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Food Production, Processing and Nutrition

REVIEW

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Immune boosting functional components of natural foods and its health benefits

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Abstract

Naturally available foods contain nutrients like vitamins (A, C, E, and D), zinc, calcium, magnesium, folate iron, omega fatty acids, selenium, and phytochemicals that have profound protective effects (boosting immunity) on human from diseases. The critical component of obtaining incredible health is to maintain proper diet with healthy food, proper sleep, and regular exercise. This review is drafted with an aim to lay out the importance of consuming immune boosting foods, present various nutritional compounds available and their mechanism in maintaining immunity, and briefly discuss some of the exotic immunity building food sources, nutrients present, health benefits, and its utilization. Some of the immune-boosting foods like almonds, spinach, citrus fruits, avocado, red bell pepper, pomegranate, kiwi, garlic, ginger, and passion fruit are deliberated to have positive impact on ameliorating cancer, diabetics, heart disease, skin, eyesight, bone health, blood pressure, brain development, anti-stress, antimicrobial, antibacterial, antifungal, anti-aging, anti-allergenicity, antimalarial, anti-mutagenicity, and anti-inflammatory. This review on immune boosting foods further emphasizes on the need and proved the importance of consuming natural fruits, vegetables, nut, and meat products for strengthening the immune system. Thus, the consumption of immune boosting foods is mandatory for maintaining the health and protecting our body from harmful pathogen and degenerative diseases naturally.

Novelty impact statement

Exploring diet-health approach is very important in the domain of food for enhancing immune response and activation in humans. Natural food that has health and nutritional benefits has made a noteworthy influence on changing consumer's lifestyles. The immune-strengthening foods with proper dietary recommendation play a significant role to increase the immunity of people.

Keywords Foods, Bioactive compounds, Nutrients, Natural products, Health benefits

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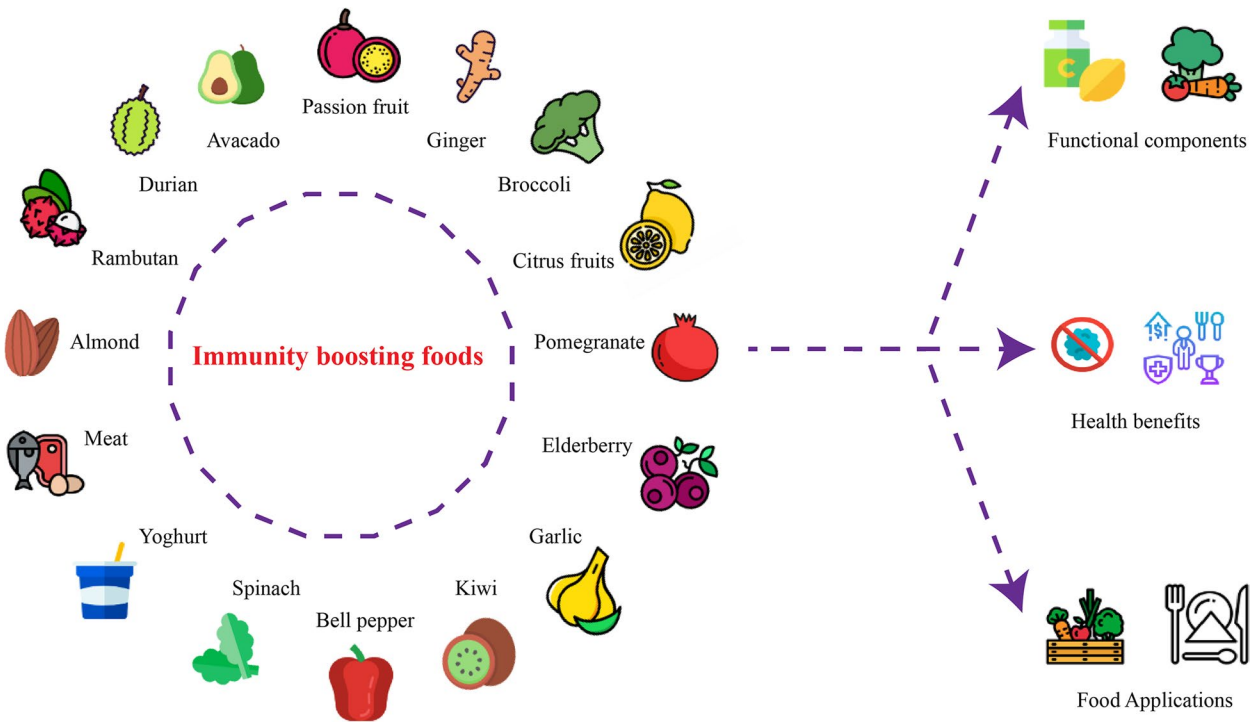
Graphical Abstract



Introduction

Consumer demands on food uptake have changed drastically these days; they started consuming food for health rather than taste. Specific intake of protein and antioxidant rich diets are being preferred in combination with regular workouts for maintaining proper health (Aggett et al. 1999; Richards & Rickard 2020). The reason behind the consumption of healthy foods on maintain health correlates closely with the maintenance of an individual's immune system. Immune system is a barrier network that acts as a first line of defence when encountered by harmful pathogens or oxidation; it comprises of an extensive network of cells and tissues in our body, which gives security against ailments. The food that we eat, the nature of our rest, and the level of stress are together important in order to charge our body's immune function for healthy living. Among which the food that we eat becomes a major source for building our body's immunity; thus, it is necessary for individuals to consume immune-boosting foods. Naturally occurring fruits and vegetables like apple (Hyson 2011), raspberry (York et al. 2002), blueberry (Smith et al. 2000), blackberry (Dai et al. 2007), cranberry (Dinh et al. 2014), blackcurrant (Nyanhanda et al. 2014), cherry (Ferretti et al. 2010), cocoa (Sanbongi et al. 1997), pomegranate (Zhao et al. 2016), grape (Percival 2009), avocado (Duarte et al. 2016), broccoli (Mukherjee & Mishra 2015), tomato (Blum et al. 2005), carrot (Sharma & Karki 2012), spinach (Bergman et al. 2001), sweet potato (Shih et al. 2009), kiwi (Tyagi et al. 2015), ginger (Srinivasan 2017), garlic (Tsai et al. 2012), turmeric (Singletary 2010b), mango (Sivakumar et al. 2011), onion (Suleria et al. 2015), lettuce (Kim et al. 2016), beetroot (Clifford et al. 2015), cabbage (Maria Alexandra et al. 2013), cauliflower (Köksal & Gülçin 2008), pineapple (Hossain et al. 2015), strawberry (Afrin et al. 2016), citrus fruits (Mohanapriya et al. 2013), pepper (Singletary 2010a), almonds (Kamil & Chen 2012) and Echinacea (Barrett 2003) are the most important immune boosting foods in which dietary antioxidants like Vitamin A, C, E, flavonoids and carotenoids are present. These antioxidants that are obtained from diet are called exogenous antioxidants, whereas, the antioxidants that are produced from the body itself is called endogenous antioxidants.

Vitamin A prevents damage to the immune cells by improving immune functions, neutralizing reactive oxygen species, and increasing resistance to infection (Meydani et al. 2001). Vitamin C prevents and treats

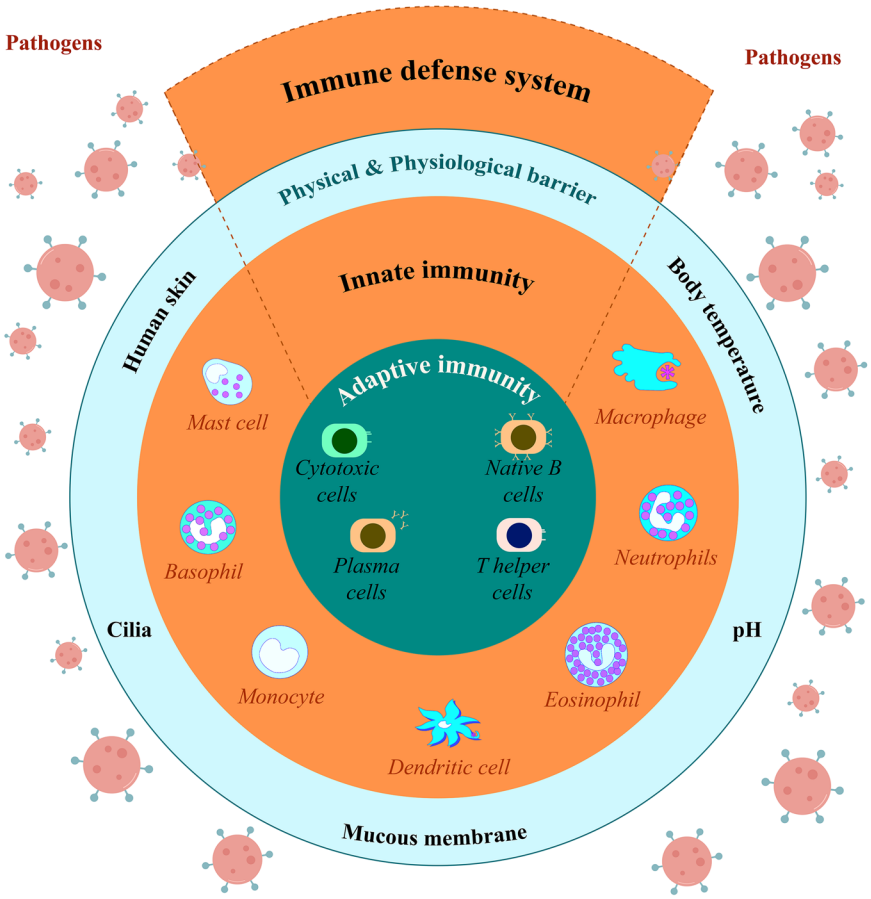
various diseases and it also reduces the destruction of immune cells (by scavenging free radicals); it also aids the immune system by promoting anti-inflammation, lymphocyte proliferation, and involvement in immune responses on delayed-type-hypersensitive skin tests, pulmonary function, and antibody production in human body at the time of attack or infection (Lopez-Varela et al. 2002). Vitamin E evades damage to immune cells by differentiating immature T cells in the thymus and modulating host immune functions (Hughes 1999). Flavonoids are biologically active polyphenolic compounds that modulate the immunity power in humans with antioxidant and anti-inflammation properties (González-Gallego et al. 2010). Carotenoids being antioxidant controls immune function by involving gene regulation and apoptosis (Chew & Park 2004; Gouveia & Empis 2003). The other nutrients like protein, vitamin B6, B12, D, copper, zinc, magnesium, iron, omega-3, folate, probiotics, and selenium are also known to be immune-enhancing nutrient factors.

When the human body is lacking nutrients, viral contaminations can cause serious diseases by weakening the immune system (Peterhans 1997). Immunity, when raised by diet, can cure diseases, and if the infection does occur, it fight against the pathogen and can reduce the severity on the individual. Populations with the highest intake of vegetables have much lower rates of cancer. The longest living inhabitants throughout the history have been those with the more consumption of vegetables in the diet regularly (Robbins 2007). When immune-boosting foods are taken as a part of the daily diet, nutrients will be supplied to human body; this nutrition increases biological defence mechanisms, prevents and recovers specific diseases, slows the aging process, and controls physical and mental disorders (Lopez-Varela et al. 2002). Numerous diseases and health concerns such as inflammation can be prevented and treated by following the diet rich in immune boosting foods. The antioxidant, anti-inflammatory, antiviral and nutritious nature of the principal compounds present in the natural food materials is the reason for the prevention and treatment of diseases. The consumption can improve heart disorders (Olas 2020), vascular diseases (Wang et al. 2011), anti-inflammation (S. Li et al. 2014), anti-diabetes (Sun et al. 2021), neurological issues (Albarracin et al. 2012), reduction of cancer risk (Afshari et al. 2019), improvement of gastrointestinal health (Veenstra & Johnson 2019), lowering of menopause symptoms (Wattanathorn et al. 2019), reduction of osteoporosis (Marcucci et al. 2023), decrease of blood pressure (John et al. 2002), antibacterial and antiviral properties (Qanash et al. 2022). This review presents a systematic insight into the immune system, functional components of immune-boosting foods, and immunity-building nourishments with its health benefits.

Immune system

The invulnerable human immune system is a disease resistance tool comprised of tissues, immune cells, and organs that cooperate to protect the body from outside components, known as antigens (Calder & Kew 2002). These remote elements are bacteria, viruses, fungi, and parasites, which infect the body causing one to feel sick. Compounds which infect humans can be increased if immunity power is less and transmitted to other people by causing. illness, serious infection, and even death (Fritsche 2006). The immune system is divided into two components namely innate immunity (non-antigen specific) and adaptive immunity (antigen-specific) are indicated in Fig. 1. Innate immunity is non-antigen specific because human body will have antibodies that will fight against all types of antigens immediately. The antibodies involve in this type of immunity are dendritic cells, macrophages, neutrophils, basophils, eosinophils, and mast cells. This innate immunity is the foremost one that kicks in immediately when the host is encountered by the infection (from minutes to hours). Innate immunity provides protection from germs without the need of preconditioning from the circumstances. Innate immunity includes skin, mucosa, immune system cells (macrophages, neutrophils, dendritic cells, and monocytes) present inside the human body are represented in Fig. 2. Macrophages are highly phagocytic and produces powerful inflammatory cytokines. Neutrophils are specialized inflammatory cells of the immune system. Dendritic cells are phagocytic and antigen presenting cell activates acquired immunity (Pan et al. 2018). Monocytes are also phagocytes that circulate in the blood. When monocytes migrate into tissues, they develop into macrophages (McComb et al. 2013). Innate immunity (Fig. 1) serves as the first line of defense and the antigen is activated as soon as it is encountered. Innate immunity has no immunological memory. It means the immune power is not generated through vaccination.

However, numerous presences of pathogen can reduce the effect of innate immunity; in this case, adaptive immunity is activated. Adaptive immunity (Fig. 1) is like an extra privilege and a more sophisticated system of defence mechanism that comprises B cells (B Lymphocytes) and T cells (T Lymphocytes). The adaptive immune mechanism and lymphocytes in the system gets activated based on the recognition of the pathogen; adaptive immunity is antigen specific because it takes times to develop antibodies through vaccination in human body and it will invade only a particular antigen. Adaptive immunity has the immunological memory and this kind



Defence mechanism: innate immunity (non-antigen specific) and adaptive immunity (antigen-specific)

Fig. 1 Innate and adaptive immunity in human body

of immunity is major for the defence in the future, if the individual is encountered with the same infection (Netea et al. 2019). Adaptive immunity is the basis of vaccination but can recognize and destroy specific substances like pathogen (immunologic memory is present—means antibodies are developed through injection). Adaptive immunity provides the second line of defence and is activated for the secondary exclusion of infectious agents (Marshall et al. 2018). Lymphocytes are one of the five categories of white blood cells circulating in the blood of humans. Each of these T and B cells can precisely bind to a specific antigen or molecular structure. T cells are there to regulate or kill intracellular parasites or activate the immune cells. The killer cell is a sort of T cell whose reason for existing is to slaughter any cells that are infected with the antigens or cells that appear to be abnormal. B cells are responsible for activating the antibodies and it is a protein that destroys antigens in the bloodstream (Murphy & Weaver 2016).

Mechanism of the immune response

The two functional divisions of the immune system (acquired, and innate immunity) comprise cytokines, antibodies, and cells, collectively called leukocytes (white blood cells) (Weyh et al. 2020). Phagocytes, monocytes, and lymphocytes come under the leukocytes category (Calder & Kew 2002). Every cell in the immune system network initiates in the bone marrow and they are found circling in the bloodstream, structured into lymphoid organs like the spleen, thymus, lymphoid tissue, and lymph nodes or scattered in different areas around the body (McComb et al. 2013). The organs and certain lymphoid systems of the human immune system where the cells do their actual work of fighting off germs and foreign substances are presented in Fig. 2. When direct cell–cell contact happens in the immune system (both innate and acquired), the involvement of adhesion molecules occurs by producing cytokines (chemical messengers), which are proteins.

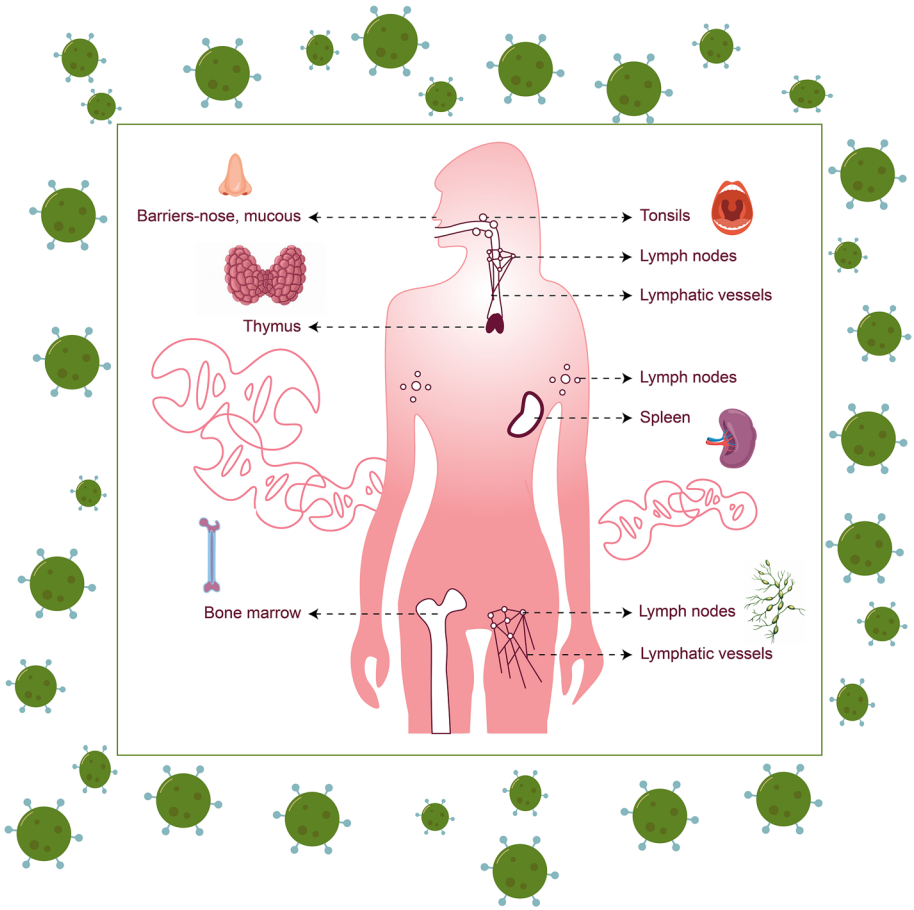


Fig. 2 Representation of immune systems which includes skin, mucosa, immune system cells (macrophages, neutrophils, dendritic cells, and monocytes) present inside the human body

Every cytokine might have many activities on various cells. These chemical messengers act by binding to particular receptors on the surface of the cell and subsequently instigate changes in the development, advancement, or action of the target cell. Initially, innate immunity responds quickly when an immunological stimulus is encountered and acts directly to destroy pathogens (Calder & Kew 2002). Cytokines (interleukin-1, interleukin-6, tumor necrosis factor-α) created by the cells associated with the innate reaction, particularly macrophages and monocytes, will regulate this response by eliminating germs. Then, cytokines act fundamentally on the liver to advance intense stage protein synthesis, on adipose tissue and skeletal muscle to endorse lipolysis and proteolysis, respectively (Ibrahim & El-Sayed 2016). And finally acts on the cerebrum to diminish appetite and prompt fever. Macrophages and monocytes (antigen-presenting cells) will introduce antigens to T cells and B cells (Fig. 1) so that the reaction will be activated, and the production of antibodies occurs by destroying the pathogens (Calder & Kew 2002).

A healthy body is a disease-resistant immune system that can secure itself against antigens. The human body delivers typically white platelets, which aids a vital role in creating safe cells. Likewise, it also delivers synthetic substances (chemicals) and proteins that can assault and remove the antigens. The human defence system finds the antigens and kills it before having the options to recreate and spread (Wentworth et al. 2000). Contingent upon the antigen's load, the immune system reacts quickly by delivering the particular responders against the antigen in higher amounts. The adequacy of the immune system is balanced by its capacity to perceive a vast number of antigens and creating specific resistant molecules to battle them. As the immune power can attack many antigens, it is necessary to build immunity in humans by taking proper nutrients in precise quantity (as per recommendation) to act violently against these immune

destructing pathogens (Chowdhury et al. 2020). If the nutrients externally supplied to the body is less, then it can affect the immune system's function by reducing the antibody production (Iddir et al. 2020).

Immune system functions in good health depending on the nourishment we consume, good mood without stress, and proper sleep. Stress can also account for the proper function of immune system; as nervous, endocrine and immune systems are interconnected, stressful lifestyle and negative mood can lead to the dysfunction of the immune system by disorganizing the interplay of the three systems (Seiler et al. 2020). Deficiency of proper sleep and insomnia impacts the central nervous system, which could also impact the proper immune function (Kuna et al. 2022). Immune-boosting foods like fruits and vegetables can boost the immune power in humans because it contains inflammation-fighting nutrients like vitamins, carotenoids, and phytochemicals (Venter et al. 2020). Intake or utilization of particular food in exact amounts that give extra advantages to the human body is essential in order to boost the immune system.

Functional components of immunity-boosting foods

Nutrition is a significant factor to build immunity in humans. The functional components of immunity-boosting foods like antioxidants (carotene, vitamin C, vitamin E, folate, selenium, and phytochemicals), vitamin D, zinc, iron, dietary fiber, and omega -3 fatty acids are essential to maintain a healthy immune system. Supplementation of these nutrients from natural sources (fruits and vegetables) enhances the immunity power by diminishing viral infections, cancer, cardiovascular disease, blood pressure, memory loss, and neurological problems (Jayawardena et al. 2020). The function of nutrients, its deficiency, and supplementation in immune-boosting foods are represented in Table 1.

Antioxidants

Antioxidants are vitamins, minerals, and phytochemicals that aid the body in evacuating free radicals and controlling free-radical creation (McDowell et al. 2007). These comprise vitamin C, vitamin E, selenium, folate, alpha-carotene, beta-carotene, and various other phytochemicals like allium compounds, anthocyanin, allyl sulfides, coumestans, betalains, indols, flavonoids, flavonols, glucosinolates, isoflavones, limonoids, lignans, pectins, organosulfides, phytosterols, phenolic compounds, terpenes, protein inhibitors, and tyrosol esters (Vázquez et al. 2014). The majority of antioxidants are made available in the body through consuming fruits, vegetables, and natural plants. Many antioxidants are present mostly in fruits, vegetables and nut (Zeb 2020). Animal products also contains important antioxidants such as zinc and iron, however, meat and meat products are devoid of phytochemicals and vitamins. To be specific there are studies which involves adding fruit and plant extract as an additive for meat and meat product (Domínguez et al. 2021; Pateiro et al. 2021).

Oxidative damage occurs when free-radical activity in cell increases, and free radicals burst out of their cell segments to affect more extensive regions of the cell. Specific oxygen-derived free radicals comprise hydroperoxyl (HOO^-), superoxide (O_2^-), peroxyl (ROO^-), hydroxyl (OH^-), and others are peroxynitrite anion ($ONOO^-$) and the nitric oxide (NO^-) (Kaur & Kapoor 2001). Free radicals are all not harmful but have a critical role in lesser amount. It is very well utilized by the immune cells and destroys the damaged one that could be a danger to humans if they are not deteriorated it will be potentially developed into cancer. When free radicals increase in amount, they begin to destroy healthy tissue and cells in the body. Hence, antioxidants are essential in removing and controlling free radicals. Some of the antioxidants like carotene, vitamin C, vitamin E, selenium, and phytochemicals are elaborated.

Carotene

Consumption of green vegetables is the best way to find out the total antioxidant capacity of the diet as it is a synergetic method to keep our body free from diseases. Vitamin A deficiency affects immune function, particularly the antibody response to T-cell-dependent antigens (Ross 2003). Vitamin A helps to increase the activity of natural killer cells that have antiviral defense. Vitamin A can be included in the diet by consuming its precursor Carotene. Carotenoids (provitamin A) are a large group of compounds with the basic skeleton of a polyisoprenoid carbon chain with many conjugated double bonds (Chakraborty et al. 2009). Each molecule of carotenoids gets converted to two molecules of previtamin A (Retinol) in the body; the enzyme beta-carotene 15,15′-dioxygenase (present in intestinal mucosal layer) cleaves the carotene in to two molecules of retinol. Carotenoids are classified into two categories as alpha and beta carotene. The most common carotenoid that gets converted to Vitamin A is Beta-carotene (Alexander et al. 1985). Beta-carotene (colour compound) served as a marker for those populations with high fruits and vegetable intake. It is available high in carrots and other orange vegetables. These carotenoids increase the population of lymphocytes and enhance macrophage for the production of cytokines. Cytokines are hormonal regulators produced through the body necessary for cell signalling. Cytokines rise in a vitamin A deficient situation helps the

Table 1 Functions of various nutrients, role in immune system, effect of its deficiency and supplementation in immune-boosting foods

Nutrients	Foods	Functions	Role in the immune system	Effects of deficiency	Effects of supplementation	Reference
Zinc	Meat, spinach, oysters, yogurt, pumpkin seeds, cashews, dark chocolate, mushrooms	Acts on growth and cell replication	Structural and catalytic components of the superoxide dismutase	Abridged lymphocyte number and function, improved thymic atrophy, altered cytokine production toward oxidative stress and inflammation, enhanced infectious diseases	The higher number of T cells, decreased incidence of infections, enriched natural killer cell cytotoxicity	(Prentice 2017)
Carotene	Carrot, pumpkin, red and yellow pepper, sweet potatoes, muskmelon, apricot, mangoes, papaya, chilly, tomatoes	Antioxidant	Lower incidence of acute respiratory disorder	Poor vision and weak bones, the resistance to infection reduces	The carotene intake reduces the CPR which indicates antioxidant and immunomodulatory effect	(Khalil et al. 2021)
Folate	Cow pea, chickpea, mung bean, sunflower seed, quinoa, seafoods	Fetal development	The mechanism with which folates aid in development of mammalian cells is DNA methylation	Improper developmental effects in fetus	Folate has been reported to have a major role in proper development of mammalian cells during pregnancy; thus, during pregnancy it is recommended to consume folic acid capsules	(Farran et al. 2019)
Dietary fibre	Banana, artichoke, sprouts, lentils, oats, almonds, chia seeds	Maintains bowel movement	Strengthening mucus layer, gastrointestinal immune barrier	Constipation and colon cancer	It improves the beneficial gut microbes which can aid in easy digestion. When gut microbes ferment the dietary fibres, it produced short chain fatty acids and also in replicating the beneficial microbial load	(Beukema et al. 2020)
Anthocyanin	Berries, grapes, carrots, pomegranate, beetroot	Antioxidant	Treats hyperglycaemia, prevents oxidation	Aging and improper immunity	It treats atherosclerosis, inhibit free radical activity, and decreases inflammation and aging	(Yilmaz 2019)
Omega 3 fatty acid	Fish and other sea foods	Pro resolving mediators, aids immune system	Regulation of immune function	It affects the immunity, nervous system and also causes inflammation and irritation on the dermis	It activates both the innate and the adaptive immunity. Regulation of cellular membrane properties, such as membrane fluidity or complex assembly in lipids	(Gutiérrez et al. 2019)
Iron	Red meat, dark-green leafy vegetables (spinach, collard greens), artichokes, blackstrap molasses, tofu, quinoa, prunes	Component of hemoglobin and myoglobin and important in oxygen transfer	Involvement of Fenton reaction with the production of free radicals with antimicrobial action	Drop-in immune response, lessened lymphocyte bactericidal activity	Hypothetically rise immunity to infections, but untargeted supplementation may enhance the availability of iron for pathogen growth	(Calder et al. 2007; Prentice 2017)

Table 1 (continued)

Nutrients	Foods	Functions	Role in the immune system	Effects of deficiency	Effects of supplementation	Reference
Selenium	Fish, seafood, wheat germ, and brazil nut	Involved in the metabolism of fat and vitamin E	Component of glutathione peroxides	Concealment of immune function, harmed humoral and cell-mediated immunity	Improves cell-mediated immunity and builds immune response in people with deficiency, yet may deteriorate allergic asthma and injury the immune response to parasites	(Calder et al. 2007)
Vitamin A	Liver, egg, milk, and carrots	Protective action on the skin and mucus and essential role in retinal function	Inhibition of the lipid peroxidation and the generation of hydroperoxides	Impacts immune functions, and exposure to infections	Diminished danger of morbidity and mortality from contagious disease. Not beneficial in pneumonia	(Prentice 2017)
Vitamin C	Citrus fruits, tomatoes, peppers, and leafy vegetables	Increases the absorption of nonheme iron	Enzymatic cofactor with redox properties	Improved oxidative damage, enlarged incidence, and expanded contamination, decreased protection from diseases, diminished DTH response	Secured against oxidative stress, decreased duration and occurrence of pneumonia and basic cold indications	(Calder et al. 2007; Hemilä 2017; Hemilä & Chalker 2013; Prentice 2017)
Vitamin D	Fish (oil liver), egg yolk, butter, cheeses, and meats	Maintaining homeostasis of calcium and phosphorus	Expression of antimicrobial peptides	Expanded weakness to contaminations, better morbidity, and mortality, Enhanced danger of autoimmune diseases	Improved immune function in transmittable disease	(Calder et al. 2007; Medzhitov 2001)
Vitamin E	Vegetable oils, olive oil, almonds, and avocados	Protection of cell membrane–unsaturated phospholipids	Decreased lipid peroxidation	Damage humoral, T and B cell function	Enhanced DTH response and proliferation of T cell	(Meydani et al. 1990)

inflammatory immune system. Beta-carotene supports the enzymatic defence systems by diminishing oxidative damage. Beta-carotene is regarded as a safe, gainful antioxidant and even suggested as an anti-cancer vitamin by increasing the risk of lung cancer (Omenn et al. 1998) when directed as a supplement rather than ingested from food.

Alpha-carotene is absent in many multivitamins and supplements, however, and it is an excellent marker of high-nutrient vegetable intake (green and orange vegetables). It is available in asparagus, cabbage, carrots, green pepper, red pepper, swiss chard, winter squash, broccoli, collards, and peas. The researchers have discovered that increased alpha-carotene was related to a diminished danger of death. The humans with the highest alpha-carotene had a 39% decline in risk of death (Li et al. 2011) from specific causes including cardiovascular disease, night blindness, neurodegenerative, age-related macular degeneration disease, and cancer, but other causes as well, remarkably infection (Chaudhary et al. 2020).

Vitamin C

Vitamin C is an essential antioxidant, reducing agent, water-soluble electron donor vitamin, and, thereby, neutralizes reactive oxygen species (Padayatty et al. 2003). It donates two electrons from C-2 and C-3 double bond carbons to act as an antioxidant that results in the creation of an intermediate free radical, and semi-dehydroascorbic acid E. These free radicals reduce to a neutral ascorbate molecule (Spears & Weiss 2008). Vitamin C can protect bio membranes against lipid peroxidation decay by eradicating peroxyl radicals in the aqueous phase before initiation of peroxidation occurs and aids in the relocation of leukocytes to the sites of infections (Carr & Maggini 2017). Vitamin C is situated in the aqueous stage of cells, contributing to radical scavenging (McDowell et al. 2007). Vitamin C (ascorbic acid) builds the production of antibodies and assists with separating lymphocytes (white platelets), enabling the body to figure out what sort of protection is required. The lack of vitamin C prompts scurvy. Consequently, vitamin C enriched nourishments such as orange, strawberries, grapes, papaya, berries, Brussel sprouts, cauliflower, kiwi, pepper, tomatoes, and sweet potatoes should be taken regularly (Zee et al. 1991). Intake of vitamin C recommendation is 150–200 mg per day for preventing and inhibiting cancer, coronary heart disease, and cataract (Doseděl et al. 2021; Weber et al. 1996); which is a general value range provided globally. As the vitamin C works on scavenging reactive species and prevention of DNA damage which is one of an important forerunners for cancer transformation (Pawlowska et al. 2019). The quantities of RDA for Vitamin C vary with respect to different countries and their regulatory bodies. In United states, FDA recommended 90 mg/day for adult men and 75 mg/day for adult women. Whereas in European union, the recommendation varies; 110 mg/day for adult men and 95 mg/day for adult women (Carr & Lykkesfeldt 2021).

Vitamin E

Vitamin E (α-tocopherol) is an effective lipid-soluble antioxidant and can regulate host immune functions by inhibiting free radicals. α-Tocopherol acts either by donating hydrogen radicals to remove the free lipid radical, or reacts with it to form non-radical products, or merely traps the lipid radical. Vitamin E contains four tocotrienols and four tocopherols (alpha, beta, gamma, and delta). Vitamin E prevents several oxidative reactions and has a major role against lipid peroxidation by improving the activity of helper T lymphocyte. Vitamin E is rich in plant-based foods such as avocado, nuts, seeds, vegetable oil, chiku. canola oil, and turnip greens (Traber 1955). It enhances immune function by protecting white blood cells and other components of the immune system (T cells and B cells). It helps the body defend against illness and disease (Yeomans et al. 2005). Vitamin E deficiency leads to infectious diseases like ataxia, respiratory tract problems, and the incidence of tumors (Jiang 2014). Supplementation with vitamin E substantially improves the cell-mediated and humoral immune functions in humans, particularly in aged ones (Moriguchi & Muraga 2000). Vitamin E recommendation every day is 15–20 mg (Wooltorton 2003).

Selenium

Selenium is a cancer prevention agent, yet it plays a unique role in our body by building optimum immunity power (both innate and acquired) and finally oxidizes excessive free radicals produced in our body (Rayman 2000). Selenium will improve the immune system (T cells and B cells) while decreasing inflammation (Arthur et al. 2003). Selenium is mostly present in the parts of the spleen, liver, and lymph nodes in our body and its deficiency can reduce cell-mediated immunity and B cell function. Selenium rich foods include brazil nuts, seafood, eggs, yogurt, and meat products (Solomons 2000). The selenium recommendation is 55 mg a day for an adult (Godswill et al. 2020).

Folate

Folate is a member of the vitamin B family and is found generally in plant foods, mainly in green vegetables. Folate has been reported to have a major role in proper

development of mammalian cells during pregnancy; thus, during pregnancy it is recommended to consume folic acid capsules. The mechanism with which folates aid in development of mammalian cells is DNA methylation. DNA methylation is a process of covalent modification of DNA that in turn modifies gene expression and regulates DNA replication and cell division (Crider et al. 2012). This primary role makes folate essential in foetal development and nerve tissue health, along with cancer initiation and progression. Folate is available broadly in asparagus, broccoli, lentils, chickpeas, brussels sprouts, and spinach. Greater consumption of levels of food-derived folates can be related to less breast and prostate cancer (Figueiredo et al. 2009). The folate recommendation is 0.4 mg a day for an adult (Ashokkumar et al. 2020).

Phytochemicals

Phytochemicals are non-nutritive naturally occurring secondary metabolites that have either defensive or disease-protective properties. The main role of these phytochemicals in plants is to protect and safeguard the plants from insects, animals and other microorganisms. Traditionally, these plant extracts are used for healing wounds and improve health in Ayurvedic medicine which is known as phytotherapy. Phytochemicals when ingested improve the immune cells destructive power, reduces tumour causing cells, induces detoxification enzymes, protects cell structures from damage by toxins, controls the production of free radicals, impedes the replication of cells with DNA damage, fuels mechanisms to repair damaged DNA sequences, inhibits the function of damaged or genetically altered DNA, deactivates and detoxifies cancer-causing agents, induces beneficial antiviral, antifungal and antibacterial effects (Fuhrman 2011). One significant importance of using phytochemical is its effect on suppressing the cancer cell; in this case, the phytochemicals disturb the redox reaction of the tumour cells, inhibits proliferation of cells and ultimately apoptosis of the cells. This effect of phytochemicals reduces the tumour proliferation and suppresses its activity (Lee et al. 2021). Based on the structure and chemical composition phytochemicals are divided into 7 categories, glycosides, alkaloids, polyphenols, polysaccharides, lectins, saponins and terpenoids. Most phytochemicals deals with antimicrobial, antitumour activity, stimulation of nervous and immune system (Behl et al. 2021). A phytochemically deficient diet is largely liable for a powerless immune system. Phytochemical enriched foods are apricot, broccoli, apple, carrot, cabbage, cauliflower, legumes, sweet potatoes, garlic, red pepper, tomato, and soybean (Keservani & Sharma 2014). There is no recommended dietary allowance for phytochemicals (Liu 2003).

Vitamin D

Vitamin D is an important immunity increasing nutrient for individuals because of its function in the bone (Turner et al. 2012). Vitamin D is available in two forms Vitamin D2 and Vitamin D3; Vitamin D3 is produced naturally in skin and available in fish and fish oils, whereas Vitamin D2 is synthesised from ergosterol present in mushrooms and yeast upon exposure to sunlight. Upon consumption of Vitamin D, it enters the kidney where it gets converted into its active form, 1, 25-dihydroxy vitamin D (Christakos et al. 2011). This active form is responsible for increasing the absorption of calcium in the intestine and calcium mobilization from bones (Charoenngam et al. 2019); thus aiding in the bone health.

The active form 1, 25-dihydroxy vitamin D is synthesised locally at the site of infection by the macrophages which leads to the generation of antimicrobial peptides (Ismailova & White 2022). Vitamin D increases antimicrobial peptide synthesis in epithelial tissue (Gombart 2009), prevents the proliferation of T cell, and the creation of cytokines by T helper 1 (Th1) lymphocyte. Vitamin D exists in sources like liver, oily fish, eggs, and dairy products. The adverse effects due to low consumption of vitamin D include allergic asthma (Arihiro et al. 2019), chronic obstructive pulmonary disease (Urashima et al. 2014), and pneumonia (Zhou et al. 2019) in children. As these diseases are common during early stages, Vitamin D intake is necessary for children. The deficiency of Vitamin D leads to hyperresponsiveness in the airway, reduced pulmonary function and resistance to medicine (steroids) (Sandhu & Casale 2010). The vitamin D recommendation is 10–100 mg (400–4000 IU) a day (Patseadou & Haller 2020).

Zinc and iron

Zinc and iron are fundamental minerals that play a critical role in maintaining a healthy immune function. These trace minerals get attached to the proteins and enzymes for maintaining the biological functions. Zinc is a nutrient that many people are in borderline deficient; it is a much-needed protein for the function of almost 300 proteins and enzymes and is also forms a significant part in regulation of major genes in the human body. The daily recommendation of zinc in US and Canada are 11 mg for men and 8 mg for women (Age above 19) (McClung 2019). Foods rich in zinc are oysters, sunflower seeds, beef, cashew nuts, kale, and broccoli. Zinc deficiency leads to dysfunction of both antibody-mediated and cell-mediated immunity and thus increases susceptibility

to infection. It leads to loss in T helper cell, liable for spleen and thymus (Chowdhury 2020). Zinc supplements decrease the incidence of pneumonia, antibiotic use, duration of colds, infant infections, and child mortality (Meydani et al. 2007; Walker & Black 2004). The day by day intake recommendation of zinc is 11 mg (Godswill et al. 2020). Iron is a nutrient that is a part of haemoglobin (protein) required for the transport of oxygen and carbon dioxide in the blood and also in dehydrogenase enzyme for proper electron transport in the respiratory cycle (McClung 2019). Iron in available in various oxidation states, the ferrous (Fe + 2: soluble form) and ferric (Fe + 3: Insoluble form), further these two are interchangeable (Zygiel et al. 2019). The Fe + 3 ion is stored in ferritin, an intracellular protein whereas the Fe + 2 binds to heme group of the haemoglobin. Iron obtained from meat and meat products are in the form of ferritin (Murdoch & Skaar 2022). Iron supplementation is mandatory for pregnant women for the gestational needs of the baby; thus 27 mg/day has been recommended. Also, the intake of iron in the menopause state is also important for proper health (18 mg/day). The intake recommendation of iron is 7 mg/day for a child i.e. 12–24 months old (Buzigi et al. 2020). Iron enriched foods are meat, legumes, fish, milk, apricots, spinach, pumpkin, broccoli, and nuts. Iron deficiency leads to anaemia because of the decrease in the number of red blood cells.

Dietary fibres

Dietary fibres play a vital role in immune response, and it includes hemicellulose, cellulose, gums, pectins, polyfructose, lignin, galactooligosaccharides, mucilages, and resistant starches. Dietary fibres are rich in food like peas, nuts, beans, berries, broccoli, oranges, watermelon, and seeds. The consumption of dietary fibres free from diseases like lowering of cholesterol, reduction in cardiovascular diseases (Ötles & Ozgoz 2014), reduction in the risk of breast and colon cancer (McEligot et al. 2006; Wakai et al. 2007), preventing diabetes (Hannan et al. 2007), avoiding obesity (Murakami et al. 2007), irritable bowel syndrome (Malhotra et al. 2004) and constipation (Castillejo et al. 2018). The recommended dietary fibre intake for adults is 25–38 g/day (Soliman 2019). Before dietary fibres were considered as indigestible part of fruit or vegetable which helps in the bowel movement. Yet, the real reason behind the effect of dietary fibre in bowel movement is that it improves the beneficial gut microbes which can aid in easy digestion (Cohen & Elinav 2023). When gut microbes ferment the dietary fibres, it produced short chain fatty acids and also in replicating the beneficial microbial load; these short chain fatty acids aids in reducing the inflammation and also in immunomodulation (Yang et al. 2020).

Omega fatty acids

Omega fatty acids are essential fatty acids crucial to the body function and are introduced externally through the diet. Poly saturated fatty acids are classified into two types, mainly omega 3 (n-3) fatty acids and omega 6 (n-6) fatty acids based on the position of the last double bond. Omega-3 fatty acids mostly consist of eicosapentaenoic acid (EPA), α-linolenic acid (ALA), and docosahexaenoic acid (DHA). α-linolenic acid is the precursor of eicosapentaenoic acid and docosahexaenoic acid. At the same time, Omega-6 fatty acids contain linoleic acid (LA), arachidonic acid (ARA), and γ-linolenic acid (GLA). Linoleic acid is the parent fatty acid of this group. Eicosapentaenoic acid and docosahexaenoic acid are present in fatty fishes like salmon, trout, mackerel, and bluefin tuna (Ackman 2007). α-linolenic acid is found mainly in soybeans, canola, and flaxseed. Linoleic acid is improved in sources like vegetable oils (sunflower, soybean, corn, and safflower). Arachidonic acid is usually well-known in animal sources like meat, eggs, and poultry. The positive health effect of omega fatty acids include brain development, heart health, increasing metabolism, reduces blood pressure, immunomodulatory effect and elimination of plague from arteries (Wall et al. 2010). There is no recommended intake for omega fatty acids (Tessier & Chevalier 2018). One particular study on the assessment of omega 3 and omega 6 fatty acids on the regulation of immunity in the intestinal barrier of animals revealed that omega 3 fatty acid was effective in reducing the inflammation and maintaining the homeostasis of the intestine. The EPA and DHA of omega 3 fatty acids acts reduces intestinal inflammation and also scours the debris caused by inflammation; there by it maintains the homeostasis. However, in case of omega 6 fatty acid (ARA), it acts on the gut microbial composition and disrupts the homeostasis (Sundaram et al. 2022). Thus, it was revealed that omega 3 fatty is more effective than omega 6 fatty acid; and each has its own merits and demerits.

Immune-boosting foods with their health benefits

Immune-boosting foods like fruits and vegetables which are all-natural sources have shown health benefits like immunomodulatory, antioxidant, anti-bacterial, antiviral, anti-cancer, and anti-inflammatory effects (Blum et al. 2005; Percival 2009). Each immune-boosting food possesses different nutrients like vitamins, minerals, and fats which is essential for good health. The most widely researched immune-boosting foods, along with their bioactive compounds and health benefits, are given in Table 2. Some of the immune building foods which have been studied widely for the past two decades like almonds, rambutan, durian, avocado, passion fruit,

Table 2 Origin, bioactive compounds and health-promoting properties of immune-boosting foods

Foodstuff	Family	Origin	Compound	Immune boosting property	Reference
Apple	*Rosaceae*	California	Phloretin, Quercetin, Kaempferol	Rich in quercetin, antioxidants, and polyphenols	(Hyun & Jang 2016)
Almonds	*Rosaceae*	Egypt	Naringenin, Myricetin	Iron, Vitamin E	(Barreca et al. 2020; Huang & Lapsley 2019; Kamil & Chen 2012)
Avocado	*Lauraceae*	Mexico	Catechin, Niacin, and pyrogallol	Antioxidant, antiobesity property	(Jimenez et al. 2021; Tramontin et al. 2020)
Beetroot	*Amaranthaceae*	Egypt	Betalains	High in minerals, anti-inflammatory, anticancer, antioxidant, and detoxifying properties	(Clifford et al. 2015)
Bell Pepper	*Solanaceae*	South America	Luteolin	Vitamin A, Vitamin C	(Nadeem et al. 2011)
Broccoli	*Brassicaceae*	Italy	Sulforaphane, Luteolin, Kaempferol	Guards against cancer, Vitamin C and E, antioxidants, folate, iron, choline, lutein, sulforaphane	(Vasanthi et al. 2009)
Carrots	*Apiaceae*	Dutch	Luteolin	Beta carotene, Vitamin C	(Ahmad et al. 2019)
Chia seed	*Lamiaceae*	Central and southern Mexico	Fibre, polyphenols, antioxidants, omega-3 fatty acid vitamins, minerals, and peptides	cardiovascular disease, platelet aggregation, cholesterol, diabetes and constipation	(Khalid et al. 2023)
Cinnamon	*Lauraceae*	Egypt	Cinnamaldehyde	Anti-inflammatory properties	(Singletary 2019)
Citrus fruits	*Rutaceae*	Southeast Asia	Tangeritin, Quercetin, Hesperitin, Naringenin	Vitamin C & polyphenols, Anti-inflammatory properties	(W. Liu et al. 2022; Ma et al. 2020; Musumeci et al. 2020)
Dark leafy vegetables	*Amaranthaceae*	Asia	Riboflavin	Antioxidants, Vitamin C, K & Folate	(Jiménez-Aguilar & Grusak 2017)
Durian	*Malvaceae*	Borneo	Carotenoids	Antioxidant activity	(Ali et al. 2020)
Echinacea	*Asteraceae*	North America	echinacoside, cynarin, cichoric acid	Antimicrobial	(Barrett 2003; Billah et al. 2018)
Garlic	*Amaryllidaceae*	Central Asia	Allicin	Antibacterial, antifungal and anti-inflammatory properties	(Zhang et al. 2020)
Ginger	*Zingiberaceae*	Southeast Asia	Gingerols	Antibacterial activity	(J. O. Lee et al. 2015; Srinivasan 2017; Tramontin et al. 2020)
Ginseng	*Araliaceae*	Korea	Ginsenosides, saponins	Antioxidant, antitumor, antihyperglycemic, skin protecting, anti-osteoporotic anticancer, anti-infective and respiratory problems	(Riaz et al. 2019)
Goji berries	*Solanaceae*	Asia	Phytochemicals	Prebiotic, neuroprotective and hepatoprotective properties	(Skenderidis et al. 2020)
Grapes	*Vitaceae*	Egypt	Naringenin, resveratrol	Antioxidant activity, anti-inflammatory activity, and immune system modulator	(Percival 2009)
Green tea	*Theaceae*	China	Epigallocatechin gallate, Quercetin, Kaempferol	Anticarcinogenic activity and antioxidant activity	(Muhammad Saeed et al. 2017)
Kiwi	*Actinidiaceae*	China	Cyanidin-3-O-sambubioside	Vitamin C, antioxidant	(Richardson et al. 2018)

Table 2 (continued)

Foodstuff	Family	Origin	Compound	Immune boosting property	Reference
Moringa leaves	*Moringaceae*	India	Vitamin C, vitamin A, calcium, essential nutrients, proteins, carbohydrates, iron, and potassium	Oxidative stress, boost antioxidant ability and immunity, malnutrition, swelling, bacterial contaminations, viral contagions, hyperglycemia, and cancer	(Mehwish et al. 2022)
Mushroom	*Agaricaceae*	France	β-glucans, Nicotinamide	Vitamin D and anti-cancer effects	(Ma et al. 2018)
Onion	*Amaryllidaceae*	Central Asia	Quercetin, Kaempferol	Anticarcinogenic activity and antioxidant activity	(Suleria et al. 2015)
Parsley	*Apiaceae*	Greece	Luteolin, Apigenin	High levels of coumarin	(Ajmera et al. 2019)
Passion fruit	*Passifloraceae*	Brazil	Quercetin	Antioxidant activity, anticonvulsant, anti-sedative, anticancer properties	(Lourith & Kanlayavattanakul 2020)
Pomegranate	*Punicacea*	Iran	Punicalagin	Antioxidant activity	(Gil et al. 2000; Puneeth & Sharath Chandra 2020; Viuda-Martos et al. 2010)
Pepper	*Piperaceae*	India	Piperine	Antiviral and antibacterial activity	(Choudhary et al. 2020)
Pumpkin	*Cucurbitaceae*	Mexico	Luteolin	Betacarotene	(S. Kaur et al. 2019)
Rambutan	*Sapindaceae*	Malaysia	Geraniin, ellagic acid, corilagin	Antioxidant, anti-cancer, anti-diabetic activity	(Bhat 2020)
Strawberry	*Rosaceae*	France	Phloretin	Antioxidant activity and anticarcinogenic activity	(Afrin et al. 2016)
Sunflower seed	*Asteraceae*	North America and Central America	Diterpene, carboxylic acid, aldehyde, steroid, polyphenol, vanillic acid, ferulic acid, trans-caffeic acid, coumaric acid, nicotinic acid, allelochemical	Polyunsaturated fatty acids (linoleic acid), tocopherols and phytosterols	(Rauf et al. 2020)
Sweet potato	*Convolvulaceae*	Central America	Dietary fibre, starch, protein, manganese, copper, potassium, iron, vitamin B complex, vitamin C, vitamin E, and provitamin A	Anti-cancer, antidiabetic, and anti-inflammatory activities	(Amagloh et al. 2021)
Tomato	*Solanaceae*	Peru	Ascorbic acid, Naringenin	Antioxidant activity and anticarcinogenic activity	(Blum et al. 2005)
Turmeric	*Zingiberaceae*	Southeast Asia	Curcumin, Berberine	Antibacterial activity, anti-inflammatory activity, and antioxidant activity	(Singletary 2010b)

ginger, broccoli, citrus fruits, pomegranate, elderberry, garlic, kiwi, red bell pepper, spinach, yogurt, meat, and egg products are elaborated below.

Almonds

Almonds are a kind of dry organic fruits that are considerably consumed to prevent and cure colds associated with viral infections. Almonds are small in size and enclose a lot of nutrients beneficial to the body. The entire body pulp is made of vitamins, minerals, and healthy fats (Masihuzzaman et al. 2020). Almond controls blood sugar, brings down blood pressure level, elevate constipation, anaemia, respiratory disorders, regulate cholesterol level, helps in nail strengthening, dental strength, hair repair, and growth (Alasalvar et al. 2020). Vitamin C and E present in almonds are great immune boosters. It is rich in antioxidants that manage free radicals, preventing infections, anti-inflammatory effects, immune-boosting properties, and anti-hepatoxicity (Huang & Lapsley 2019). Almonds are reported to progress the movement of food through the colon, thereby preventing colon cancer (Davis & Iwahashi 2001). The composition of fatty acids (rich in unsaturated oleic acid) present in almond is the essential compound for the easy movement of food through colon; the almond oil plays a significant role in signalling the molecules which imparts effects on proliferation of colon carcinoma cells and tumour viability metastasis (Mericli et al. 2017). Vitamin E in almonds also decreases the risk of heart diseases and combined with magnesium helps in inhibiting coronary failures.

Almond oil is a nutritive component giving good health and functioning of the nervous systems. As a dry natural fruit, it contains riboflavin and L-carnitine to enhance brain development and movement. Almond oil is generally given for children to help brain development and decrease the danger of Alzheimer's disease (Barreca et al. 2020). Vitamin, minerals, and phosphorus have been connected to bone development and strengthening (Masihuzzaman et al. 2020). Almond oil is applicable for massaging, improving skin appearance, and reversing the signs of aging. Almonds can be consumed in various manners like making almond milk a nutritive refreshment superior to milk and utilized as a top-up in yogurt or oatmeal. The nuts are pounded to make powder that can be applied to prepare almond butter by including salt, sprinkling almond powder in vegetables, and servings of mixed greens. It can also be utilized as an embellishment in dishes and pizzas (Angelica Vazquez-Flores et al. 2018).

Rambutan

Rambutan (*Nephelium lappaceum L.)* is a succulent and delicious immune-boosting fruit (Shahrajabian et al. 2020). The Malay-Indonesian word rambut means hairy and it is bright red to maroon color (Mahmood et al. 2018). Rambutan is enriched with nutrients like vitamin B, calcium, potassium, magnesium fiber, and natural sugars. It comprises of immune-boosting properties like antibacterial, antihyperlipidemic, antioxidant, hepatoprotective, biosorbent, antidiabetic, antimalarial, antiadipogenesis, and antiproliferative properties (Lestari et al. 2018; Mistriyani et al. 2018). Health benefits of rambutan include treating diarrhoea, viral infection, reducing unwanted fat from the body, helps in enriching skin, protects hair care, anticancer, and improves sperm quality. Humans can utilize rambutan as fresh fruit, juice, canned fruit jam, and jellies (Bhat 2020).

Durian

Durian (*Durio zibethinus*) is an exotic and tropical fruit with disease-resistant properties. In Southeast Asian countries, durian fruit is said to be the "King of the fruits" and the Maly word duri means the thorns of the fruit (Husin et al. 2018). The reddish-orange durian fruit is comprised of nutrients like a vitamin (A, B, C, E), copper, magnesium, calcium, phosphorus, potassium, flavonoids, tannins, improve the production of white blood cells. Durian fruit retains numerous health benefits like antioxidant, antiproliferative, antipyretic, reduce cholesterol, decrease blood pressure, diminish diarrhea, protect eyesight, stimulate proper digestion, treat menstrual problems by inducing insulin, inhibit metabolic syndrome, and enhance fertility in the polycystic ovary. Durian fruit can be potentially used for candies, jams, ice creams, toffies, milkshakes, and cake (Ali et al. 2020).

Avocado

Avocado (*Persea Americana*), also called butter fruit or aguacate or cura or cuppandra is an exotic, nutritious, perennial, and healthy fruit. It comprises of immunity building nutrients like carotenoids, phytosterols, folate, lutein, flavonoids, potassium, calcium, iron, magnesium, omega-3-fatty acids, epicatechin, lipids, peptides, sodium, vitamin (B, E, C, K), and potassium (Selladurai & Awachare 2020). The entire avocado (pulp, peel, seed) is rich in extensive health benefits like antioxidant, antimicrobial, antidiabetic, anticancer, antifungal properties, cardiovascular health, healthy aging, and weight management (Jimenez et al. 2021). The pulp of avocado can be utilized as a natural source of guacamole or avocado puree, ice creams, packed slices, salads, bread toasts, sandwich fillings, dried avocado, honey, oil, and milkshakes (Araújo et al. 2018).

Passion fruit

Passion fruit (*Passiflora incarnate*) is an export-oriented immune modulator fruit. It is supplemented with

nutritional assets of dietary fiber, antioxidants, vitamins, and minerals like vitamin B, riboflavin, niacin, magnesium, iron, phosphorus, vitamin C, flavonoids, beta carotene, and folate. The benefits of passion fruit in the human body encompasses a good bone structure, muscle, cartilage, anticancer, anti-stress, antidiabetic, antiobesity, and anticarcinogenic. It enhances the activity of the brain, and blood vessels. It is proven to be anticholesterolemic, hepatoprotective, and also prevents hyperlipidemia (Lourith & Kanlayavattanakul 2020; Padmapriya et al. 2020). The passion fruits are consumed raw or processed into products such as squash, fruit salads, cool drinks, sherbets, jams, ice-cream, pies, cakes, and juices (Thokchom & Mandal 2017).

Ginger

Ginger (*Zingeber Officinale Roscoe*), the most important spices in the world, was first found by William Roscoe in the year 1807. It comprises of phytochemicals like phenols and flavonoids (Palatty et al. 2013). Ginger contains gingerol, which helps to reduce chronic pain and cholesterol levels. It has several antioxidants, which are potent anti-inflammatory and immune-boosting elements. These impacts are assisted by the mechanisms inspired by the body during an infection. The human body releases free radicals causing oxidative stress. These free radicals join with the antioxidants delivered by ginger, causing the anti-inflammatory effect and the immune-boosting properties. The medicinal properties of ginger include anti-inflammatory (Li et al. 2012), antibacterial, antiviral, anticancer (Pereira et al. 2011), antiemetic (Palatty et al. 2013), hypoglycemic (Lee et al. 2015), weight control, inhibition of metabolic disorders (Tramontin et al. 2020) and antilipidemic (Brahma Naidu et al. 2016). Ginger is taken by humans in different manners like including grated ginger in hot tea or chocolate, and grated ginger can likewise be added to pastries when cooking (for example muffins, cookies, cupcakes). It can be used to cook marinate meats, chicken, and vegetables. Ginger can also be taken along with honey and high-temperature water (Vasala 2012).

Broccoli

Broccoli (*Brassica oleracea L.*) is a vegetable known as the "Crown Jewel of Nutrition" that is plentiful in vitamins, minerals, sulforaphane, polyphenols, flavonoids, carotenoids, and fiber (Dhiman et al. 2019). Broccoli contains antioxidants like Vitamin A, C and, E. Broccoli is a good source of potassium, sodium, magnesium, copper, zinc, selenium and, chromium. The potential benefits include anticancer, anti-aging, antiobesity, antidiabetic, chemoprotective, decreasing the risk of heart problems, antimicrobial activity, inhibiting cholesterol, and allergic reactions to enhance bone health, skin, hair care, and ulcers (Vasanthi et al. 2009). To retain all nutrients from broccoli, cook it for a short time or eat it as raw. Broccoli is well consumed as salads, juices, broccoli pasta, broccoli muffins, roasted broccoli, and butternut squash broccoli curry (Mukherjee & Mishra 2015).

Citrus fruits

Citrus fruits are immune-boosting fruit that contains vitamin C and folate. It lifts the immune system by enhancing white blood cells, which are the significant components engaged in protecting and fighting infections in the body. These natural fruits include orange, lemon, grape, lime, clementine, and tangerine (Ahmed & Azmat 2019). Citrus fruits are excellent sources of high antioxidants, limonoids, coumarins, ascorbic acid (vitamin C), potassium, riboflavin, vitamin B6, folate, carotenoids, flavonoids, and calcium (Yaqoob et al. 2019). Citrus fruits have a beneficial impact in treating flu, cardio-vascular diseases (reduces cardio-pulmonary resuscitation), antidiabetic, antimalarial, anti-mutagenicity, antifungal, antiviral, anti-aging activity, cancer prevention, diminishing diabetes, and preventing osteoporosis (Miles & Calder 2021). Citrus fruits can be taken as a whole, or they can be squeezed into the meal while eating or as jams, and juices (Ma et al. 2020).

Pomegranate

Pomegranate (*Punica granatum L.*) is an ancient red fruit that is rich in antioxidants, vitamin C, potassium, vitamin K, and folate. Because of the presence of polyphenol in the seeds of the pomegranate, the bright red color is attained. The antioxidant removes free radicals, which may cause cell damage and reduce inflammation (Oliveira et al. 2020). Pomegranate contains vitamins, protein, minerals, pectin, polyphenols, sugars, and tannins (Vučić et al. 2019). The probable health-promoting profits of pomegranate include antioxidant, antibacterial, antidiabetic, anticarcinogenic, antitumoral, and antiviral activity. It includes inhibition of bacterial growth in the mouth, reduction in cholesterol level, improvements in blood flow, and diminishes ulcers. It cures dysentery, decline in the risk of cancers, ensure liver health, and improves oral health. It lessens the risk of infertility in women, rises the testosterone in men, slows down Alzheimer's disease, and diminishes gut inflammation. It reduces insulin resistance by reducing blood sugar, enhancing digestion with ulcerative colitis, Crohn's disease, and bowel disease (Pirzadeh et al. 2021; Viuda-Martos et al. 2010). Flavonols present in the pomegranate fruit inhibits inflammation like osteoporosis arthritis and other joint pains. Pomegranate being an memory

booster, can be utilized and taken by blending juices, adding color to fruit salads, added to lemon juices, dairy products, food packaging films, coatings, meat, fish, cereal products, and making meat tasty (Kandylis & Kokkinomagoulos 2020).

Berries

Berries are filled with numerous phytochemicals; as discussed earlier phytochemicals are significant compounds in building immunity for cancer and altering the beneficial compounds of gut microbes (Pan et al. 2018). Based on the structure and composition there are various functions such as targeting cancer and immune cells and cytokines. The most common berries used for consumption are strawberries, blackberries, blueberries, cranberries, raspberries, gooseberries, and elderberries. Berries are mostly coloured fruits that are rich in phytochemicals; strawberry and blackcurrant are reported to contain more amounts of Vitamin C; also, they are rich in flavonoids and antioxidants which can aid in reducing heart problems such as reduction of cholesterol that clogs the arteries. Strawberry is a significant berry which has been observed to exhibit anti inflammatory impact on the macrophages treated with lipopolysaccharides; it reduced the proliferation of pro-inflammatory cytokines which in turn reduced the occurrence of colon cancer (Han et al. 2019). Consumption of blueberries were also found to increase the gastrointestinal migration and was observed to maintain the homeostasis of the gut (Rathinasabapathy et al. 2022).

Among berries, honeyberry and blackberry contains more amounts of vitamins loaded in it (Gonçalves et al. 2022). Honeyberry is also rich in minerals such as potassium, calcium, magnesium, sodium, iron and aluminium (Nile & Park 2014). Anthocyanins are abundantly available in almost all berries which can be indicated by the color of the fruit (red, purple and blue). Cancer preventing catechins which are major components in tea leaves are also present in cane berries. Apart from which raspberry contains Quercetin, which is a antioxidant that has been used in ayurvedic medicine for curing flu. Elderberries contain anthocyanin, vitamin C, fiber, tannins, phenolic acid, vitamin B, folic acid, biotin, carotene, pectin, potassium, glucose, phosphorus, fatty acids, and fructose (Ağalar 2018). Elderberries are present in syrups, which are remedies for flu, and bacterial sinus infections (Ağalar 2018). Consumption of elderberry in daily intake reduces headache, constipation, fever, stress, kidney problems, joint pain, and epilepsy (Silva et al. 2017). In general, berries are full of antioxidants that can scavenge free radical activity; the type of free radical scavenging varies based on the type and cultivar.

Garlic

Garlic (*Allium sativum*) is the most mainstream supplement of the majority people's diets because of its immunity power build-up. The immune-boosting properties of garlic are because of the presence of major concentrations of sulfur-containing compounds such as allicin (Batiha et al. 2020). Garlic is a good source of calcium, potassium, protein, zinc, iron, magnesium, saponins, arginine, selenium, polyphenols, vitamin A, vitamin B, vitamin C, and antioxidant (Singh et al. 2019). The garlic bulbs are beneficial in antioxidants because of the presence of free radicals that can support the treatment of cancers, Alzheimer's, arthritis, fever, heart diseases, leprosy, and constipation. It cures diarrhoea, asthma, infertility, hypertension, loss of appetite, cholesterol, abdominal pain, edema, anemia, diabetes, and foot sprains. It suppresses mutagenesis, regulates enzymes, lessens blood pressure, and reduces the hardening of arteries (Ekşi et al. 2020; Zhang et al. 2020). Garlic can be consumed in various forms like pickle, added to salads, pizza, tea, honey, guacamole, and sandwich.

Kiwi

Kiwi (*Actinidia arguta*) is a nutrient-dense and one of the fruits due to its anti-inflammatory, antifungal, antiviral, and antioxidant properties (Stonehouse et al. 2013). It comprises several fundamental nutrients such as Vitamin C, K, dietary fibre, folate, antioxidants, phytonutrients, magnesium, calcium, carotenoids, lutein, copper, polyphenols, alkaloids, and potassium (Richardson et al. 2018). Vitamin C enhances white blood cells to defeat infections. The other nutrients are basic for keeping up appropriate body functions, which are higher than apples and grapes. Some of the health benefits of the immunity-boosting food kiwi include prevention of diabetes, anti-allergic, cardiovascular disease, antiatherosclerotic, neurodegenerative diseases, anti-edematous, promotes digestion, increases immunity power, platelet aggregation, and progresses metabolic health (Baranowska & Dominik 2019). It can be used as a raw fruit, jam, wine, juices, and jelly.

Red bell pepper

Red bell pepper (*Capsicum annuum L)* is a crucial immunity-boosting food that has twofold times of vitamin C content of citrus fruits. The red color is due to the occurrence of carotenoids and is incredibly perishable. Red bell pepper comprises flavonoids, vitamin A, vitamin C, phenolic acids, and minerals (Kaur et al. 2020). Being anti-oxidative, anti-allergic, and anti-inflammatory, red bell pepper helps in protecting eyesight, skin, shields the stomach by enhancing the

digestive juice flow, blood purifier, healing wounds, arthritis, and protects from cancer (Nadeem et al. 2011; Zhang & Hamauzu 2003). It is available as a paste, powder, flavoring agent, red bell pepper powder enriched bread, salads, and the coloring agent (Ashok et al. 2020).

Spinach

Spinach is one of the dark leafy green vegetables and known as superfoods because of its richness in vitamin A, C, beta carotene, calcium, fibre, magnesium, phenolic acids, iron, tannins, oxalic acid, flavonoids, and many antioxidants which are properties that increase the body's immunity power to fight against infections (Bergman et al. 2001; Singh et al. 2018). The essential nutrients present in spinach mediates the cell division process and DNA repair. The alpha-lipoic antioxidant is present in spinach, which reduces glucose levels by enhancing insulin sensitivity and inhibits the oxidative stress produced by the impact of diabetes. As spinach contains chlorophyll pigments, beta-carotene, iron, vitamin K, fibre, and vitamin A this can be used to treat cancer-causing impacts, diminish asthma, restrain bone defects, cures constipation, anaemia, and skin diseases (Roberts & Moreau 2016). Spinach can be applied in different ways as garlic sautéed spinach, spinach lasagne, cheese-stuffed pasta shells, spinach-artichoke dip, and creamed spinach.

Yogurt

Yogurt is the thick liquid nutritious product obtained from milk and effervesced dairy product with added sugar, probiotics, and bacteria. Lactic acid is formed during bacterial fermentation, making proteins in the milk to curdle, generating a single flavor and texture. Yogurt is flavored or unsweetened, but it builds immunity power in humans due to vitamin D, calcium, vitamin B, phosphorous, magnesium, proteins, and probiotics (Jørgensen et al. 2018). Calcium is available in yogurt, which is required for the development of bones. Yogurt benefits include the risk of danger of heart disease, irritable bowel syndrome, blood pressure, osteoporosis, body metabolism, appetite, depression, and obesity (Sarkar 2019). Yogurt applications are lassi, skim milk, ice cream, raita, and powder (Meybodi et al. 2020).

Meat and egg products

Meat products include chicken, beef, and fish which is a rich source of essential protein in diet. Red meat is rich in the sources of protein, potassium, iron, selenium, linoleic acid, vitamin B, zinc, and omega-3-fatty acids. Meat products being immune-boosters are improved with vitamin B6 and zinc, which plays a vital role in the formation of red platelets. Meat (rich in amino acids) also acts as an antioxidant, antimicrobial, anticancer, antihypertensive, and essential for immunity building power (Jiang & Xiong 2016). The amino acids present in meat aids in preventing diseases that wastes muscles, maintaining gut environment by the nucleotides present, maintain the homeostasis of blood pressure by the ACE inhibitory property of connecting tissues (Young et al. 2013). Apart from these functions, the presence of antioxidants, linoleic acids, and phytanic acids which also aids in the maintenance of immunity. Aqua foods are enriched with polyunsaturated fatty acids, iodine, vitamin D, selenium, and protein (Suraiya et al. 2022). Fish is an anti-inflammatory, antithrombotic, anti-adipogenic, antioxidant, anticancer, antiarrhythmic, neuroprotective, and helpful in treating arthritis (Li et al. 2020). Eggs are rich in protein and mainly have avidin, ovomucin, ovalbumin, lysozyme, phospholipids, lutein, and ovotransferrin. Antibacterial and anti-inflammatory properties are present in the egg. Consumption of egg prevents wound, neurons, cardiovascular diseases, allergic reactions, and anti-aging (Xiao et al. 2020). It is utilized in the form of salads, curries, pizzas, and fried meat products.

Though the immune boosting foods have several essential nutrients in them, still only few clinal studies has been conduced to prove the fact that raw fruits and vegetables increase immunity. Table 3 is the compilation of clinical studies that has been conducted on natural foods for increasing immunity.

Conclusion

Food is the only medicine to maintain good health. Consumption of immune-boosting foods like almonds, rambutan, durian, avocado, passion fruit, ginger, broccoli, citrus fruits, pomegranate, elderberry, garlic, kiwi, red bell pepper, spinach, yogurt, meat, and egg products at recommended levels helps in maintaining human body metabolism and immune system. These immunity-boosting foods are enriched with nutrients like vitamins, minerals, and antioxidants for a strong defence against diseases. Two types of immunity (innate and adaptive immunity) which are essential for the destruction of infected cells and the immune system of humans were explained in this review. The functional components of immune-building foods like antioxidants (carotene, vitamin C, vitamin E folate, selenium, and phytochemicals), vitamin D, zinc, iron, dietary fiber, and omega -3 fatty acids were also discussed. Naturally obtained fruits and vegetables loaded with numerous antioxidants and meat products with essential amino

Table 3 The beneficial effects of immune boosting foods assessed by clinical trials

S.No	Commodity	Clinical study subject	Clinical trial parameters and objective	Results of the trial	Reference
	Red ginseng extracted from root (active compound: ginsenosides)	Mouse	Different types of ginsenosides were extracted (20 mg/kg) and were evaluated for inhibiting lung inflammation.	Ginsenosides such as Rc, Re, Rg1 and Rh2 were found to reduce the cells in bronchoalveolar lavage fluids (cause by inflammation)	(Lee et al. 2018)
	Açai (active compound: ellagic acid, resveratrol, anthocyanin and proanthocyanin)	Human (women)	40 healthy women, aged 24, were given 200 g Açai per day for 4 weeks and assessed for n plasma lipids, apolipoproteins, the transfer of lipids to HDL and redox metabolism.	Açai consumption was found to significantly decrease the reactive species, Ox-Low density lipoprotein (LDL) and malondialdehyde content in the blood sample. Further the total antioxidant capacity was also observed to increase in women after 4 weeks.	(Pala et al. 2018)
	Garlic (active compound: allicin)	Human	Adults- 192 members with low LDL were selected and given garlic (raw garlic, powdered garlic, and garlic extract) for 6 days per week for 6 months and assessed for changes in the LDL.	No significant changes in LDL were observed for consumption of all garlic products	(Gardner et al. 2007)
	Fermented milk (active compound: probiotics)	Mice	Milk fermented using *Lactobacillus casei* ($2 \pm 1 \times 10^9$ CFU/ml) was subjected (60 days) to mice for assessing its effect on metastatic stage of breast cancer	Fermented milk administered were found to reduce the metastasis and inflammatory cells in lungs and the reductions were more than mice administered with raw milk	(Mendez Utz et al. 2019)
	Cream cheese (active compound: probiotics)	Mice	Cream cheese produced using Lactococcus chungangensis dry cells. 1.4 g dissolved in 200 µl of water was administered to mice for 8 weeks to assess the treatment of atopic dermatitis	The administration aided in reducing the IgE, basophil cells and eosinophil in mice	(Kim et al. 2019)
	Peach palm waste (active compound: β-carotene, γ-carotene, and lycopene)	Wistar rats	Carotenoids from peach palm wastes were extracted (ionic liquid mediated process) and subjected to animal trials through gavage feeding for assessing its effect on safety, anti-inflammatory and antioxidant activity.	Carotenoids supplemented wistar rats were less in weight. Increase in antioxidant and anti-inflammatory actions were observed.	(Santamarina et al. 2022)
	Palm oil, native to amazon-Tucuma (active compound: oleic/elaidic fatty acids)	Diabetic mice	Palm oil was subjected to diabetic mice 5 ml/kg for 14 days through gavage feeding to analyse the effect on memory, enzymatic activities of sodium–potassium pump and TBARS value.	Compared to the mice subjected with normal supplements, the ones provided with tucuma oil was found to have more memory, reduced ROS activity, TBARS value and oxidation	(Baldissera et al. 2017)
	Plant flavonoids (active compound: genistein and hesperidin- purchased from commercial company)	Broiler chicken	Administered to lipopolysaccharides challenged broiler, 5 mg genistein /kg feed and 20 mg hesperidin per kg feed for 6 weeks for assessing the immunomodulatory effect.	The supplementation in chickens were observed to increase the plasma antioxidant effect during the growth. Further humoral and mucosal immunity was also found to be increased	(Kamboh et al. 2016)
	Curcumin (purchased commercially)	Wistar rats	50 mg/kg of curcumin was administered to wistar rats for 30 days to analyse the antioxidant activity on curcumin	Spleen size and Adenosine deaminase activity reduced. Lipid damage was reduced by 40% in liver and 56% in kidney	(Manzoni et al. 2020)
	Litchi (active compound: polysaccharide)	Mice	Litchi pulp polysaccharide was given to mice at different concentrations- 50, 100 and 200 mg/kg each day to assess the immunomodulatory and antioxidant activities.	The administered dosage was found to have immunomodulatory effect in serum and liver. The antioxidant activity and superoxide dismutase activity increased	(Huang et al. 2016)

acids when ingested as a portion of a balanced diet, can maintain a proper immune function which in turn can act against diseases like cardiovascular disease, blood pressure, allergic reaction, constipation, anaemia, asthma, restrain bone defects, memory loss, night blindness, stress, kidney problems, joint pain, epilepsy, neurodegenerative, age-related macular degeneration disease, healing wounds, arthritis, irritable bowel syndrome, osteoporosis, appetite, depression, obesity, and cancer. Therefore, having a healthy diet in in our everyday life is essential for healthy living.

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