

Review Article

The Immunomodulatory Role of Micronutrients and Traditional Functional Foods in the Prevention and Management of Communicable Diseases: An Integrative Review

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A B S T R A C T

The global burden of communicable diseases remains substantial despite antimicrobial therapy advancements; the worldwide burden of infectious illness is still high, and antibiotic resistance is emerging as a major public health concern. Micronutrients and bioactive food molecules play a major role in immune system function and pathogen resistance; nutrition has emerged as a vital pillar of immunological defence. In addition to examining the antimicrobial qualities of traditional functional foods such as garlic, turmeric, ginger, honey, propolis, fermented foods, and bioactive plant compounds, this review summarises the most recent research on the immunomodulatory mechanisms of important micronutrients such as vitamins D, C, E, and A; zinc; selenium; and iron.

This review investigates molecular mechanisms such as direct antimicrobial action, cytokine regulation, oxidative stress management, nutritional immunity and adaptive immune modulation. Optimal micronutrient status significantly protects against respiratory infections, including COVID-19, TB, HIV and influenza as per clinical and epidemiological evidence. Through membrane disruption, enzyme inhibition, and biofilm disruption, traditional functional foods exhibit broad-spectrum antimicrobial activity. The idea of nutritional immunity, in which hosts starve infections by sequestering trace nutrients, is an evolutionarily conserved defence strategy with potential therapeutic applications. Probiotic therapies, functional food consumption and vitamin supplementation offer a synergistic approach to improve immunological resilience, stave off and aid in healing. Nevertheless, there are still issues with bioavailability variability and ideal dosage, as well as common possible toxicity. The study highlights the transitional potential of nutritional immunology in clinical practice, public health policy, and the creation of supplementary treatment approaches to combat communicable diseases and antibiotic resistance.

Keywords: Communicable Diseases, Bioactive Food Molecules, Immunomodulatory Mechanisms, Probiotic Therapies

Introduction

Micronutrients are needed in hundreds of biochemical activities, gene-regulatory networks, and cellular processes that support host defence against pathogens, contributing less than 0.01% of total body mass.¹ Micronutrients (vitamins and minerals) are required in small daily amounts. However, they are crucial for optimal psychological functioning, such as immune competence, because endogenous synthesis is sufficient to meet bodily needs.

Antimicrobial resistance and the high global burden of communicable diseases over the recent decades have increased interest in nutritional sciences as an alterable determinant of infection risk and outcome. Deficiency of key micronutrients like iron, zinc, selenium and vitamins D, C, E and A has been linked in an increasing amount of research to poor clinical outcomes, impaired innate and adaptive immunity responses and high susceptibility to gastrointestinal, respiratory and systemic infections.²

Garlic, turmeric, ginger, honey, propolis, fermented foods and other bioactive plant-based preparations are examples of traditional functional foods that provide complex matrices of micronutrients and bioactive compounds that have antimicrobial, immunomodulatory, and antioxidant characteristics.³ Such functional foods can affect the epithelial barrier integrity, cytokine production, oxidative balance, phagocytic function, and microbial colonisation, providing a supplementary strategy to conventional medications for the management and prevention of communicable diseases.⁴

Communicable diseases continue to impose a substantial global health burden despite advances in prevention, diagnosis and antimicrobial therapy. Tuberculosis (TB), one of the major infectious diseases addressed in this review, affected an estimated 10.7 million people worldwide in 2024 and caused approximately 1.23 million deaths, including 150,000 deaths among people living with HIV.⁵ The challenge is further compounded by antimicrobial resistance (AMR), with bacterial AMR estimated to be associated with approximately 4.71 million deaths globally in 2021, including 1.14 million deaths directly attributable to AMR.⁶ In 2023, approximately one in six laboratory-confirmed bacterial infections causing common infections worldwide was resistant to antibiotic treatment.⁷ These trends highlight the continuing need for complementary strategies that can support host defence and improve resilience against infectious diseases.

Although previous studies have examined individual micronutrients, functional foods, and specific infectious diseases, the available evidence remains fragmented across nutrient-specific, food-based, mechanistic, and disease-

specific literature. There is a need for an integrated synthesis linking micronutrient status, traditional functional foods, nutritional immunity, and immunomodulatory mechanisms across different communicable diseases. Therefore, this integrative review aims to synthesise current evidence on the immunomodulatory and antimicrobial roles of selected micronutrients and traditional functional foods, examine their underlying mechanisms in communicable diseases, and discuss their potential implications for disease prevention, supportive management, and future nutritional interventions.

Methodology

This integrative review was conducted to synthesise evidence on the immunomodulatory roles of micronutrients and traditional functional foods in the prevention and management of communicable diseases. Literature was searched using PubMed, Scopus, ScienceDirect, and Google Scholar, covering publications available up to December 2025. Keywords included combinations of micronutrients, vitamins, minerals, immunity, immunomodulation, nutritional immunity, functional foods, traditional foods, bioactive compounds, probiotics, antimicrobial activity, and communicable/infectious diseases, along with terms related to respiratory, gastrointestinal, viral, and bacterial infections. Additionally, a search was conducted across relevant journals relevant to micronutrients, functional foods and bioactive compounds, disease categories, immunological mechanisms, and translational implications.

Selection criteria

Peer-reviewed articles, clinical studies, observational studies, reviews, systematic reviews, and meta-analyses relevant to the relationship between nutrition, immune function, functional foods, and communicable diseases were considered. Articles unrelated to the review objectives, duplicate publications, and studies lacking relevant nutritional or immunological evidence were excluded. Titles and abstracts were initially screened for relevance, followed by full-text assessment of potentially eligible articles.

Micronutrients in Immunity and Communicable Diseases: Mechanisms and Targeted Applications

Micronutrients exert significant complex effects on both innate and adaptive arms of the immune response. Through a variety of different pathways, such as receptor-mediated transcriptional regulation, post-translational modifications, enzymatic cofactor functions, antioxidant activity, and second messenger signalling.⁸ The way in which micronutrient deficiencies weaken host defence and how targeted supplementation might improve resistance to infection and restore immunological competence becomes

clear when understanding the molecular interactions.⁹ Numerous communicable diseases present unique dietary needs and immunological obstacles, leading to the creation

of disease-specific approaches that integrate nutritional immunology with traditional medical care.¹⁰ As shown in Figure 1, micronutrient interaction interventions can be tailored to the type of infections, like respiratory tract infection, viral systemic infection and gastrointestinal

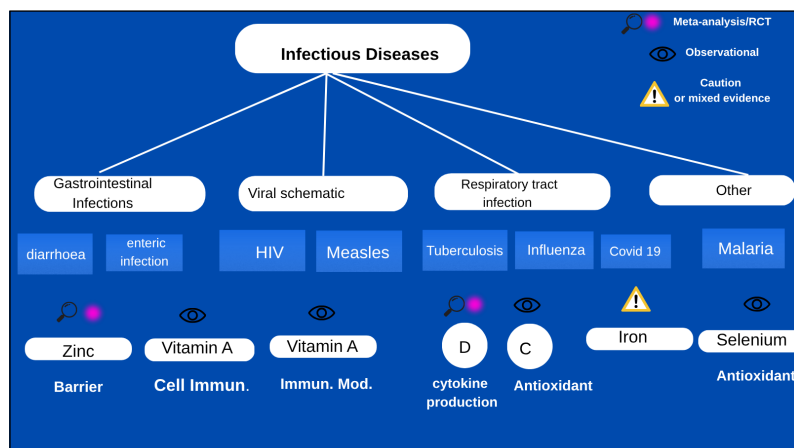


Figure 1. Disease-targeted micronutrient supplementation in communicable diseases

Table 1. Disease-Specific Micronutrient Requirements

Infection Type	Primary Micronutrients	Mechanisms of Action	Clinical Evidence Level
Respiratory Tract Infections (COVID-19, TB, Influenza, Pneumonia)	Vitamin D, Zinc, Selenium, Vitamin C	Antimicrobial peptides, antiviral RNA polymerase inhibition, antioxidant defence, cytokine modulation	Strong (meta-analyses, RCTs)
Gastrointestinal Infections (Diarrhea, enteric pathogens)	Zinc, Vitamin A, Vitamin C	Epithelial barrier integrity, tight junction maintenance, immune cell function, reduced duration	Strong (WHO-recommended for zinc in diarrhea)
Systemic Viral Infections (HIV, Viral hepatitis)	Selenium, Multi-micronutrients, Vitamin E	Selenoprotein function, viral mutation prevention, oxidative stress management, CD4+ preservation	Moderate (observational + limited RCTs)
Bacterial Sepsis and Severe Infections	Vitamin C (high-dose IV), Zinc, Vitamin E	Antioxidant defense, cytokine storm suppression, endothelial protection, immune cell support	Moderate (emerging evidence, some RCTs)
Parasitic Infections (Malaria, helminth)	Zinc, Vitamin A, Iron (caution)	Immune enhancement, but iron sequestration is critical for host defence.	Moderate (complex iron-pathogen interactions)

Recent clinical trials, WHO & GRAM guidelines, and nutrient supplementation recommendations for communicable diseases 2019–2024.

infections, offering clinically relevant guidance for target supplementation.

Micronutrients in Gastrointestinal Infections

Based on this meta-analytic evidence, the World Health Organisation suggests zinc supplementation for

childhood diarrhoea as routine treatment (10-20 mg elemental zinc daily for 10-14 days).¹¹ Overall mortality and diarrhoea incidence, according to a meta-analysis of zinc supplementation trials in children of the supplemented population, were shown to be lower.¹² Incidence of diarrhoea is lowered by 20-30% in populations where

zinc supplementation is provided daily or weekly as a preventive measure.¹³

Retinoic acid promotes goblet cell growth and mucin secretion to enhance the protective layer of mucus covering the intestinal epithelium.¹⁴ Vitamin A maintains the function of the GI barrier through its influence on epithelial development and the production of mucus.¹⁵ By increasing the production of IgA, the major immunoglobulin at mucosal surfaces, vitamin A supports the immunological exclusion of enteric pathogens.¹⁶ The benefits of vitamin A are less effective than those of zinc; still, its supplements are provided to populations lacking vitamin A, as it lessens the severity of diarrhoeal illness.¹⁷

Stimulation of macrophage and neutrophil activity in gut-associated lymphoid tissue helps vitamin C to enhance the functions of intestinal immune cells and decrease the duration.¹⁸

Strengthening of intestinal epithelial antioxidant defences and decreasing the severity of gastroenteritis are functions performed by selenium.¹⁹ A complicated picture is presented by iron when it comes to GI infections. During active diarrhoeal illness, iron supplementation may be contraindicated, as several enteric pathogens, such as pathogenic *E. coli*, *Shigella* and *Salmonella*, regardless of whether iron deficiency inhibits immune function, need iron for virulence.²⁰ The iron-withholding reaction of the host, also called hypoferremia, serves as a protective nutritional immune tactic during GI illness.²¹ Deficiency of iron should be treated either before or after active GI infections but not during them, as per current guidelines.²²

Micronutrients in Respiratory Tract Infections (COVID-19, Tuberculosis, Influenza, Pneumonia)

Respiratory tract infections (RTIs), which can range from lower respiratory infections (bronchitis, pneumonia, COVID-19, and tuberculosis) to upper respiratory tract infections (common cold, pharyngitis, and sinusitis), represent the main infectious cause of death worldwide.²³ Numerous micronutrients have been shown to have critical roles in the nutritional immunology of RTIs.

Vitamin D is the most extensively studied micronutrient for respiratory infections. Vitamin D enhances respiratory immune defences through:

- Direct antimicrobial efficiency against respiratory bacterial and viral pathogen protection is provided by antimicrobial peptide induction, which stimulates cathelicidin and β -defensin production in alveolar macrophages and respiratory epithelium.²⁴
- Epithelial barrier integrity: preventing pulmonary edema, reducing viral invasions, and preserving tight connections in the respiratory epithelium.²⁵
- *Mycobacterium tuberculosis* and other respiratory bacterial pathogen infections are known as macrophage activation.²⁶
- Acute respiratory distress syndrome (ARDS) can be avoided by cytokine regulation, which suppresses excessive inflammation (cytokine storm) while maintaining effective pathogen clearance.²⁷
- Autophagy induction: Encouraging the breakdown of intracellular pathogens such as respiratory viruses and *M. tuberculosis* by autophagy.²⁸

Vitamin D insufficiency is regularly linked to an increased respiratory infection risk, according to epidemiological evidence.²⁹ As per meta-analyses, vitamin D supplementation lowers the incidence of acute respiratory infections. The strongest effect is in vitamin D-deficient individuals (serum 25(OH)D <25 nmol/L or <10 ng/mL), where treatment reduces risk by about 70% (number needed to treat = 4).^{30,31} Particularly with COVID-19, vitamin D deficiency is correlated with two to three times greater infection rates as well as significantly higher severity, ICU admissions, and mortality.³² Geographical analysis shows that areas with higher COVID-19 mortality are in regions with greater rates of vitamin D deficiency.³³

The significance of vitamin D in tuberculosis is both mechanistically compelling and clinically inconsistent. Randomised controlled trials produce heterogeneous results, despite in vitro studies demonstrating vitamin D-enhanced macrophage killing of *M. tuberculosis*.³⁴ Benefits in vitamin D-deficient TB patients, specifically those with VDR gene variants, are suggested by subgroup analysis.³⁵ Vitamin D supplementation in TB patients speeds up the resolution of inflammation, which may potentially reduce immunopathology.³⁶

Zinc exhibits potent antiviral effects against respiratory viruses:

- Zinc ions directly inhibit the RNA-dependent RNA polymerase of Coronaviruses (including SARS-CoV-2), Influenza viruses, and Rhinoviruses, preventing the reproduction of the viral genome.³⁷
- **Viral entry blockade:** Zinc reduces viral entry by interfering with viral spike protein-receptor interferences and modulating ACE2 expression.³⁸
- Zinc deficiency reduces the synthesis of type 1 (IFN- α/β) interferon, which is critical for antiviral defence; supplementation restores interferon responses.³⁹
- **Zinc ionophore synergy:** Intracellular zinc availability in antiviral activity is increased when zinc is combined with zinc ionophores (molecules that facilitate zinc transport across cell membranes), such as quercetin, a flavonoid found in many plants.⁴⁰
- Meta-analysis demonstrated that zinc lozenges

shorten the duration of the common cold by about 33% when initiated within 24 hours of symptom onset and provided clinical evidence for zinc in children with RTIs.⁴¹ Children who take preventive zinc supplements experience fewer respiratory infections.⁴² Although randomised control trials are needed for confirmation, observational studies for COVID-19 suggest that supplementation (50-100 mg) daily correlates with lower mortality, shorter hospital stays and better symptoms.⁴³

Selenium status strongly predicts COVID-19 outcomes. According to Chinese epidemiological investigations, provinces with higher selenium consumption (measured by hair selenium concentration) had significantly lower mortality and better cure rates (>40% vs. <15%).⁴⁴ Selenoprotein expression is downregulated by SARS-CoV-2 infection, potentially contributing to disease pathogenesis by weakening antioxidant defences and elevating oxidative stress.⁴⁵ Selenium inhibits viral genome alterations that increase virulence; this is probably true for SARS-CoV-2, as it has been shown for influenza and Coxsackievirus.⁴⁶ Clinical trials are being conducted on the selenium compound ebselen, which inhibits SARS-CoV-2 primary protease.⁴⁷

Vitamin C (especially high-dose intravenous formulations) has been investigated for severe respiratory infections such as COVID-19, pneumonia and ARDS [48]. Vitamin C improves oxygen metrics, reduces ventilation duration, lowers inflammatory biomarkers (IL-6, CRP) and may shorten ventilation times and ICU stays [49]. Meta-analysis shows modest benefits, with heterogeneity probably due to variation in time, patient severity and dosage (oral 1-3 g/day vs. intravenous 6-24 g/day).⁵⁰

Vitamin E enhances T cell function and vaccine responses in the older population, which may lower the incidence of respiratory infections in elderly people.⁵¹ Although vitamin A maintains the integrity of respiratory epithelium, it has inconsistent effects on respiratory infection outcomes; its benefits are mostly shown in populations lacking in vitamin A rather than general preventive measures.⁵²

Vitamin E enhances T cell function and improves vaccination responses in elderly populations, potentially reducing respiratory infection risk in immunosenescent individuals.⁵³

Although vitamin A preserves the integrity of the respiratory epithelium, it shows variable effects on respiratory infection outcomes; its benefits are mostly shown in populations deficient in vitamin A rather than as a general preventive measure.⁵⁴

Challenges to Implementation

Some of the obstacles that personalised nutrition must overcome are affordability, cost, evidence gaps and medical literacy.⁵⁵ Both metabolomic analysis and genetic screening

are still uncommon and costly.⁵⁶ Clinical knowledge and advanced algorithms are needed to comprehend complicated multi-omic data and turn it into practical suggestions.⁵⁷ The rise of inequality in health could occur if tailored diets primarily help wealthy communities. To obtain direct-to-consumer genetic screening and customised dietary advice, it is necessary to create laws and regulations.⁵⁸

There is still little evidence to favour customised approaches over conventional recommendations in many situations. For large-scale studies, it is necessary to compare individualised and population-based therapies.⁵⁹ Personalised nutrition, which promises increased immune resistance through tailored therapies, despite the challenges, reflects the future direction of nutritional immunology.⁶⁰

The integration of nutritional immunology and customised nutrition into daily practices has been hindered by some important obstacles. These can be grouped into economic and technical regulatory evidence-related challenges.⁶¹

- **High costs and limited access:** Personalised methods based on genetic screening, microbiome analysis, and metabolic profiling are still costly and rarely available in standard clinical settings, increasing concerns that the advantages will be restricted to rich populations of society.⁶²
- **Complex data and capacity gaps:** Most health systems still lack the advanced decision support algorithms, strong bioinformatics structure and Specific clinical expertise required to interpret multi-omics datasets.⁶³
- **Regulatory and ethical issues:** To avoid abuse and commercial oval promising direct to consumer genetic testing and tailored nutritional recommendations require explicit restrictions on data population, quality control and professional oversight.⁶⁴
- **Evidence gaps and scalability:** There are currently few rigorous studies comparing personalised diet to conventional population-based recommendations for many illnesses, which makes it difficult to support widespread adoption or insurance coverage.⁶⁵ Qualitative access models in supportive policy frameworks are crucial.

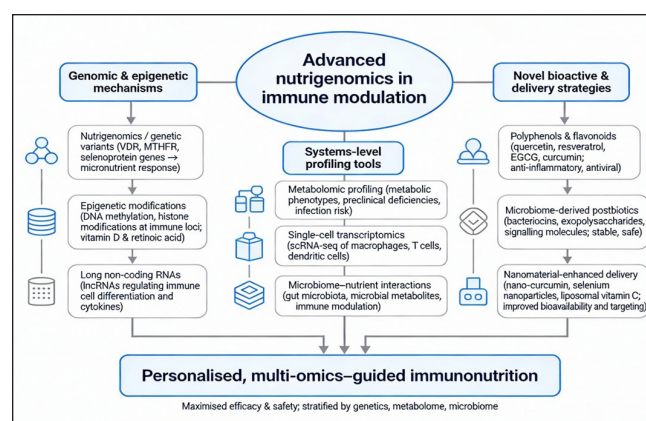


Figure 2. Personalised multi-omics-guided immunonutrition

Single-Cell Transcriptomics

Characterisation of nutritional impacts on particular immune cell groups is previously unheard-of clarity via single-cell RNA sequencing. Improvement in supplementation techniques will be made by knowing how micronutrients influence macrophage phenotypes, T cell types, and dendritic cell maturation differently.⁶⁶

Epigenetic Modifications

Immunological expression of genes controlled by histone modifications and DNA methylation are among epigenetic processes affecting micronutrients.⁶⁷ Regulation of Chromatin availability at immunological loci is achieved by vitamin D and retinoic acid.⁶⁸ The functional implications and nutrient-mediated epigenetic patterns will be mapped in future studies.

Long non-coding RNAs

The differentiation of immune cells and the generation of cytokines are controlled by the long non-coding RNAs, or lncRNAs. Modulation of lncRNA expression by micronutrients may offer additional scientific knowledge. Improvement in the immune system is made by therapeutically targeting nutrient-induced lncRNAs.⁶⁹

Role of Microbiome–Nutrient Interactions

- A major area of study in nutritional immunology is gut microbiome, representing a key frontier in mediating the effects of nutrition on immunity.
- Emerging Bioactive Compounds with Immunonutritional Relevance
- Novel bioactive substances have immunomodulatory potential in addition to traditional vitamins and minerals.⁷⁰

Polyphenols and Flavonoids

Polyphenols from fruits, vegetables, tea and wine have anti-inflammatory, antimicrobial and antioxidant properties.⁷¹ Clinical translations of polyphenol-based treatments for infections are accelerating.⁷² Quercetin, resveratrol, epigallocatechin gallate (EGCG) and curcumin modulate immune signalling inhibit viral replication and reduce cytokine storms.⁷³

Microbiome-Derived Postbiotics

Postbiotics are bioactive compounds produced by probiotics, such as bacteriocins, exopolysaccharides and

signalling molecules that modulate immunity without the need for live bacteria.⁷⁴ In terms of stability, safety and regulatory acceptance, postbiotic supplements might more advantageous and superior to probiotics.⁷⁵

Nanomaterial-Enhanced Delivery

Stability, bioavailability and target distribution are improved when micronutrients and bioactive substances are encapsulated.⁷⁶ Nano-formulated curcumin, selenium nanoparticles, and lipid liposomal vitamin C have all shown improved efficacy. Nutritional therapies made possible by biotechnology are a promising area.

Conclusion

This integrative review indicates that micronutrients and traditional functional foods may contribute to host defence against communicable diseases through complementary immunomodulatory, antimicrobial, antioxidant, epithelial-barrier, and nutritional-immunity mechanisms. Vitamins and minerals such as D, C, A and E, zinc, selenium and iron have important roles in innate and adaptive immune function, although clinical benefits vary according to nutrient status, disease context, dosage and individual characteristics. Traditional functional foods and their bioactive compounds also show promising antimicrobial and immunomodulatory properties, but much of the evidence remains mechanistic or preclinical.

The interpretation of available evidence is limited by heterogeneity in study designs, populations, nutritional status, dosages, bioavailability and clinical outcomes, as well as limited high-quality clinical evidence for several food-based interventions. Therefore, micronutrient supplementation or functional foods should not be considered substitutes for established antimicrobial treatment or disease-prevention strategies. Future research should prioritise well-designed clinical trials, standardised dosing and outcome measures, investigation of microbiome–nutrient and host-specific interactions, and evaluation of the safety, bioavailability and clinical applicability of emerging bioactive compounds.

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