident that there is a clear need for more primary robust research from real-world contexts rather than depending only on economic modeling and microsimulation models. In a country like India, where various factors such as social, economic, and geographic factors influence success of programs, it becomes crucial that the focus of future research should be on conducting randomized controlled trials with a strong economic cost-effective evaluation component.

Additionally, research should examine the scalability and long-term sustainability of these intervention strategies in Indian contexts, for instance, examining the role of various delivery mechanisms including public-private partnerships, community-based models, and the use of technology to improve program reach and efficiency. Future studies may also investigate the enabling policy environment and the political will necessary to sustain these strategies.

Moreover, a social cost-benefit analysis that considers the wider economic and social benefits of micronutrients interventions may be incorporated in future research. While many of the studies in this review worked on averting DALYs, a more complete and comprehensive analysis would account for outcomes, such as improved cognitive development, higher educational achievements, and overall national economic productivity. Determining and quantifying these long-term effects would give a more complete view of the true value of investing in micronutrient supplementation programs for the country.

5. Conclusions

Shouldering the high burden of hidden hunger due to micronutrient deficiencies and associated diseases can be economically detrimental for developing countries such as India. Evidence on micronutrient supplementation and food fortification in India was synthesized in this scoping review from 14 diverse studies, including economic modeling, social

cost-benefit analysis, *ex ante* assessments, systematic reviews, and RCT, confirming that these are highly cost-effective strategies for combating hidden hunger and its related disease burden. The evidence on MMS strategies and programs consistently demonstrated that it is a more economically efficient approach than the standard IFA supplementation capable of preventing more DALYs.

Similarly, biofortification of staple crops like rice and wheat at large-scale with essential nutrients such as iron and zinc, fortification of regularly consumed products such as double-fortified salts and wheat flour, deliver significant health benefits at a relatively low cost per DALY averted. Although considerable financial and logistical constraints and challenges were raised in the literature by certain studies, the data collectively suggests that these interventions give a substantial return on investment for improving public health. Even if the primary focus is on DALYs averted, the evidence indicates that these interventions may also result in improved cognitive development, educational achievements, and increased economic productivity for the country. To meet national nutrition targets and eventually improve the health and well-being of India's people, it is imperative and economically reasonable to prioritize the scale-up of MMS and large-scale or universal food fortification projects.

Abbreviations

DALY	Disability Adjusted Life Year
WHO	World Health Organisation
MMS	Micronutrient Supplementation
IQ	Intelligence Quotient
USD	United States Dollar
QALY	Quality Adjusted Life Year
ICER	Incremental Cost- Effectiveness Ratios
WHO-CHOICE	World Health Organisation Choosing Interventions That Are Cost-Effective
WTP	Willingness to Pay
IFA	Iron and Folic Acid
SUN	Scaling Up Nutrition
SCBA	Social Cost-Benefit Analysis
ORS	Oral Rehydration Solution
BEP	Balanced Energy Protein
CEA	cost-effectiveness assessment
CCT	Conditional Cash Transfers
SSNPs	Social Safety Net Programs
DFS	Double Fortified Salt
BCR	Benefit Cost Ratio
ID	Iron Deficiency
RCT	Randomized Controlled Trial
ORT	Oral Rehydration Therapy
IFAS	Iron Folic Acid Supplementation
LMIC	Low-and Middle-Income-Countries
ZnD	Zinc Deficiency
BCC	Behavior Change Communication

Author Contributions

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Santosh Choudhary: Methodology

Shantanu Sharma: Conceptualization, Methodology

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The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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