Scholars LITERATURE

Journal of Food and Nutritional Health

Short Communication

DOI: https://doi.org/10.47275/2692-5222-128
Volume 6 Issue 1

Food, Nutrients, and Immunity: A Review on Advances in Nutritional Health

Navya Praneetha[1*], Aditya Krishna[2], Pasupuleti Ankitha[3*] and Darren Fernandez[4]

[1]Sri Siddhartha Medical College, Tumkur, Karnataka, India
[2]Mamata Academy of Medical Sciences, Hyderabad, Telangana, India
[3]Maharajah's Institute of Medical Sciences, Nellimarla, Andhra Pradesh, India
[4]Father Muller Medical College, Mangaluru, Karnataka, India

Abstract

Recent global health crises have spotlighted the critical connection between nutrition and immune function, emphasizing the urgency to reassess dietary strategies for disease prevention. There is a growing recognition that food and nutrients are not merely sources of energy but vital modulators of immune responses. However, inconsistencies in nutritional guidelines and a lack of awareness about functional foods still limit their clinical and public health impact. This review offers a synthesis of recent advancements in understanding how specific nutrients, plant-based diets, and functional foods influence immune mechanisms. It examines the role of vitamins (D, C, and A), minerals (zinc and selenium), and polyphenols in regulating inflammatory responses and enhancing immune resilience. It evaluates the promise of fermentation biotechnology and biofortification in improving nutrient availability. Nutritional interventions in vulnerable groups, including the elderly and burn patients, are explored with attention to measurable immune outcomes. Studies associate plant-based diets with milder COVID-19 symptoms and reduced metabolic syndrome risk further underscore diet's central role in public health. Looking forward, personalized nutrition guided by nutrigenomics could revolutionize dietary interventions by tailoring them to individual genetic and metabolic profiles. Expanding functional food innovation and addressing challenges such as standardization, clinical validation, and consumer education are crucial. Future efforts must integrate nutrition more firmly into preventive healthcare, recognizing diet as a cornerstone of immune defense and overall wellness.

Keywords: Biofortification, Functional foods, Gut microbiota, Immune modulation, Nutritional interventions, Plant-based diet, Vitamins and minerals

Correspondence to: Navya Praneetha and Pasupuleti Ankitha, Sri Siddhartha Medical College, Tumkur, Karnataka, India and Maharajah's Institute of Medical Sciences, Nellimarla, Andhra Pradesh, India.

Citation: Praneetha N, Krishna A, Ankitha P, Fernandez D (2025) Food, Nutrients, and Immunity: A Review on Advances in Nutritional Health. J Food Nutr Health, Volume 6:1. 128. DOI: https://doi.org/10.47275/2692-5222-128

Received: January 19, 2025; **Accepted:** March 13, 2025; **Published:** March 18, 2025

Introduction

The relationship between food, nutrients, and immunity has garnered significant attention in recent years, particularly as researchers explore how dietary components can influence health outcomes [1, 2]. Recent advancements in nutritional health focus on the role of various food sources and their impact on immune function. One of the critical areas of research is the use of intake biomarkers to objectively assess dietary habits and their association with health outcomes [3, 4]. Prentice [5] discusses the potential of metabolomics profiles derived from blood and urine to enhance nutritional epidemiology. This methodology could provide insights into how specific food and nutrient intakes correlate with chronic diseases, thereby making dietary recommendations aimed at improving immune health. Fermentation biotechnology has emerged as a promising approach to enhance the nutritional quality of food products. Fan et al. [6] highlights the benefits of fermented wheat bran, which not only improves the degradation of cell wall fibers but also enhances the nutritional profile of whole grain products. This process may contribute to better health outcomes by improving nutrient absorption and supporting immune function.

The role of specific nutrients in modulating immune responses is also critical [7, 8]. Vassilopoulou et al. [9] emphasizes the importance of allergenic proteins, iron, and vitamin A, particularly under conditions of inflammation. Their findings suggest that while these nutrients may have reduced bioavailability during inflammatory states, they can also support immune cell function when adequately absorbed. This dual role underscores the need for dietary strategies that enhance nutrient absorption, especially in populations at risk of malnutrition. Biofortification is another innovative strategy aimed at improving the nutritional content of food crops (Figure 1) [10]. Słyszyk et al. [11] discuss the process of fungal biofortification, which can enhance the levels of essential nutrients in mushrooms, thereby potentially improving dietary intake and supporting immune health. Similarly, Jha et al. [12] explore biofortification in fruit crops, highlighting its potential to address micronutrient deficiencies in developing regions, which is crucial for maintaining immune function in vulnerable populations.

The impact of dietary patterns on health is further illustrated in the review by Ribet et al. [13], which examines the nutritional contribution of bread. Their findings indicate that bread consumption

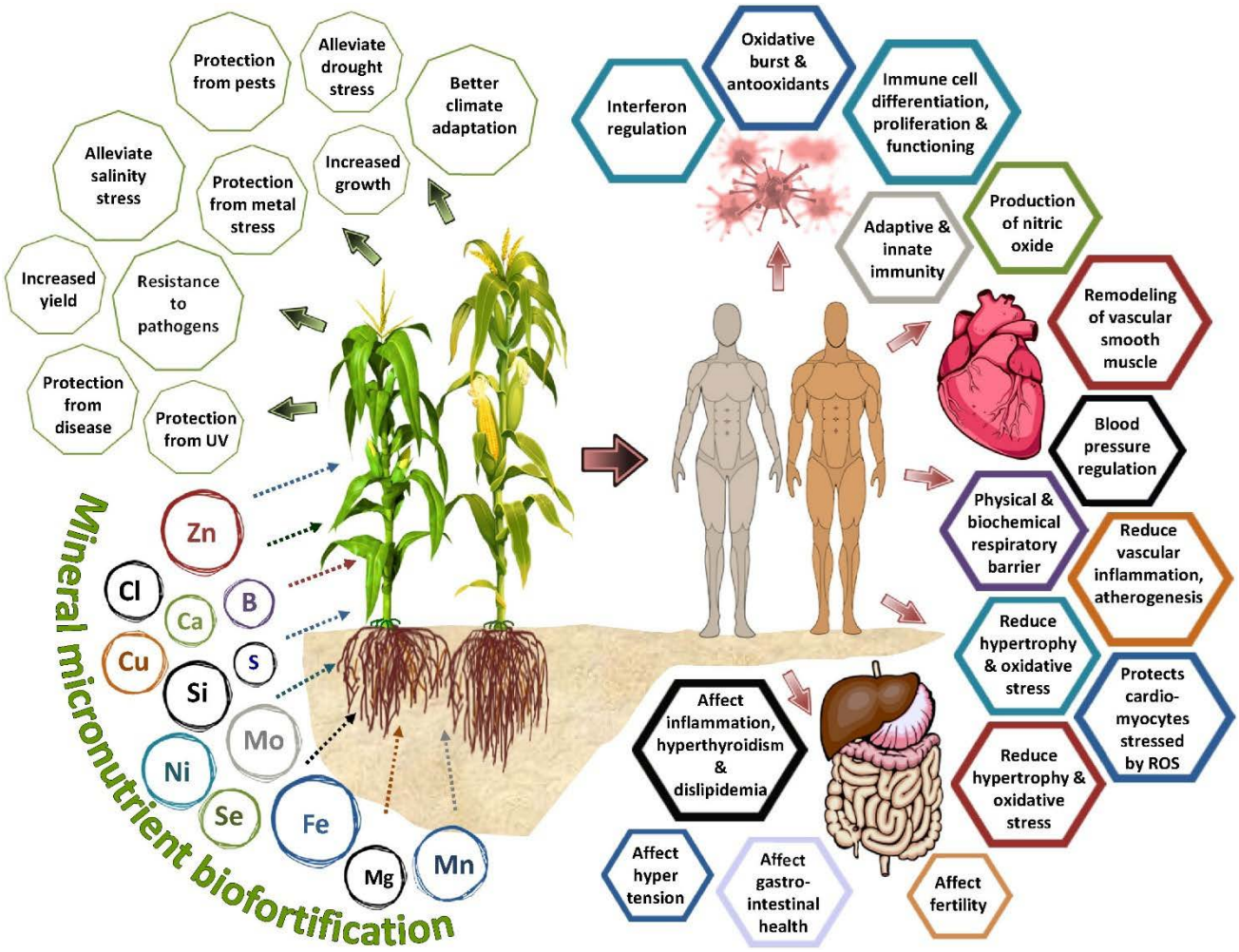

Figure 1: Influence of mineral micronutrient biofortification on the plant physiological processes and its relation to human health and immunity [10].

is associated with various health outcomes, including cardiometabolic health, suggesting that staple foods can play a significant role in overall dietary quality and immune support [13]. The interplay between food, nutrients, and immunity is complex and multifaceted [14, 15]. Advances in methodologies for assessing dietary intake, innovative food processing techniques, and strategies for enhancing nutrient content are all contributing to a deeper understanding of how nutrition can bolster immune health [16, 17]. Continued research in these areas is essential for developing effective dietary interventions that promote health and prevent disease.

The relationship between food, nutrients, and immunity has garnered significant attention in recent years, particularly in light of global health challenges such as the COVID-19 pandemic [18-20]. Nutritional health plays a crucial role in maintaining and enhancing the immune system, which is essential for combating infections and diseases [21, 22]. This review explores recent advances in nutritional health, focusing on the role of various foods and nutrients in supporting immune function.

The Role of Nutrients in Immune Function

The role of nutrients in immune function is a multifaceted area of research that highlights the intricate connections between dietary components, immune responses, and various health conditions [23, 24]. Recent studies have provided valuable insights into how specific nutrients can modulate immune function, particularly in the context of chronic diseases and aging [23, 24]. One significant nutrient that has garnered attention is vitamin D. Research by Soda et al. [25] emphasizes the importance of adequate vitamin D levels in maintaining a balanced immune response, particularly in conditions like Hashimoto's thyroiditis, which is characterized by chronic inflammation and autoantibody production. The review indicates that vitamin D can inhibit pro-inflammatory cytokine secretion, thereby promoting an immune balance that may alleviate symptoms associated with autoimmune disorders [25]. This aligns with findings from Balamurugan et al. [26], who discuss the role of various micronutrients, including vitamin D, as immunomodulators in the aging population, suggesting that targeted nutritional supplementation could enhance immune resilience and counteract inflammation-related issues.

Selenium is another nutrient that has been linked to immune function, particularly in the context of thyroid health. Jiang et al. [27] conducted a Mendelian randomization analysis to explore the relationship between dietary selenium and thyroid dysfunction, highlighting the mediating role of immune cells in this process. This study underscores the potential of selenium to influence immune responses and thyroid health, suggesting that adequate selenium intake may be crucial for maintaining immune function and preventing

thyroid-related disorders [27]. The gut microbiota also plays a critical role in nutrient metabolism and immune modulation. Dontamsetti et al. [28] reviews the interactions between luminal nutrients and gut epithelium, noting that various nutrients and metabolites can influence immune cell activity. This interaction is essential for maintaining gut health and overall immune function, as the gut microbiome is known to produce metabolites that can modulate immune responses [28]. Furthermore, the metabolic reprogramming of immune cells in response to nutrient availability has been highlighted in the context of cancer. Li et al. [29] discussed how tumor cells can alter the immune microenvironment through nutrient competition, affecting immune cell function and promoting immune evasion. This suggests that understanding the metabolic needs of immune cells could be crucial for developing effective immunotherapies [29].

Nutrients are vital for the proper functioning of the immune system (Table 1). Vitamins and minerals such as vitamin C, vitamin D, zinc, and selenium have been shown to enhance immune responses [30, 31]. For instance, vitamin C is known for its role in supporting various cellular functions of both the innate and adaptive immune system, while zinc is crucial for the development and function of immune cells [32]. A balanced diet rich in these nutrients can significantly reduce the risk of infections and improve overall health. The interactions between dietary components, gut microbiota, and immune cells further complicate this relationship, suggesting that a holistic approach to nutrition may be necessary to optimize immune health [33, 34]. Future research should continue to explore these connections to develop targeted nutritional strategies for enhancing immune resilience across different populations.

Plant-based Foods and Immunity

Plant-based foods have been increasingly recognized for their potential to enhance immunity, particularly in the context of viral infections such as COVID-19 [35, 36]. These foods are rich in essential vitamins, minerals, and bioactive compounds that support the immune system. The consumption of plant-based diets has been associated with improved immune responses and reduced severity of infections [37, 38]. This section explores the role of plant-based foods in boosting immunity, focusing on their nutritional components, bioactive compounds, and overall health benefits. Plant-based foods, particularly leafy vegetables, are essential for maintaining a robust immune system. They are rich in vitamins, minerals, and antioxidants that help combat oxidative stress and inflammation. Research indicates that a diet high in fruits and vegetables can enhance the immune response and reduce the incidence of infections [32]. For example, leafy greens like *Moringa oleifera* are particularly noted for their high folic acid content, which is beneficial for immune function [32].

Plant-based foods are rich in essential vitamins such as C, D, and E, and minerals like zinc, selenium, and magnesium, which are crucial for immune function [39, 40]. These nutrients help in the formation of immune cells and enhance the body's ability to fight infections

Table 1: Nutrients and their roles in immune function.

Nutrient	Immune function	Primary food sources	Recommended daily intake
Vitamin A	Maintains integrity of mucosal surfaces; supports function of T and B lymphocytes	Liver, sweet potatoes, carrots, spinach, fortified dairy products	Men: 900 µg/day; Women: 700 µg/day
Vitamin C	Enhances function of phagocytes; supports skin barrier function; acts as an antioxidant	Citrus fruits, strawberries, bell peppers, broccoli, Brussels sprouts	Adults: 75 to 90 mg/day
Vitamin D	Modulates innate and adaptive immune responses; promotes antimicrobial peptide expression	Fatty fish (e.g., salmon), fortified dairy products, egg yolks, sunlight exposure	Adults: 600 to 800 IU/day
Vitamin E	Protects cell membranes from oxidative damage; supports T-cell function	Nuts (e.g., almonds), seeds, spinach, sunflower oil	Adults: 15 mg/day
Vitamin B6	Supports biochemical reactions in the immune system; aids in antibody production	Poultry, fish, potatoes, bananas, fortified cereals	Adults: 1.3 to 1.7 mg/day
Vitamin B12	Essential for red blood cell formation and DNA synthesis; supports immune cell function	Meat, dairy products, fortified cereals	Adults: 2.4 µg/day
Folate (Vitamin B9)	Necessary for DNA synthesis and repair; supports production of WBC	Leafy greens, legumes, fortified grains	Adults: 400 µg/day
Zinc	Essential for development and function of immune cells; supports skin integrity	Meat, shellfish, legumes, nuts, whole grains	Men: 11 mg/day; Women: 8 mg/day
Selenium	Plays a role in antioxidant defense systems; influences development and function of immune cells.	Brazil nuts, seafood, meats, cereals.	Adults: 55 µg/day
Iron	Necessary for proliferation and maturation of immune cells; supports production of reactive oxygen species used to kill pathogens	Red meat, poultry, legumes, fortified cereals, spinach	Men: 8 mg/day; Women: 18 mg/day
Copper	Supports development and maintenance of immune system; involved in production of WBC	Shellfish, nuts, seeds, whole-grain products	Adults: 900 µg/day
Magnesium	Involved in numerous biochemical reactions, supports immune cell function	Nuts, seeds, whole grains, leafy green vegetables	Men: 400 to 420 mg/day; Women: 310 to 320 mg/day
Omega-3 fatty acids	Modulate inflammatory responses; support function of immune cells	Fatty fish (e.g., mackerel, sardines), flaxseeds, walnuts	No established RDA; 250 to 500 mg/day of EPA and DHA combined is often recommended
Protein	Provides amino acids necessary for synthesis of immune mediators and antibodies; supports proliferation of immune cells	Meat, poultry, fish, dairy products, legumes, nuts, seeds	0.8 g/kg body weight/day
Probiotics	Enhance gut microbiota composition; modulate gut-associated lymphoid tissue responses	Yogurt with live cultures, kefir, fermented foods (e.g., sauerkraut, kimchi)	No established RDA; varies based on strain and product
Polyphenols	Possess antioxidant properties; modulate immune responses	Berries, tea, dark chocolate, red wine, fruits, vegetables	No established RDA; beneficial effects observed with regular consumption of polyphenol-rich foods
Flavonoids	Exhibit anti-inflammatory and antioxidant effects; support immune health	Onions, apples, berries, citrus fruits, tea	No established RDA; included as part of a diet rich in fruits and vegetables

[41, 42]. Compounds like glutathione and quercetin found in plant-based foods act as powerful antioxidants, reducing oxidative stress and inflammation, which are critical in managing viral infections like COVID-19 [42, 43]. Ingredients such as turmeric, ginger, garlic, and neem have been highlighted for their immunomodulatory properties. These bioactive compounds can enhance immune responses and possess antiviral properties [41, 44]. Plant-based functional foods contain bioactive compounds that influence immune organs and pathways, promoting a balanced immune response. This includes influencing cellular and humoral immunity, as well as nonspecific immune responses [45].

A study by Sharma [46] outlined in the paper aims to explore the relationship between plant-based food intake and COVID-19 outcomes. The study categorized 500 adults aged 18 to 65 who tested positive for COVID-19 in 2022 into different severity groups: asymptomatic, mild, moderate, severe, and critical. It was anticipated that participants with the highest and most frequent intake of plant-based foods and seafood will report milder COVID-19 symptoms. This is aligned with previous studies suggesting that a diet rich in plant-based foods can enhance immune response. Conversely, those with the lowest intake of plant-based foods were expected to exhibit symptoms associated with the critical and severe COVID-19 groups. This suggested a potential link between lower plant-based food consumption and more severe COVID-19 outcomes. The study posits that plant-based foods are rich in vitamins and minerals that serve as anti-inflammatories and boost immunity. This nutritional profile might have contributed to better health outcomes in individuals infected with COVID-19. The research also highlighted that plant-based diets are typically low in fat and sodium, which can lead to lower body mass index and reduced risk of comorbidities such as heart disease. This reduction in comorbidities may further decrease the risk of severe COVID-19 symptoms. The study concluded that adopting a plant-based diet could be a beneficial lifestyle change for managing COVID-19, emphasizing the importance of nutrition in enhancing immunity against infectious diseases. Overall, the expected results of the study suggest a significant association between plant-based food intake and the severity of COVID-19 symptoms, highlighting the potential role of diet in public health strategies during the pandemic [46].

Another study by Park and Kang [47] investigated the relationship between overactivated immunity and the risk of metabolic syndrome, along with the impact of lifestyle factors such as diet and physical activity. The research involved 40,768 adults over 40 years old, collected from a large-scale hospital-based cohort study conducted between 2010 and 2013. Participants were categorized based on white blood cell counts (WBC) and serum C-reactive protein (CRP) levels into four groups: (i) L-WBC + L-CRP (n = 25,604), (ii) H-WBC + L-CRP (n = 13,880), (iii) L-WBC + H-CRP (n = 464), and (iv) H-WBC + H-CRP (n = 820). The study found that individuals in the H-WBC + L-CRP and H-WBC + H-CRP groups had a significantly higher risk of developing metabolic syndrome, with odds ratios of 1.75 and 1.86, respectively, compared to the L-WBC + L-CRP group. Key components of metabolic syndrome, such as plasma glucose, triglyceride levels, and systolic blood pressure, were found to be higher in the H-WBC + L-CRP and H-WBC + H-CRP groups compared to the L-WBC + L-CRP group. The highest risk of hyperglycemia and elevated HbA1c levels was observed in the H-WBC + H-CRP group, indicating a strong association between overactivated immunity and metabolic disturbances. The study highlighted that a plant-based diet, physical activity, and non-smoking behaviors were associated with lower WBC counts and CRP levels. Conversely, a Western-style diet was linked to increased CRP levels. The interaction between a high intake of plant-based diet and smoking status significantly influenced metabolic syndrome risk, with low plant-based diet intake and current smoking correlating with higher metabolic syndrome risk in the H-WBC + H-CRP group. In conclusion, the study suggests that overactivated immunity, as indicated by elevated CRP and WBC levels, is associated with an increased risk of metabolic syndrome, and that lifestyle modifications, particularly through diet and physical activity, may help mitigate this risk [47].

While plant-based foods offer numerous benefits for enhancing immunity (Table 2), it is important to consider a balanced approach to diet and lifestyle [48, 49]. The integration of plant-based foods should be part of a comprehensive strategy that includes regular physical activity and other healthy lifestyle choices [50]. Additionally, while plant-based diets are beneficial, they should be well-planned to ensure adequate intake of all essential nutrients, particularly for individuals with specific dietary needs or restrictions.

Functional Foods and Nutraceuticals

Functional foods and nutraceuticals have emerged as significant contributors to enhancing immunity, offering potential benefits beyond basic nutrition [51, 52]. These foods and supplements contain bioactive compounds that can modulate immune responses, reduce inflammation, and provide antioxidant, antibacterial, and antiviral properties [53, 54]. The integration of these elements into daily diets can help in disease prevention and health promotion, particularly in the context of chronic diseases and viral infections [55]. Functional foods, which provide health benefits beyond basic nutrition, have gained popularity as immune boosters. Foods rich in bioactive compounds, such as probiotics, polyunsaturated fatty acids, and phytochemicals, have been shown to possess immunomodulatory properties [52]. For instance, dairy-derived proteins and egg whites have been highlighted for their potential to enhance immune responses against infections like COVID-19 [56]. The incorporation of these functional foods into daily diets can play a significant role in improving health outcomes.

Functional foods and nutraceuticals contain ingredients like polyphenolic antioxidants, vitamins, probiotics, prebiotics, and peptides, which act as immunomodulators [57, 58]. These compounds can stimulate immune cells, enhance antibody production, and regulate cytokine secretion, thereby supporting both innate and acquired immune responses [57, 59]. Probiotics (Figure 2) and prebiotics, in particular, play a crucial role in maintaining gut health, which is closely linked to immune function [60]. A healthy gut microbiome can enhance the gut-associated lymphoid tissue, a critical component of the immune system [61]. Nutraceuticals and functional foods have been shown to possess multiple therapeutic benefits, including anti-inflammatory, antimicrobial, and antioxidant activities. These properties are essential in preventing and managing conditions such as obesity, diabetes, cardiovascular diseases, and autoimmune disorders [62, 63]. The consumption of foods rich in omega fatty acids, vitamins, and phytochemicals can help reduce the risk of chronic illnesses by filling nutritional gaps and regulating disease pathways [64].

A study by Liu et al. [65] on nutritional interventions for burn patients yielded several significant results that highlight the effectiveness of targeted nutritional strategies. The research involved 120 burn patients enrolled between December 2022 and January 2024, focusing on their immune function and infection rates through individualized nutritional interventions. The interventions included: (i) protein

Table 2: Plant-based foods that enhance immunity.

Food	Key nutrients	Immune supporting functions	Consumption tips
Citrus fruits	Vitamin C	Boosts WBC production; enhances skin barrier; supports iron absorption	Consume fresh or as juice; pair with iron-rich foods to enhance absorption
Red bell peppers	Vitamin C and beta-carotene	Provides more vitamin C than citrus; beta-carotene converts to vitamin A, supporting mucosal health	Eat raw in salads or light sauté to retain nutrients
Garlic	Allicin	Stimulates WBC; exhibits antiviral, antifungal, and antibacterial properties	Crush or chop and let sit before cooking to activate allicin
Ginger	Gingerol and antioxidants	Reduces inflammation; supports immune response; aids digestion	Use fresh in teas, stir-fries, or smoothies
Turmeric	Curcumin	Anti-inflammatory; enhances antibody responses; may improve immune cell function	Combine with black pepper to enhance curcumin absorption
Spinach	Vitamins A, C, E, and antioxidants	Enhances infection-fighting ability; protects cells from oxidative stress	Consume raw or lightly cooked to preserve nutrients
Broccoli	Vitamins A, C, E, fiber, and antioxidants	Supports immune defense; contains sulforaphane, which may boost immune system	Steam or roast to retain maximum nutrients
Mushrooms	Beta-glucans and B vitamins	Enhance WBC activity; modulate immune response; reduce inflammation	Include varieties like shiitake, maitake, and reishi in meals
Almonds	Vitamin E and healthy fats	Acts as an antioxidant; supports immune cell function; protects against oxidative stress	Snack on raw or roasted; add to cereals or salads
Sunflower seeds	Vitamin E and selenium	Boosts immune function; acts as an antioxidant; supports WBC production	Sprinkle on salads, yogurt, or oatmeal
Chia seeds	Omega-3 fatty acids, fiber, and protein	Reduce inflammation; support immune cell membranes; promote gut health	Add to smoothies, puddings, or baked goods
Sweet potatoes	Beta-carotene (Vitamin A)	Enhances skin barrier; supports mucosal surfaces; promotes WBC production	Bake, roast, or mash; pair with healthy fats for better absorption
Carrots	Beta-carotene (Vitamin A)	Supports mucosal health; enhances immune defense; acts as an antioxidant	Eat raw, steamed, or juiced
Berries	Vitamin C, antioxidants, and fiber	Protect against oxidative stress; support immune cell function; promote gut health	Consume fresh, frozen, or in smoothies
Whole grains	Fiber, B vitamins, and zinc	Support gut microbiota; enhance immune response; provide essential nutrients	Choose brown rice, quinoa, oats, and whole wheat products
Legumes (beans, lentils)	Protein, iron, zinc, and fiber	Provide essential amino acids; support gut health; enhance immune cell function	Incorporate into soups, stews, or salads
Fermented foods (miso, tempeh)	Probiotics and enzymes	Promote healthy gut microbiota; enhance immune response; improve digestion	Include in soups, stir-fries, or as side dishes
Green tea	Catechins and antioxidants	Enhance immune function; provide antiviral properties; reduce inflammation	Drink freshly brewed; avoid adding excessive sugar
Dark chocolate	Flavonoids and antioxidants	Boost immune system; protect against oxidative stress; support heart health	Choose dark chocolate with at least 70% cocoa; consume in moderation

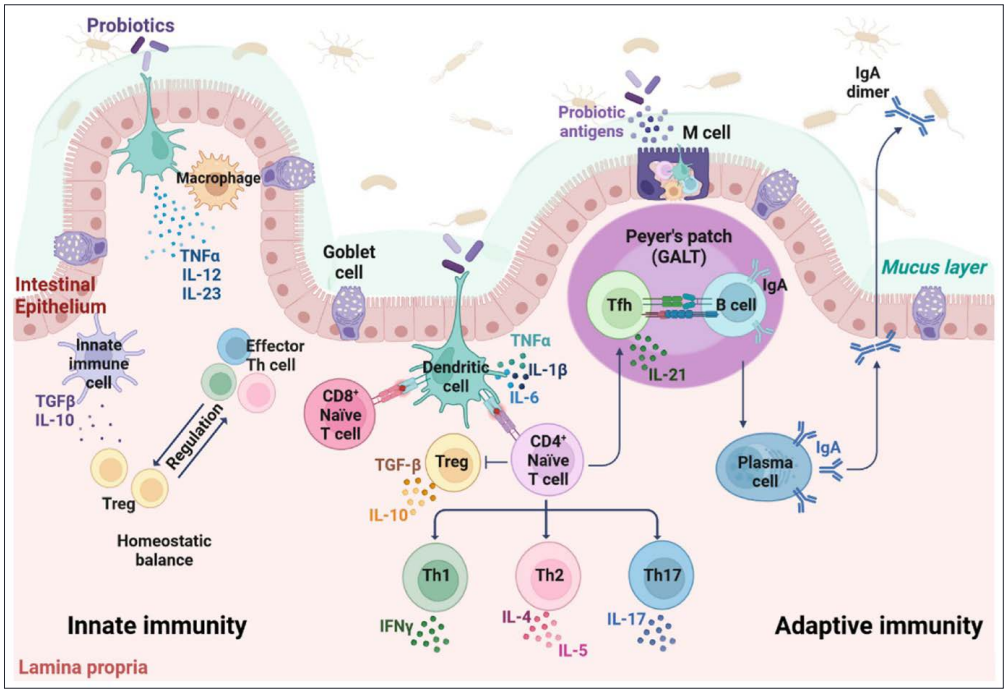

Figure 2: Schematic representation of the interaction between host intestinal immune cells and probiotics [60].

supplementation (essential for leukocyte production, which is crucial for immune response), (ii) micronutrient replenishment (specifically, zinc and vitamin C were supplemented to enhance immune function), and (iii) anti-inflammatory nutrients (Omega-3 fatty acids were included to reduce inflammation and promote wound healing). Nutrients were provided through oral, enteral, and parenteral routes, tailored to the patients' dietary preferences and medical conditions. The study assessed various outcomes, including changes in leukocyte and lymphocyte counts, levels of cytokines (which are important for immune signaling), infection rates and wound healing rates, and length of hospital stays. There was a significant increase in leukocyte counts post-intervention, indicating improved immune function. The levels of cytokines decreased significantly, suggesting a reduction in inflammation. The infection rate among patients dropped from 30% to 14.2%, which is a notable reduction and statistically significant ($p < 0.05$). The results underscored the effectiveness of the nutritional interventions in enhancing immune health and reducing infection rates in burn patients, advocating for the integration of comprehensive nutritional strategies in burn injury management. These findings provide strong evidence for the role of tailored nutritional interventions in improving clinical outcomes for burn patients, emphasizing the importance of nutrition in recovery and immune support [65].

A study by Yoshikawa and High [66] highlights that older adults are at a significant risk of malnutrition, which can lead to a higher chance of infections. Nutritional supplementation can help reduce this risk and improve immune function in this age group. It emphasizes the importance of specific nutritional strategies, such as daily multivitamin or trace-mineral supplements. The recommended dosages include 120 mg of elemental zinc and 100 mg of selenium, along with additional vitamin E to reach a total of 200 mg per day. The review discusses that certain nutritional interventions, like cranberry juice, may help reduce urinary tract infections in older adults, particularly those living in long-term care facilities. This could also lead to a decrease in unnecessary antibiotic use. The paper notes that while many studies have shown improvements in surrogate markers of immune response (like antibody levels), there are few studies demonstrating clear clinical benefits, such as reduced infections or hospitalizations. It mentions that trace mineral supplementation, particularly zinc and selenium, has shown promise in reducing infection rates among institutionalized elderly individuals. This suggests that these minerals may be crucial for preventing infections. The authors point out that malnutrition can lead to immune dysfunction, which is characterized by a decline in the body's ability to respond to infections. This dysfunction is partly due to age-related changes in the immune system. The paper concludes that while nutritional strategies can be beneficial, more research is needed to identify specific groups of elderly individuals who would benefit the most from these interventions. Future studies should focus on clinical outcomes rather than just immune markers. Overall, the findings suggest that addressing nutritional deficiencies in older adults is essential for improving their immune health and reducing the risk of infections [66].

The interplay between food, nutrients, and immunity is a critical area of research that holds promise for improving public health. A diet rich in diverse, nutrient-dense foods can significantly enhance immune function and reduce the risk of infections [67, 68]. As the global community continues to navigate health challenges, prioritizing nutritional health through informed dietary choices will be essential for fostering resilience and well-being.

Specific Foods and Their Health Benefits

The relationship between specific foods and their immune-related health benefits has garnered significant attention in recent literature, highlighting various dietary components and their roles in modulating immune responses. This section focuses on recent studies that explore the health benefits of specific foods, particularly focusing on short-chain fatty acids (SCFAs), polyphenols, probiotics, and traditional plant-based foods. Facchin et al. [69] provides a comprehensive overview of SCFAs, which are produced through the fermentation of dietary fibers in the gut (Figure 3) [70]. These metabolites, including acetate, propionate, and butyrate, are associated with numerous health benefits, particularly in enhancing gut health and modulating immune responses. The production and absorption dynamics of SCFAs are crucial for understanding their therapeutic implications, suggesting that dietary interventions rich in fiber could promote SCFA production and, consequently, immune health [69]. The role of the

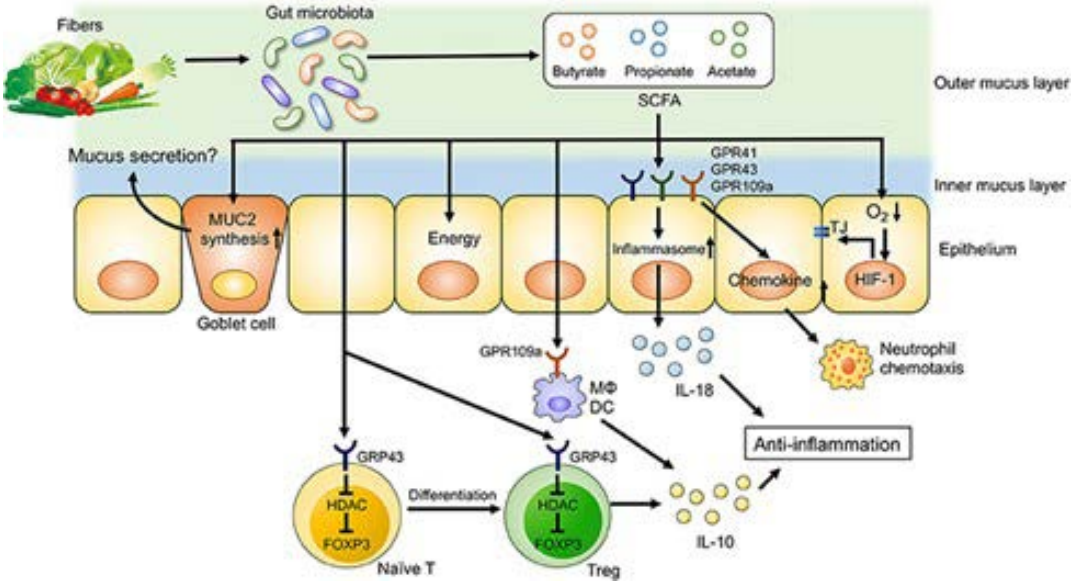

Figure 3: Dietary fiber-derived SCFAs regulate intestinal homeostasis [70].

gut microbiota in immune modulation is further explored by Shan et al. [71], who examined the potential of functional foods in treating rheumatoid arthritis. This study identifies specific microbial taxa linked to rheumatoid arthritis and suggests that dietary strategies targeting these microbes could offer therapeutic benefits. The modulation of gut microbiota through diet underscores the importance of specific foods in influencing immune-related health outcomes [71].

Polyphenols, particularly those found in Tartary buckwheat, have also been highlighted for their immune-related benefits. Perlmutter et al. [72] investigates the epigenetic effects of a polyphenol-rich supplement on immune cells, suggesting that these compounds may influence longevity-related physiological pathways. This research indicates that incorporating polyphenol-rich foods into the diet could have significant implications for immune health and aging [72]. Probiotics, as discussed by Pyo et al. [73] and Mafe et al. [74], are another critical component of immune health. Pyo et al. [73] emphasizes the anti-viral, immunomodulatory, and anti-cancer benefits of probiotics found in fermented foods. Mafe et al. [74] expands on this by exploring how probiotics can enhance gut health and address metabolic disorders, linking their consumption to improved immune support and overall health outcomes. The incorporation of probiotics into both traditional and modern food systems presents a promising avenue for enhancing immune function.

The concept of postbiotics, as explored by Mojgani et al. [75] and D'Amico et al. [76], further enriches the discussion on food-derived immune benefits. Mojgani et al. [75] highlight the immunomodulatory functions of postbiotic metabolites, suggesting their potential to enhance vaccine responses and improve disease prevention strategies. D'Amico et al. [76] focus on the microencapsulation of probiotics, which enhances their stability and health benefits, indicating that innovative food technologies can optimize the immune-enhancing properties of probiotics. The potential of traditional plant-based foods in promoting healthy aging and immune function is underscored by Das et al. [77]. This review suggests that these foods may offer practical solutions for counteracting aging effects and improving overall well-being, although further research is needed to establish their efficacy and safety [77].

Pineapple (*Ananas comosus*) is a tropical fruit known for its rich nutritional profile, including vitamins, minerals, and bioactive compounds. It has been associated with various health benefits, including anti-inflammatory and antioxidant properties, which are crucial for immune health [78]. The increasing demand for pineapple in the global market reflects its recognized health benefits and potential for food-based processing. Millets are an underutilized group of grains that are rich in essential nutrients and bioactive compounds. They have been shown to possess high antioxidant activity and can contribute to improved health outcomes, including enhanced immune function [79, 80]. The promotion of millets as a nutritious alternative to staple grains like rice and wheat is gaining traction, particularly in regions facing food security challenges. Quinoa (*Chenopodium quinoa*) greens are another nutrient-dense food that offers numerous health benefits. They are rich in essential amino acids, vitamins, and minerals, making them a valuable addition to the diet for supporting immune health [81]. Despite their potential, quinoa greens remain underutilized in many diets, highlighting the need for increased awareness and consumption. Curcumin can also provide an immunomodulatory effect (Figure 4) [82].

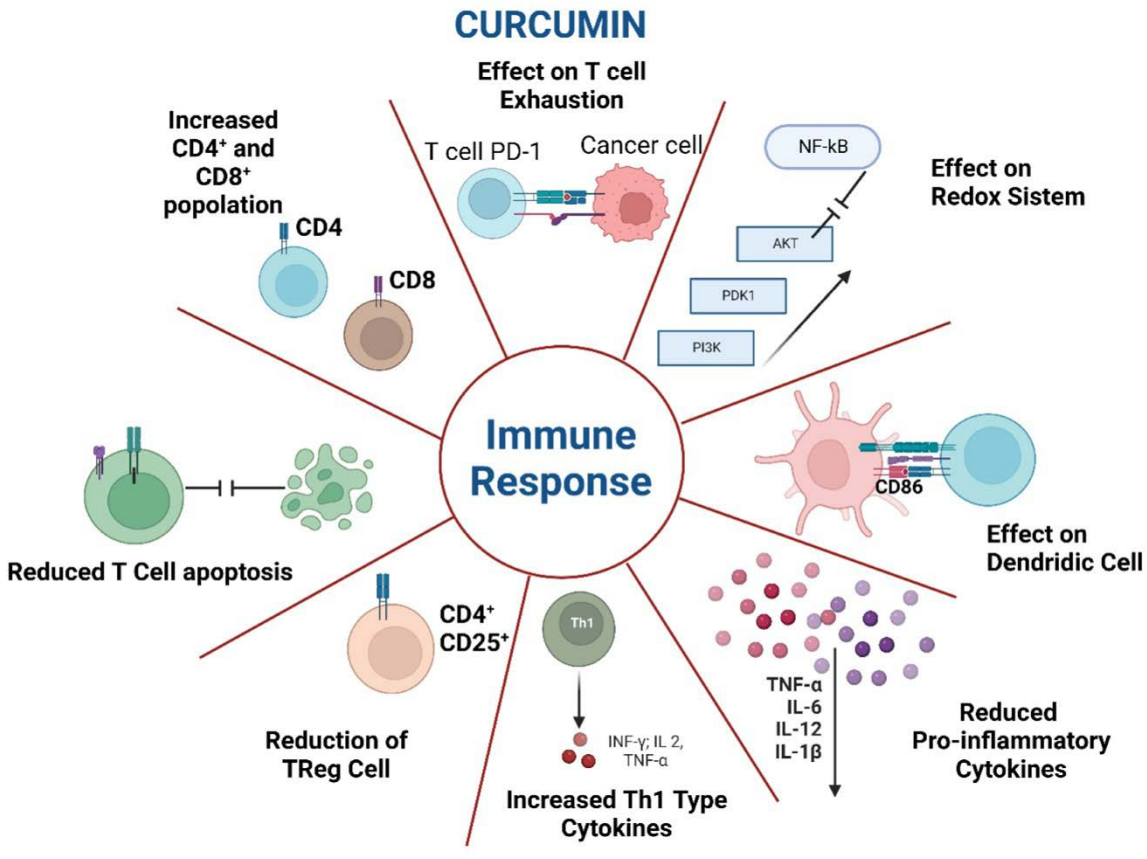

Figure 4: Effects of curcumin on immunological effectors [82].

A study by Kim et al. [83] reviews various functional foods that can enhance the immune system, highlighting their potential to protect against diseases like cancer and infections. These foods include ginseng, mushrooms, chlorella, and probiotics, specifically *Lactobacillus plantarum*. Ginseng, particularly white and red ginseng, has been shown to stimulate immune cell activity. White ginseng enhances the function of macrophages and natural killer cells, leading to increased production of important immune signaling molecules like cytokines (e.g., TNF-α, IL-6). Red ginseng also boosts natural killer cell activity and improves the immune response against viral infections. Mushrooms, such as *Agaricus blazei* and *Ganoderma lucidum*, have demonstrated immunostimulatory effects. For instance, *A. blazei* can enhance cytokine production and activate immune cells, which may help in tumor rejection. *G. lucidum* has been shown to increase the activity of macrophages and natural killer cells, contributing to its potential cancer-fighting properties. Chlorella, a type of green algae, has been found to improve immune responses in both animal models and humans. It can enhance the activity of natural killer cells and increase the production of cytokines, which are crucial for a strong immune response. Probiotics like *L. plantarum* have been shown to enhance both innate and adaptive immune responses. They can increase the production of antibodies and improve the activity of immune cells, which helps the body fight off infections. Overall, the findings suggest that incorporating these functional foods into the diet may strengthen the immune system and provide a natural way to combat diseases. The paper emphasizes the importance of further research to explore the mechanisms behind these effects and to identify new functional foods that can support immune health [83].

Another review by Stephen et al. [67] highlights various nutrients found in natural foods that contribute to immune boosting. These include vitamins (A, C, E, and D), minerals (zinc, calcium, magnesium, and iron), omega fatty acids, selenium, and phytochemicals. Each of these components plays a significant role in supporting the immune system and protecting against diseases. The paper discusses the health benefits associated with consuming immune-boosting foods. These foods are linked to improvements in various health conditions, including cancer, diabetes, heart disease, skin health, eye health, bone health, blood pressure regulation, brain development, and stress reduction. Furthermore, antimicrobial, antibacterial, antifungal, anti-aging, anti-allergenicity, antimalarial, anti-mutagenicity, and anti-inflammatory effects. The review also provides a list of specific foods that are particularly beneficial for immunity. These include almonds, spinach, citrus fruits, avocado, red bell pepper, pomegranate, kiwi, garlic, ginger, and passion fruit. Each of these foods is noted for its positive impact on health and immunity. The paper emphasizes the importance of a balanced diet that includes these immune-boosting foods. It suggests that maintaining a proper diet, along with adequate sleep and regular exercise, is crucial for optimal health and immune function. The findings indicate that there is a growing awareness among consumers about the health benefits of natural foods. This shift in lifestyle choices is seen as a positive trend towards enhancing immune responses and overall health. In summary, the paper underscores the critical role of natural foods in boosting immunity and highlights the need for dietary recommendations that incorporate these beneficial components for better health outcomes [67].

Overall, the literature indicates that specific foods, including those rich in SCFAs, polyphenols, probiotics, and traditional plant-based ingredients, play a vital role in modulating immune responses and promoting health. Continued research in this area is essential to fully understand the mechanisms through which these foods exert their effects and to develop targeted dietary interventions for enhancing immune health. Several specific foods have been identified for their nutritional value and health benefits, particularly in relation to immunity.

Challenges and Future Directions

Despite the clear benefits of various foods and nutrients for immune health, several challenges remain. The lack of awareness regarding the nutritional value of certain foods, such as millets and quinoa greens, limits their consumption [80]. Additionally, the food industry faces challenges in developing and promoting functional foods that effectively enhance immune system [52]. The nutraceutical industry faces challenges such as a lack of awareness, insufficient clinical trials, and the need for standardized dosages. These barriers hinder the translation of research findings into marketable products [52, 84]. Further research is needed to explore the mechanisms of action, safe and effective dosages, and strategies to improve consumer adherence to functional foods and nutraceuticals [64].

Future research should focus on the development of innovative food products that incorporate these nutrient-rich ingredients, as well as strategies to educate consumers about the importance of nutrition in supporting immune health. Furthermore, exploring the role of nutrigenomics in understanding how individual genetic profiles respond to different nutrients could pave the way for personalized nutrition strategies [85]. While the potential of functional foods and nutraceuticals in enhancing immunity is well-supported by research, it is essential to consider the broader context of dietary habits and lifestyle. A balanced diet, regular physical activity, and other healthy lifestyle choices are crucial for maintaining a robust immune system. Additionally, the integration of functional foods and nutraceuticals should be guided by scientific evidence and personalized to individual health needs and conditions.

Conclusion

The evolving understanding of the intricate relationship between food, nutrients, and immunity marks a promising turning point in both clinical nutrition and public health. Scientific evidence now firmly supports those strategic dietary choices—rich in essential vitamins, minerals, phytochemicals, and bioactive compounds—can significantly enhance immune responses, reduce inflammation, and lower the risk of chronic and infectious diseases. Functional foods, nutraceuticals, and plant-based diets are not mere health trends but scientifically grounded approaches that hold the potential to transform immune resilience across populations. These nutritional tools empower individuals and healthcare systems alike to adopt preventive strategies that are both natural and sustainable.

Looking ahead, the integration of advanced methodologies like metabolomics, nutrigenomics, and personalized nutrition will usher in a new era of precision dietary interventions. Such advancements will allow nutrition to move from general recommendations to targeted solutions that align with individual health needs. The future of immune health lies in making informed, nutrient-rich food choices an integral part of everyday life. By embracing the synergy between nutrition and immunity, we can build stronger, more resilient communities—better equipped to face current and emerging health challenges. This is not just a shift in diet; it is a shift in mindset, policy, and long-term health strategy.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Munteanu C, Schwartz B (2022) The relationship between nutrition and the immune system. Front Nutr 9: 1-23. https://doi.org/10.3389/fnut.2022.1082500
2. Shao T, Verma HK, Pande B, Costanzo V, Ye W, et al. (2021) Physical activity and nutritional influence on immune function: an important strategy to improve immunity and health status. Front Physiol 12: 1-20. https://doi.org/10.3389/fphys.2021.751374
3. Hart MJ, Torres SJ, McNaughton SA, Milte CM (2021) Dietary patterns and associations with biomarkers of inflammation in adults: a systematic review of observational studies. Nutr J 20: 1-14. https://doi.org/10.1186/s12937-021-00674-9
4. Huang Y, Zheng C, Tinker LF, Neuhouser ML, Prentice RL (2022) Biomarker-based methods and study designs to calibrate dietary intake for assessing diet–disease associations. J Nutr 152: 899-906. https://doi.org/10.1093/jn/nxab420
5. Prentice RL (2024) Intake biomarkers for nutrition and health: review and discussion of methodology issues. Metabolites 14: 276. https://doi.org/10.3390/metabo14050276
6. Fan L, Ma S, Li L, Huang J (2024) Fermentation biotechnology applied to wheat bran for the degradation of cell wall fiber and its potential health benefits: a review. Int J Biol Macromol 260: 133529. https://doi.org/10.1016/j.ijbiomac.2024.133529
7. Tourkochristou E, Triantos C, Mouzaki A (2021) The influence of nutritional factors on immunological outcomes. Front Immunol 12: 1-17. https://doi.org/10.3389/fimmu.2021.665968
8. Mitra S, Paul S, Roy S, Sutradhar H, Bin Emran T, et al. (2022) Exploring the immune-boosting functions of vitamins and minerals as nutritional food bioactive compounds: a comprehensive review. Molecules 27: 555. https://doi.org/10.3390/molecules27020555
9. Vassilopoulou E, Venter C, Roth-Walter F (2024) Malnutrition and allergies: tipping the immune balance towards health. J Clin Med 13: 4713. https://doi.org/10.3390/jcm13164713
10. Bhardwaj AK, Chejara S, Malik K, Kumar R, Kumar A, et al. (2022) Agronomic biofortification of food crops: an emerging opportunity for global food and nutritional security. Front Plant Sci 13: 1-23. https://doi.org/10.3389/fpls.2022.1055278
11. Słyszyk K, Siwulski M, Wiater A, Tomczyk M, Waśko A (2024) Biofortification of mushrooms: a promising approach. Molecules 29: 4740. https://doi.org/10.3390/molecules29194740
12. Jha A, Jayswal DK, Shikha D, Kumar A, Ahmad F (2025) Empowering vital fruit crops with enhanced nutritional contents. Front Plant Sci 16: 1-17. https://doi.org/10.3389/fpls.2025.1519673
13. Ribet L, Kassis A, Jacquier E, Monnet C, Durand-Dubief M, et al. (2024) The nutritional contribution and relationship with health of bread consumption: a narrative review. Crit Rev Food Sci Nutr 64: 5698-5725. https://doi.org/10.1080/10408398.2024.2428593
14. Umar M, Anal AK (2023) Unraveling the food-nutrition-health nexus to build healthier food systems. In Pandemics and Innovative Food Systems. CRC Press, pp 1-32.
15. Dunbar CL, Aukema HM, Calder PC, Gibson DL, Henrickson SE, et al. (2023) Nutrition and immunity: perspectives on key issues and next steps. Appl Physiol Nutr Metab 48: 484-497. https://doi.org/10.1139/apnm-2022-0276
16. Vadiveloo MK, Juul F, Sotos-Prieto M, Parekh N (2022) Perspective: novel approaches to evaluate dietary quality: combining methods to enhance measurement for dietary surveillance and interventions. Adv Nutr 13: 1009-1015. https://doi.org/10.1093/advances/nmac007
17. Xiao YL, Gong Y, Qi YJ, Shao ZM, Jiang YZ (2024) Effects of dietary intervention on human diseases: molecular mechanisms and therapeutic potential. Signal Transduct Target Ther 9: 1-34. https://doi.org/10.1038/s41392-024-01771-x
18. Manca R, Bombillar F, Glomski C, Pica A (2022) Obesity and immune system impairment: a global problem during the COVID-19 pandemic. Int J Risk Saf Med 33: 193-208. https://doi.org/10.3233/jrs-227007
19. Alagawany M, Attia YA, Farag MR, Elnesr SS, Nagadi SA, et al. (2021) The strategy of boosting the immune system under the COVID-19 pandemic. Front Vet Sci 7: 1-17. https://doi.org/10.3389/fvets.2020.570748
20. Antwi J, Appiah B, Oluwakuse B, Abu BA (2021) The nutrition-COVID-19 interplay: a review. Curr Nutr Rep 10: 364-374. https://doi.org/10.1007/s13668-021-00380-2
21. Davison G, Kehaya C, Jones AW (2016) Nutritional and physical activity interventions to improve immunity. Am J Lifestyle Med 10: 152-169. https://doi.org/10.1177/1559827614557773
22. Morales F, Montserrat-De la Paz S, Leon MJ, Rivero-Pino F (2023) Effects of malnutrition on the immune system and infection and the role of nutritional strategies regarding improvements in children's health status: a literature review. Nutrients 16: 1. https://doi.org/10.3390/nu16010001
23. Poles J, Karhu E, McGill M, McDaniel HR, Lewis JE (2021) The effects of twenty-four nutrients and phytonutrients on immune system function and inflammation: a narrative review. J Clin Transl Res 7: 333-376. https://doi.org/10.18053/jctres.07.202103.004
24. Boccardi V, Marano L (2024) Improving geriatric outcomes through nutritional and immunonutritional strategies: focus on surgical setting by a comprehensive evidence review. Ageing Res Rev 92: 102272. https://doi.org/10.1016/j.arr.2024.102272
25. Soda M, Priante C, Pesce C, De Maio G, Lombardo M (2024) The impact of vitamin D on immune function and its role in Hashimoto's thyroiditis: a narrative review. Life 14: 771. https://doi.org/10.3390/life14060771
26. Balamurugan BS, Marimuthu MMC, Sundaram VA, Saravanan B, Chandrababu P, et al. (2024) Micro nutrients as immunomodulators in the ageing population: a focus on inflammation and autoimmunity. Immunity Ageing 21: 1-15. https://doi.org/10.1186/s12979-024-00492-7
27. Jiang YJ, Xiong YQ, Huang T, Xiao YX (2024) Toenail and blood selenium mediated regulation of thyroid dysfunction through immune cells: a mediation Mendelian randomization analysis. Front Nutr 11: 1-17. https://doi.org/10.3389/fnut.2024.1378969
28. Dontamsetti KD, Pedrosa-Suarez LC, Aktar R, Peiris M (2024) Sensing of luminal contents and downstream modulation of GI function. JGH Open 8: e13083. https://doi.org/10.1002/jgh3.13083
29. Li S, Han H, Yang K, Li X, Ma L, et al. (2025) Emerging role of metabolic reprogramming in the immune microenvironment and immunotherapy of thyroid cancer. Int Immunopharmacol 144: 113702. https://doi.org/10.1016/j.intimp.2024.113702
30. Shakoor H, Feehan J, Al Dhaheri AS, Ali HI, Platat C, et al. (2021) Immune-boosting role of vitamins D, C, E, zinc, selenium and omega-3 fatty acids: could they help against COVID-19? Maturitas 143: 1-9. https://doi.org/10.1016/j.maturitas.2020.08.003
31. Kumar P, Kumar M, Bedi O, Gupta M, Kumar S, et al. (2021) Role of vitamins and minerals as immunity boosters in COVID-19. Inflammopharmacology 29: 1001-1016. https://doi.org/10.1007/s10787-021-00826-7
32. Khadim RM, Al-Fartusie FS (2021) Antioxidant vitamins and their effect on immune system. In: J Phys: Conf Ser 1853: 1-13. https://doi.org/10.1088/1742-6596/1853/1/012065
33. Wiertsema SP, van Bergenhenegouwen J, Garssen J, Knippels LM (2021) The interplay between the gut microbiome and the immune system in the context of infectious diseases throughout life and the role of nutrition in optimizing treatment strategies. Nutrients 13: 886. https://doi.org/10.3390/nu13030886
34. García-Montero C, Fraile-Martínez O, Gómez-Lahoz AM, Pekarek L, Castellanos AJ, et al. (2021) Nutritional components in Western diet versus Mediterranean diet at the gut microbiota–immune system interplay. Implications for health and disease. Nutrients 13: 699. https://doi.org/10.3390/nu13020699
35. Khalid W, Arshad MS, Ranjha MMAN, Różańska MB, Irfan S, et al. (2022) Functional constituents of plant-based foods boost immunity against acute and chronic disorders. Open Life Sci 17: 1075-1093. https://doi.org/10.1515/biol-2022-0104
36. Vishwakarma S, Panigrahi C, Barua S, Sahoo M, Mandliya S (2022) Food nutrients as inherent sources of immunomodulation during COVID-19 pandemic. Lebensm Wiss Technol 158: 113154. https://doi.org/10.1016/j.lwt.2022.113154
37. Park S, Zhang T (2021) A positive association of overactivated immunity with metabolic syndrome risk and mitigation of its association by a plant-based diet and physical activity in a large cohort study. Nutrients 13: 2308. https://doi.org/10.3390/nu13072308
38. Suardi C, Cazzaniga E, Graci S, Dongo D, Palestini P (2021) Link between viral infections, immune system, inflammation and diet. Int J Environ Res Public Health 18: 2455. https://doi.org/10.3390/ijerph18052455

39. Calder PC (2022) Foods to deliver immune-supporting nutrients. Curr Opin Food Sci 43: 136-145. https://doi.org/10.1016/j.cofs.2021.12.006

40. Vignesh A, Amal TC, Sarvalingam A, Vasanth K (2024) A review on the influence of nutraceuticals and functional foods on health. Food Chem Adv 5: 100749. https://doi.org/10.1016/j.focha.2024.100749

41. Chinababu D, Voleti VK (2024) A review of dietary suggestions during COVID-19. J Pharma Insights Res 2: 079-087. https://doi.org/10.69613/7acn6e80

42. Ahmad MH, Afzal MF, Imran M, Khan MK, Ahmad N (2022) Nutrition: a strategy for curtailing the impact of COVID-19 through immunity booster foods. In Handbook of Research on Pathophysiology and Strategies for the Management of COVID-19. IGI Global, pp 253-269.

43. Sahiba N, Sethiya A, Agarwal DK, Agarwal S (2023) An overview on immunity booster foods in coronavirus disease (COVID-19). Comb Chem High Throughput Screen 26: 1251-1284. https://doi.org/10.2174/1386207325666220629161828

44. Djaoudene O, Romano A, Bradai YD, Zebiri F, Ouchene A, et al. (2023) A global overview of dietary supplements: regulation, market trends, usage during the COVID-19 pandemic, and health effects. Nutrients 15: 3320. https://doi.org/10.3390/nu15153320

45. Jiang L, Zhang G, Li Y, Shi G, Li M (2021) Potential application of plant-based functional foods in the development of immune boosters. Front Pharmacol 12: 1-18. https://doi.org/10.3389/fphar.2021.637782

46. Sharma I (2023) Associations between plant-based food intake and COVID-19 outcomes: a study protocol. Undergrad Res Nat Clin Sci Technol J 7: 1-9. https://doi.org/10.26685/urncst.531

47. Park S, Kang S (2021) Association between polygenetic risk scores of low immunity and interactions between these scores and moderate fat intake in a large cohort. Nutrients 13: 2849. https://doi.org/10.3390/nu13082849

48. Craddock JC, Neale EP, Peoples GE, Probst YC (2020) Plant-based eating patterns and endurance performance: a focus on inflammation, oxidative stress and immune responses. Nutr Bull 45: 123-132. https://doi.org/10.1111/nbu.12427

49. Herpich C, Müller-Werdan U, Norman K (2022) Role of plant-based diets in promoting health and longevity. Maturitas 165: 47-51. https://doi.org/10.1016/j.maturitas.2022.07.003

50. Fehér A, Gazdecki M, Véha M, Szakály M, Szakály Z (2020) A comprehensive review of the benefits of and the barriers to the switch to a plant-based diet. Sustainability 12: 10. https://doi.org/10.3390/su12104136

51. Cencic A, Chingwaru W (2010) The role of functional foods, nutraceuticals, and food supplements in intestinal health. Nutrients 2: 611-625. https://doi.org/10.3390/nu2060611

52. Basak S, Gokhale J (2022) Immunity boosting nutraceuticals: current trends and challenges. J Food Biochem 46: e13902. https://doi.org/10.1111/jfbc.13902

53. Mrityunjaya M, Pavithra V, Neelam R, Janhavi P, Halami PM, et al. (2020) Immune-boosting, antioxidant and anti-inflammatory food supplements targeting pathogenesis of COVID-19. Front Immunol 11: 1-12. https://doi.org/10.3389/fimmu.2020.570122

54. Rahman MM, Mosaddik A, Alam AK (2021) Traditional foods with their constituent's antiviral and immune system modulating properties. Heliyon 7: 1-10. https://doi.org/10.1016/j.heliyon.2021.e05957

55. Airhihenbuwa CO, Tseng TS, Sutton VD, Price L (2021) Global perspectives on improving chronic disease prevention and management in diverse settings. Prev Chronic Dis 18: 1-7. https://doi.org/10.5888/pcd18.210055

56. Batiha GES, Alqarni M, Awad DA, Algammal AM, Nyamota R, et al. (2021) Dairy-derived and egg white proteins in enhancing immune system against COVID-19. Front Nutr 8: 1-13. https://doi.org/10.3389/fnut.2021.629440

57. García-Gurrola A, Wall-Medrano A, Olivas-Aguirre MA, Olivas-Aguirre FJ, Escobar-Puentes AA (2023) Immunomodulatory properties of nutraceuticals and functional foods. In Kesharwani RK, Keservani RK, Sharma AK (eds) Nutraceuticals and Functional Foods in Immunomodulators. Springer Nature, Singapore, pp 21-72.

58. Ooi SL, Pak SC (2021) Nutraceuticals in immune function. Molecules 26: 5310. https://doi.org/10.3390/molecules26175310

59. Oyedepo TA, Morakinyo AE, Babarinde SO (2022) Immune boosting activity of nutraceuticals and functional foods. In Kesharwani RK, Keservani RK, Sharma AK (eds) Immunomodulators and Human Health. Springer Nature, Singapore, pp 71-100.

60. Mazziotta C, Tognon M, Martini F, Torreggiani E, Rotondo JC (2023) Probiotics mechanism of action on immune cells and beneficial effects on human health. Cells 12: 184. https://doi.org/10.3390/cells12010184

61. Kuthiala R, Jindal P, Nalwaya NC (2022) Potential health benefits of functional foods in boosting immunity and relationship between immunosuppressant diseases and severity of viral infections-COVID-19–a review article. Asian Pac J Health Sci 9: 252-255. https://doi.org/10.21276/apjhs.2022.9.4s.48

62. Das S, Das MK, Kesharwani RK (2023) Recent advances of nutraceutical and functional foods in immune health. In Kesharwani RK, Keservani RK, Sharma AK (eds) Nutraceuticals and Functional Foods in Immunomodulators. Springer, Singapore, pp 313-330.

63. Alba G, Dakhaoui H, Santa-Maria C, Palomares F, Cejudo-Guillen M, et al. (2023) Nutraceuticals as potential therapeutic modulators in immunometabolism. Nutrients 15: 411. https://doi.org/10.3390/nu15020411

64. Sharma M, Vidhya CS, Ojha K, Yashwanth BS, Singh B, et al. (2024) The role of functional foods and nutraceuticals in disease prevention and health promotion. Eur J Nutr Food Saf 16: 61-83. https://doi.org/10.9734/ejnfs/2024/v16i21388

65. Liu S, Ji G, Tian T, Chen C, Luo B (2024) Nutritional interventions to improve immune function and reduce infection rates in burn patients. Curr Top Nutraceutical Res 22: 1097-1101. https://doi.org/10.37290/ctnr2641-452X.22:1097-1101

66. Yoshikawa TT, High KP (2001) Nutritional strategies to boost immunity and prevent infection in elderly individuals. Clin Infect Dis 33: 1892-1900. https://doi.org/10.1086/324509

67. Stephen J, Manoharan D, Radhakrishnan M (2023) Immune boosting functional components of natural foods and its health benefits. Food Prod Process Nutr 5: 1-25. https://doi.org/10.1186/s43014-023-00178-5

68. Altomare A, Giovanetti M, Baldaro F, Ciccozzi M, Cicala M, et al. (2024) The prevention of viral infections: the role of intestinal microbiota and nutritional factors. Nutrients 16: 2445. https://doi.org/10.3390/nu16152445

69. Facchin S, Bertin L, Bonazzi E, Lorenzon G, De Barba C, et al. (2024) Short-chain fatty acids and human health: from metabolic pathways to current therapeutic implications. Life 14: 559. https://doi.org/10.3390/life14050559

70. Sugihara K, Morhardt TL, Kamada N (2019) The role of dietary nutrients in inflammatory bowel disease. Front Immunol 9: 3183. https://doi.org/10.3389/fimmu.2018.03183

71. Shan L, Chelliah R, Rahman SME, Hwan Oh D (2024) Unraveling the gut microbiota's role in rheumatoid arthritis: dietary pathways to modulation and therapeutic potential. Crit Rev Food Sci Nutr 65: 1-11. https://doi.org/10.1080/10408398.2024.2362412

72. Perlmutter A, Bland JS, Chandra A, Malani SS, Smith R, et al. (2024) The impact of a polyphenol-rich supplement on epigenetic and cellular markers of immune age: a pilot clinical study. Front Nutr 11: 1-19. https://doi.org/10.3389/fnut.2024.1474597

73. Pyo Y, Kwon KH, Jung YJ (2024) Probiotic functions in fermented foods: anti-viral, immunomodulatory, and anti-cancer benefits. Foods 13: 2386. https://doi.org/10.3390/foods13152386

74. Mafe AN, Iruoghene Edo G, Akpoghelie PO, Gaaz TS, Yousif E, et al. (2025) Probiotics and food bioactives: unraveling their impact on gut microbiome, inflammation, and metabolic health. Probiotics Antimicrob Proteins 17: 1851–1892. https://doi.org/10.1007/s12602-025-10452-2

75. Mojgani N, Ashique S, Moradi M, Bagheri M, Garg A, et al. (2025) Gut microbiota and postbiotic metabolites: biotic intervention for enhancing vaccine responses and personalized medicine for disease prevention. Probiotics Antimicrob Proteins 2025: 1-23. https://doi.org/10.1007/s12602-025-10477-7

76. D'Amico V, Cavaliere M, Ivone M, Lacassia C, Celano G, et al. (2025) Microencapsulation of probiotics for enhanced stability and health benefits in dairy functional foods: a focus on pasta filata cheese. Pharmaceutics 17: 185. https://doi.org/10.3390/pharmaceutics17020185

77. Das G, Kameswaran S, Ramesh B, Bangeppagari M, Nath R, et al. (2024) Anti-aging effect of traditional plant-based food: an overview. Foods 13: 3785. https://doi.org/10.3390/foods13233785

78. Ali MM, Hashim N, Abd Aziz S, Lasekan O (2020) Pineapple (Ananas comosus): a comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products. Food Res Int 137: 109675. https://doi.org/10.1016/j.foodres.2020.109675

79. Hassan ZM, Sebola NA, Mabelebele M (2021) The nutritional use of millet grain for food and feed: a review. Agric Food Secur 10: 1-14. https://doi.org/10.1186/s40066-020-00282-6

80. Singh S, Sharma H, Ramankutty R, Ramaswamy S (2024) Review on nutritional potential of underutilized millets as a miracle grain. Curr Pharm Biotechnol 25: 1082-1098. https://doi.org/10.2174/0113892010248721230921093208

81. Pathan S, Siddiqui RA (2022) Nutritional composition and bioactive components in quinoa (*Chenopodium quinoa* Willd.) greens: a review. Nutrients 14: 558. https://doi.org/10.3390/nu14030558

82. Allegra A, Mirabile G, Ettari R, Pioggia G, Gangemi S (2022) The impact of curcumin on immune response: an immunomodulatory strategy to treat sepsis. Int J Mol Sci 23: 14710. https://doi.org/10.3390/ijms232314710

83. Kim JH, Kim DH, Jo S, Cho MJ, Cho YR, et al. (2022) Immunomodulatory functional foods and their molecular mechanisms. Exp Mol Med 54: 1-11. https://doi.org/10.1038/s12276-022-00724-0

84. Mishra MK, Gupta J, Gupta R (2023) Mineral nutraceuticals and immunity enhancement. In Kesharwani RK, Keservani RK, Sharma AK (eds) Nutraceuticals and Functional Foods in Immunomodulators. Springer, Singapore, pp 141-154.

85. Alagawany M, Elnesr SS, Farag MR, El-Naggar K, Madkour M (2022) Nutrigenomics and nutrigenetics in poultry nutrition: an updated review. World's Poult Sci J 78: 377-396. https://doi.org/10.1080/00439339.2022.2014288