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Garlic Supplementation and Exercise-Induced Immunomodulation: A Narrative Review of Synergistic Mechanisms and Clinical Implications

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ABSTRACT

Garlic (Allium sativum) has been suggested as a natural immunomodulator, especially regarding exercise-induced immune system modulation. Due to its bioactive sulfur compounds, such as allicin, diallyl sulfides, and S-allylcysteine, garlic has been shown to have strong antioxidant and anti-inflammatory properties. The purpose of this narrative review was to assess the individual and combined effects of garlic supplement administration and exercise training on the immune system, focusing on molecular mechanisms and clinical results. A thorough literature search was performed in the PubMed, Scopus, Web of Science, and Persian databases (SID, MagIran) for articles published between 2000 and March 2025. Human and animal studies examining immunological parameters, such as immune cell activity, cytokines, immunoglobulins, oxidative stress markers, and infection rates, were qualitatively analyzed. Findings suggest that moderate garlic consumption (600-1200 mg/day of standardized garlic extract or equivalent) in combination with regular moderate to vigorous exercise may have a synergistic effect on the immune system. These immune system adaptations occur through Nrf2/ARE pathway activation, increased hydrogen sulfide production, NF-κB signalling inhibition, and gut-immune axis modulation. These results include increased NK cell and T lymphocyte activity, increased secretory IgA levels, improved antioxidant status, and decreased inflammatory markers (IL-6, TNF-α, CRP, and MDA), as well as a diminished post-exercise "open window" period. However, overuse or long-term unsupervised consumption may result in gastrointestinal side effects or adverse interactions, especially among patients taking anticoagulants. Garlic supplementation in combination with structured exercise regimens appears to be a promising approach for immune system modulation.

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Introduction

The Garlic (Allium sativum) has long been recognized as one of the most important medicinal and food plants in traditional and modern medicine. This natural substance is used in cooking not only for its unique flavor and aroma, but also because it contains active sulfur compounds (especially allicin, ajuene, and diallyl disulfide) that have potent antimicrobial, antiviral, anti-inflammatory, and antioxidant properties (1, 4). Numerous studies have shown that garlic consumption can help enhance immune function by scavenging free radicals, reducing inflammatory markers (such as CRP and interleukin-6), and modulating cytokine responses (5, 8, 9). The immune system is a complex and dynamic network of cells, tissues, and organs that is responsible for recognizing and eliminating pathogens, cancer cells, and foreign substances and plays a key role in maintaining homeostasis (2, 6). This system includes two main arms: innate immunity and adaptive immunity, which are supported by different types of white blood cells (neutrophils, monocytes/macrophages, T and B lymphocytes, natural killer (NK) cells, etc.). On the other hand, regular and moderate exercise is known to be one of the most effective non-pharmacological interventions in promoting immune health. Exercise helps to strengthen immune defence by improving lymphatic circulation, increasing the number and activity of immune cells, reducing stress hormones (cortisol), and modulating cytokine balance (increasing anti-inflammatory IL-10 and decreasing inflammatory IL-6 and TNF-α) (3). However, prolonged, strenuous exercise can temporarily suppress immunity and increase the risk of upper respiratory tract

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infections (a phenomenon known as the "open immune window") (2).

The combination of garlic consumption and regular exercise can have significant synergistic effects on the immune system. Preliminary animal and human studies have shown that garlic extract is able to increase the phagocytic activity of macrophages and NK cells, while moderate exercise enhances these effects (7-9). These two natural interventions can effectively reduce the severity and duration of viral infections (such as the common cold and influenza), especially in conditions of high oxidative stress or during periods of recovery from illness. The main objective of this narrative review is to comprehensively review the available evidence on the independent and combined effects of garlic and exercise on different components of the immune system, to elucidate the biochemical and physiological mechanisms involved (including antioxidant pathways, cytokine modulation, and effects on the gut microbiome), and to provide practical recommendations for the optimal use of these two natural agents. We hope that this review can help raise public awareness and promote a healthier lifestyle in the face of current health challenges.

Materials and Methods

This study was designed and conducted as a narrative review. The main objective is to provide a comprehensive, critical, and integrated interpretation of the available evidence regarding the independent and synergistic effects of garlic (Allium sativum) and exercise on the immune system. A targeted and comprehensive literature search was conducted between January 2000 and March 2025 in the PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, SID, and MagIran databases. The English keywords ("Garlic" OR "Allium sativum" OR "Allicin" OR "Garlic extract" OR "Garlic supplement") AND ("Exercise" OR "Physical activity" OR "Aerobic exercise" OR "Resistance training") AND ("Immune system" OR "Immune function" OR "Cytokine" OR "Lymphocyte" OR "Natural killer cell" OR "Inflammation" OR "Infection") and their Persian equivalents ("Garlic", "Garlic extract", "Allicin", "Physical activity", "Exercise", "Immune system", "Cytokine", "Lymphocyte", "NK cell", "Inflammation", "Infection") were combined using Boolean operators and truncation (*) to maximize the sensitivity and comprehensiveness of the search. Inclusion criteria included human experimental studies (randomized clinical trials, quasi-experimental trials, and cohort studies), relevant animal studies, high-quality systematic reviews and narratives, publication in English or Persian, access to full text, and examination of at least one immunological outcome (immune cell count or function, cytokine levels, antioxidant capacity, incidence or severity of infections). Studies that only addressed the effects of garlic or exercise on non-immune diseases were excluded. Screening was performed in two stages (title and abstract review, then full text review) by the lead author. Data extraction was performed manually using a standard form including study specifications, participant characteristics, type and dose of garlic intervention, type, intensity, and duration of exercise, immunological outcomes, main results, effect size, and methodological limitations.

Due to the narrative nature of the review and the high heterogeneity of the studies in terms of population, intervention, and outcomes, meta-analysis was not performed and instead, a qualitative and interpretive synthesis was performed based on the weight of evidence, consistency of results, and clinical significance. Possible biochemical and physiological mechanisms were also elucidated based on mechanistic studies and animal models. This review was written in full compliance with the ethical principles of scientific writing and Vancouver style referencing, and an attempt has been made to provide a balanced, up-to-date, and practical picture of the current state of knowledge in the field of the effects of exercise and exercise on the immune system.

Immune System

The immune system is the body's primary defence against infectious agents and health threats. It is responsible for identifying and combating a variety of microorganisms, including viruses, bacteria, and fungi. (11) The function of this system is based on various forms of defence responses, which are divided into two general categories: a) Innate immunity: This layer forms the body's baseline defence and deals with foreign agents in a rapid and non-specialized manner. Key components of this branch include cells such as macrophages, neutrophils, and dendritic cells, which respond actively to the first signals. Also, unlike other immune mechanisms, this system does not have the ability to store past patterns of pathogens, so that each new invader is targeted for defensive measures without building on previous experiences. (12). b) Adaptive Immunity: This system is more complex and targeted, which, along with the power to create specific responses to various threats, creates a long-term memory of pathogens. B and T lymphocytes are the pillars of this section. The existence of such a memory makes it possible for the body to respond more quickly and effectively when faced with a threat again. (13)

In sum, it is the coordination and complementary function of innate and adaptive elements that enables the body to prevent diseases with high efficiency or to control them well. Effects of Garlic on the Immune System: Garlic (Allium sativum) is one of the beneficial plants with a long history in traditional medicine and natural remedies, which has broad effects on the body's immune system due to the presence of bioactive compounds such as allicin (a potent antibiotic that is released when the cloves are crushed or chewed (14)), followed by sulfur compounds and organic sulfides and nitric acid, and has strengthened confidence in its role in promoting general health. (15). Research has shown that regular consumption of garlic can enhance the immune system's defence processes through the following pathways:1. Increasing the activity of the effector cells of macrophages, NK cells (natural killer cells), and lymphocytes (15). 2. Creating an effective balance between the production of pro-inflammatory cytokines (such as IL-6 and TNF-α) and anti-inflammatory cytokines (such as IL-10), which helps to improve general inflammatory conditions (15). 3. Enhancing the synthesis of immunoglobulins, including IgA and IgG, which play an important role in combating foreign particles and pathogens (15). 4. The antioxidant and antibacterial properties of garlic, which help to protect against infections while reducing the harmful effects of free radicals in the body (15). 5. Active compounds in garlic can help reduce oxidative stress and free radical damage. This helps maintain healthy cells (16). Tetrahydro-beta-carboline (17), Nα-(1-deoxy-D-fructose-1-yl)-L-arginine (18), and S-allyl-L-cysteine (SAC) (19, 20) are compounds in ripe garlic that have been shown to have antioxidant effects and protect against neurodegeneration, cardiotoxicity, and diabetic complications. This evidence suggests that garlic, in addition to being a nutritious food, is a valuable option for better protection of the body against microbial attacks, especially during special conditions or strenuous exercise.

Garlic and Immune Function

Garlic (Allium sativum) has been extensively investigated for its immunomodulatory properties. The immunological effects of garlic are primarily attributed to its organosulfur compounds, including allicin, diallyl sulfides, ajoene, and S-allyl-L-cysteine (SAC). These bioactive molecules influence both innate and adaptive immune responses through multiple molecular pathways. At the level of innate immunity, garlic enhances macrophage phagocytic activity, increases natural killer (NK) cell cytotoxicity, and stimulates dendritic cell maturation. Mechanistically, garlic-derived compounds modulate signaling pathways such as NF-κB and MAPK, leading to controlled production of cytokines. Importantly, garlic does not simply stimulate inflammation; rather, it promotes immune balance by reducing excessive production of pro-inflammatory cytokines (e.g., TNF-α, IL-6) while supporting anti-inflammatory mediators such as IL-10. Regarding adaptive immunity, garlic supplementation has been shown to enhance T lymphocyte proliferation and improve B-cell-mediated antibody production, including IgA and IgG synthesis. Additionally, aged garlic extract has demonstrated antioxidant capacity via upregulation of endogenous antioxidant enzymes (SOD, catalase, glutathione peroxidase), thereby protecting immune cells from oxidative stress–induced dysfunction. These findings position garlic not merely as an antimicrobial agent but as a systemic immunoregulatory nutraceutical capable of maintaining immune homeostasis, particularly under physiological stress conditions.

Exercise and Immune Function

Exercise exerts a dual, intensity-dependent effect on immune function. Moderate, regular physical activity is widely recognized as an immune-enhancing stimulus. It improves immune surveillance through increased circulation of neutrophils, monocytes, NK cells, and effector T cells. Chronic training adaptations include reduced systemic inflammation, improved redox balance, and enhanced immunoregulation.

At the molecular level, moderate exercise reduces basal NF-κB activation, improves mitochondrial function, and increases anti-inflammatory cytokines such as IL-10. Long-term training is also associated with reduced incidence of upper respiratory tract infections (URTI), especially in physically active populations. Conversely, prolonged or high-intensity exercise may induce transient immunosuppression, commonly described within the "open window" theory. This condition is characterized by elevated cortisol and catecholamines, increased oxidative stress, lymphocyte apoptosis, and temporary suppression of mucosal immunity (e.g., decreased salivary IgA). Therefore, strategies aimed at attenuating exercise-induced oxidative and inflammatory stress are of significant clinical and athletic interest.

Synergistic Effect: Garlic and Exercise

The combined application of garlic supplementation and structured exercise training appears to exert complementary and potentially synergistic immunomodulatory effects through partially overlapping yet mechanistically distinct biological pathways. Exercise induces the production of reactive oxygen species (ROS), which function as essential signalling molecules for cellular adaptation when maintained within physiological ranges; however, excessive ROS accumulation may compromise immune cell integrity and function. Bioactive sulfur-containing compounds in garlic, particularly S-allyl cysteine (SAC) and tetrahydro-β-carbolines, enhance endogenous antioxidant defense systems such as glutathione peroxidase and superoxide dismutase, thereby limiting oxidative damage while preserving redox-sensitive signalling required for exercise adaptation. This balanced modulation of redox homeostasis may optimize immune resilience without attenuating training-induced physiological benefits (21). In parallel, both exercise and garlic influence cytokine dynamics through distinct yet complementary mechanisms. Regular moderate exercise promotes an anti-inflammatory environment partly through myokine release, especially interleukin-6 (IL-6), which in the context of exercise exerts anti-inflammatory effects by stimulating IL-10 production and inhibiting tumor necrosis factor-alpha (TNF-α). Concurrently, garlic supplementation has been shown to suppress chronic low-grade inflammation by downregulating pro-inflammatory cytokines such as TNF-α and interleukin-1 beta (IL-1β). The interaction of these mechanisms may stabilize systemic cytokine balance, enhance IL-10–mediated immune regulation, and attenuate excessive inflammatory signalling (22, 23).

During periods of intensified or prolonged training, transient immunosuppression may occur, characterized by reductions in natural killer (NK) cell activity, impaired T-cell proliferation, and increased susceptibility to upper respiratory tract infections. Garlic's immunostimulatory properties, including enhancement of NK cell cytotoxicity, lymphocyte proliferation, and antibody production, may counterbalance this temporary suppression and support immune surveillance in athletes exposed to high training loads. Furthermore, strenuous exercise activates the hypothalamic–pituitary–adrenal (HPA) axis, resulting in elevated glucocorticoid secretion that can negatively influence immune competence. Emerging evidence suggests that garlic may attenuate stress-induced immune alterations by modulating oxidative stress and inflammatory signaling pathways, thereby indirectly contributing to improved HPA axis stability and maintenance of immune homeostasis under physiological stress.

Collectively, evidence from supplementation trials indicates that combining garlic extract with structured exercise programs may reduce circulating inflammatory biomarkers such as TNF-α and IL-6, enhance NK cell cytotoxic activity, and improve T-cell responsiveness. These findings suggest that garlic may serve as an adjunct nutritional strategy to optimize immune resilience in both athletic and general populations, particularly under conditions of increased physiological demand (24, 25).

Discussion

Laboratory and human studies have investigated the interaction of garlic supplementation and exercise on the immune system over the past two decades. A number of studies have shown that garlic consumption can have enhancing effects on immune function, antioxidant capacity, and inflammatory responses in exercise conditions. However, the results of some studies have not been completely consistent due to differences in dose, duration of intervention, health status of the subjects, and intensity of exercise. In one landmark study, Pedersen and Jensen (2019) showed that the combination of garlic and regular exercise resulted in a significant increase in lymphocytes and macrophages and a reduction in chronic inflammation compared with placebo (26,27). In another study, garlic supplementation for two weeks significantly increased IgA and IgG immunoglobulins in athletes, which play an important role in reducing upper respiratory tract infections (28). More evidence has also been reported for the anti-inflammatory and antioxidant effects of garlic. Su et al. found that 14 days of garlic supplementation (800 mg/day) reduced muscle damage and inflammation induced by eccentric exercise and improved antioxidant capacity (29). Gholami et al. also showed that acute garlic intake (1000 mg), although not altering cellular damage, improved levels of malondialdehyde (MDA) resulting from lipid oxidation (30). This body of evidence suggests that garlic may have a protective role against inflammation and oxidative stress in the interaction with exercise. Despite positive results, some studies have reported neutral or even negative effects. Johnson et al. (2020) reported that garlic supplementation had no significant effect on the immune system function of athletes (31). In another study, Thompson et al. (2018) reported that some athletes experienced gastrointestinal discomfort and decreased exercise performance after consuming a garlic-rich diet for one month (32). Furthermore, Williams et al. (2019) showed that garlic consumption in individuals treated with blood thinners can increase the risk of bleeding and even cause immune dysfunction (33). Therefore, garlic consumption, especially at high doses or in individuals with certain conditions, requires caution. Evidence in the scientific literature suggests dual and condition-dependent effects of garlic (Allium sativum) and its combination with exercise on the immune system and inflammatory-oxidative responses of the body. Active compounds in garlic, particularly allicin, diallyl disulfide, S-allylcysteine (SAC), and flavonoids, are able to reduce the systemic inflammatory response and improve the function of immune cells (lymphocytes, NK cells, and macrophages) by scavenging free radicals, increasing total antioxidant capacity (TAC), modulating the NF-κB pathway, and reducing the production of proinflammatory cytokines (TNF-α, IL-6, and CRP) (46-50, 52-54). Several human studies have shown the synergistic positive effects of garlic and moderate-to-vigorous exercise on the immune system. For example, Pedersen and Jensen (2019) showed in a randomized clinical trial that garlic supplementation combined with a regular exercise program significantly increased the number of lymphocytes and macrophages and reduced markers of chronic inflammation (26, 27). Similarly, short-term (14 days) garlic supplementation in athletes resulted in significant increases in IgA and IgG and a reduced risk of upper respiratory tract infections (28). Su et al. (2021) also reported that a daily dose of 800 mg of garlic significantly reduced oxidative and inflammatory damage induced by eccentric exercise (29). These findings are consistent with the results of Gholami et al. (2006) who found that acute administration of 1000 mg of garlic before intense exercise improved malondialdehyde (MDA) concentrations (30). Despite this positive evidence, the results are not uniform. Johnson et al. (2020) found no significant differences in immune markers between the garlic and placebo groups in a randomized trial of 50 athletes, suggesting that the effects of garlic may be dependent on the individual's underlying diet, exercise intensity, and initial antioxidant status (31). Some studies have also reported adverse effects; Thompson et al. (2018) showed that high doses of garlic can cause gastrointestinal upset and reduced exercise performance (32), and Williams et al. (2019) warned that concomitant use of garlic with anticoagulants increases the risk of bleeding and can paradoxically impair the immune response in certain individuals (33). From a mechanistic perspective, intense exercise is associated with excessive production of reactive oxygen species (ROS) and redox imbalance, leading to increased MDA, IL-6, TNF-α, CK, LDH, and inflammatory infiltration of macrophages (36-43). Garlic is able to modulate these responses by increasing hydrogen sulfide production, enhancing the glutathione system, and inhibiting NF-κB activation (51-53). Recent systematic reviews have also confirmed that doses higher than 1000 mg daily and courses shorter than 8 weeks have the greatest effect on increasing TAC and reducing MDA (54-58).

Garlic sulfur compounds (allicin, DADS, DATS, SAC) induce electrophilic stress, dissociate Nrf2 from Keap1, and induce its nuclear translocation and binding to ARE, which greatly increases the expression of HO-1, NQO1, GCLC, GCLM, and SOD, and increases the synthesis of glutathione and TAC; moderate exercise also stimulates PGC-1α through the activation of AMPK and SIRT1, enhancing the expression of the same Nrf2-dependent genes, creating a significant synergy. Allicin and SAC inhibit IκBα phosphorylation and NF-κB activation by covalently modifying critical cysteines in IKKβ and p65, and reduce the expression of IL-6, TNF-α, COX-2, and iNOS; Vigorous exercise alone transiently activates NF-κB, but moderates the course of this activation and prevents excessive inflammation.

SAC and DATS act as natural H_2S donors and open KATP channels through S-sulfhydration and further inhibit the NF-κB pathway; aerobic exercise increases endogenous H_2S production from CSE and CBS, and its combination with garlic multiplies the vasodilation and anti-inflammatory effect (59).

At the level of immune cells, garlic increases the proliferation of CD4+ and CD8+ T lymphocytes and the secretion of IL-2 and IFN-γ; moderate exercise also enhances lymphocyte mobilization through transient catecholamines and IL-6, and their combination synergistically enhances the Th1 response. NK cell activity is temporarily reduced after intense exercise (open window), but garlic supplementation compensates for and even enhances this decrease by increasing IL-15 expression and maintaining peroxidase activity.

Garlic increases macrophage phagocytosis and intraphagolysosomal ROS production, while resistance exercise increases the number of anti-inflammatory M2 macrophages; their combination enhances antimicrobial defence without systemic inflammation. Garlic polysaccharides and fructans as prebiotics increase the growth of Lactobacillus and Bifidobacterium and increase the production of SCFA (butyrate, propionate); exercise also promotes the expansion of Treg cells and the reduction of Th17 cells by increasing intestinal blood flow and stimulating GPR43/109A receptors, thus activating the gut-immune axis bilaterally (60). Finally, the combination of garlic and regular exercise, through the synergy of the Nrf2, H_2S, NF-κB, AMPK-PGC-1α pathways and the gut-brain-immune axis, optimally regulates redox balance, immune response and post-exercise recovery.

In summary, moderate garlic consumption (preferably 600-1200 mg of standardized extract or equivalent to 2-4 raw garlic cloves daily) combined with regular moderate to intense exercise has positive synergistic effects on the immune system, reducing chronic inflammation and improving post-exercise recovery in most healthy individuals. However, its effects are strongly dose-dependent, time-dependent and individual-dependent and in some conditions (high doses, concomitant use with certain medications, or the presence of gastrointestinal diseases) can be neutral or even negative. Therefore, clinical and exercise advice should be individualized and preferably carried out under the supervision of a nutritionist or physician. Future studies should focus on larger, longer-term, dose-response clinical trials to accurately determine the optimal range of garlic consumption in athletes and normal individuals and to develop safe and effective protocols to maximize the synergistic effects of garlic and exercise. Table 1 presents an overview of the participants, interventions, and findings of studies on garlic and sports activity.

Conclusion

Exercise helps improve overall health and has a positive effect on the immune system. Exercise helps improve blood circulation, increases energy levels, and decreases stress hormones, which can help boost the immune system. Exercise can also help decrease inflammation in the body, which can help boost the immune system. The production of positive chemicals in the body due to exercise and garlic consumption can help boost the immune system simultaneously.

It is important to focus on diet and exercise as two major pillars in boosting the immune system. Garlic, as a natural ingredient with special properties, and exercise as a daily activity, can help boost the immune system in the body simultaneously and together. For those who are looking to maintain their health and prevent diseases, it is recommended to consider garlic consumption in addition to a regular exercise program. These two factors not only help improve the quality of life, but they can also serve as a major protection mechanism against various infections and diseases. By following these healthy habits, one can hope to improve the quality of life and increase life span. The combination of garlic and regular exercise can be used as a natural, safe, and combined approach to boost immunity and recovery in athletes and active individuals, as long as the optimal dose and individualization of the treatment are taken into consideration. Future studies should aim to focus on dose-response and long-term clinical trials to provide more accurate practical protocols.

Table 1. Overview of participants, interventions, and findings of studies on garlic and sports activity

Author (Year)	Study Design / Participants	Intervention Protocol	Main Outcomes	Direction of Effect
Pedersen & Jensen (2019)	Randomized clinical trial; physically active adults	Garlic supplementation + regular exercise vs placebo	Lymphocytes↑, Macrophages↑, Chronic inflammatory markers↓	Increase (immune cells) / Decrease (inflammation)
Unnamed Athlete Study (Ref 28)	Human trial; athletes	Garlic supplementation for 14 days	IgA↑, IgG↑; Upper respiratory tract infections↓	Increase (immunoglobulins) / Decrease (URTI risk)
Su et al. (2021)	Human experimental; eccentric exercise model	800 mg/day garlic for 14 days	Muscle damage markers↓; Inflammation↓; Antioxidant capacity↑	Decrease (inflammation & damage) / Increase (TAC)
Gholami et al. (2006)	Acute supplementation study; trained individuals	1000 mg garlic prior to intense exercise	MDA (lipid peroxidation) ↓; no significant change in cellular damage markers	Decrease (oxidative stress) / No change (cell damage)
Johnson et al. (2020)	Randomized controlled trial; 50 athletes	Garlic vs placebo during training	No significant differences in immune markers	No significant effect
Thompson et al. (2018)	Dietary intervention; athletes	Garlic-rich diet for 1 month (high dose)	GI discomfort; Exercise performance↓	Negative effect
Williams et al. (2019)	Clinical observational; individuals on anticoagulants	Garlic intake + blood thinners	Bleeding risk↑; possible immune dysregulation	Adverse effect
Systematic Reviews (54–58)	Meta-analyses; human studies	Doses >1000 mg/day; duration <8 weeks	Total Antioxidant Capacity (TAC) ↑; MDA↓	Increase (TAC) / Decrease (oxidative stress)

Declarations

Ethical Considerations

As the present study is a review study and does not involve any direct intervention with human or animal participants or the collection of new data from research subjects, ethical approval or an ethics code was not required.

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Conflict of Interest

The author of this article declares that there are no conflicts of interest of any kind (financial, personal, or organizational) in the conduct, writing, or publication of this research.

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