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Review Article

Nuts and Nutritional Factors in Management of Male Fertility: A Review

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ABSTRACT

Infertility has a significant impact on the quality of lives of infertile couples, necessitating the exploration of approaches to reduce its prevalence and improve fertility chances. This review focuses on the role of tree nuts in male fertility, considering their potential effects on seminal fluid quality and sperm parameters. Nuts are rich in antioxidants such as vitamins C, D, and E, as well as minerals like zinc and selenium, which are known to have a positive influence on fertility. While numerous reviews have summarized the effects of various nutrients on male fertility, there is currently no published review specifically categorizing the effects of tree nuts on male fertility. This review aimed to fill that gap by summarizing the relevant literature on nuts and male infertility. The findings of reviewed studies suggest the beneficial effects of nut consumption on reproductive health and overall health. The improvement in lipid stability, oxidative stress, inflammation indicators, and endothelial function can potentially contribute to better reproductive health, particularly in relation to age-dependent decreases in sperm quality and fertility.

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Introduction

Based on the World Health Organization (WHO) definition, infertility is a condition where a female in a couple is unable to achieve a successful pregnancy despite engaging in regular unprotected sexual intercourse for a minimum period of one year (1). It is estimated that approximately 30% of couples experience infertility problems (2). On the other hand, several studies have indicated that 1 in 7 couples are affected by infertility, and male factor infertility is observed in 40-50% of all infertile patients (3). In addition, a study revealed a global decline in human sperm quality, including sperm count and motility. Changes in lifestyle factors have been suggested as potential contributors to this decline (4). Today, the deterioration in semen quality is believed to be primarily caused by various factors, including environmental air and soil pollutions, psychological factors such as anxiety and stress, smoking, dietary pesticides, and a preference for a Western-style diet and calorie counting. These factors are considered major contributors to the decline in sperm quality (5). Researchers have observed that sperm parameters can be influenced by geographic areas. For instance,

studies have shown that men living in Europe or the USA tend to have lower sperm parameters compared to men in other regions of the world. This suggests that geographical location may play a role in sperm quality and fertility outcomes (6). To date, the exact causes of low sperm quality are not well understood. There are numerous factors that can influence semen quality, including psychological, biological, anatomical, genetic, and environmental factors. The interplay of these various factors contributes to the overall quality of sperm, but the specific etiology and mechanisms behind low sperm quality are still not fully elucidated. Further research is needed to better understand and identify the underlying causes of low sperm quality (7).

Infertility is a complex and costly condition that significantly impacts the quality of life for couples experiencing it. It is crucial to find ways to reduce the prevalence of infertility and make lifestyle modifications to enhance fertility chances (8). There is substantial evidence demonstrating a direct relationship between nutrition and fertility potential in both males and females (9). Consequently, scientists have increasingly focused on studying the effects of nutrition on the male reproductive system, leading to the publication of numerous original research papers and review articles (10). Several researchers in their studies suggested that the Mediterranean dietary pattern was more beneficial for the male reproductive system and semen quality compared to the Western dietary pattern. The Mediterranean diet is characterized by the consumption of fresh fruits, green vegetables, nuts, and healthy fats such as olive oil, grape seed oil, and sesame oil. On the other hand, the Western-style dietary pattern is rich in meat, saturated fats, snacks, fast foods, and sugar. These studies indicated that adopting a Mediterranean dietary pattern may have positive effects on male reproductive health and semen quality (11).

A diet rich in antioxidants, omega-3 fatty acids, and vitamins such as C, D, and E, as well as minerals like zinc and selenium may have positive effects on seminal fluid quality and improve sperm parameters (10, 12). In separate studies, vitamin E and selenium supplementation have been shown to enhance sperm parameters and chromatin quality in men with recurrent pregnancy loss and idiopathic asthenoteratozoospermia (13, 14). Nuts, including pine nuts, hazelnuts, cashews, almonds, pistachios, and walnuts, are important sources of these nutrients and are significant components of the Mediterranean dietary pattern. These nuts are commonly referred to as tree nuts. While peanuts (*Arachis hypogaea*) are technically legumes, some studies classify them within the nut group due to their nutrient profile (15). Throughout history, nuts have been a fundamental part of the human diet (16). However, with the advent of civilization and industrialization, the consumption of nuts has decreased in many modern dietary patterns. Nevertheless, nuts remain an essential nutrient source in certain dietary plans such as the Mediterranean dietary pattern, Seventh Day Adventist Diet, and plant-based diets for vegetarians (17). It was demonstrated that nuts play a significant role in human health, and regular consumption of nuts can help prevent various diseases, including cardiovascular and non-communicable diseases (18).

Based on our current knowledge, while several review articles have been published summarizing the effects of various foods, antioxidants, minerals, and other nutrients on male fertility, there appears to be a lack of review articles specifically categorizing the effects of tree nuts on male fertility. The main objective of the present paper was to provide a summary of the available evidences regarding the relationship between nut consumption and male infertility. By examining the existing literature, the authors aimed to consolidate the persistent findings in this area of research.

Nuts

Nuts are oil seeds that are not only delicious, but also packed with nutritional benefits for human health (18). In the past, traditional and ancient physicians often prescribed nuts to alleviate symptoms of various diseases, as they believed in the medicinal properties of these nuts and their potential to prevent illnesses (19). However, in recent years, the overall consumption of nuts has declined worldwide. Despite this trend, certain dietary patterns, such as the Mediterranean diet, still emphasize the inclusion of nuts as a significant component of the overall food intake (20). Neale *et al.* from the northern United States observed that tree nuts such as almonds, walnuts, and pistachios were the primary agricultural products in that region. However, in Asian countries, cashews and hazelnuts are commonly consumed as the main nuts. The study also reported that among all the nuts, almonds had the highest number of consumers. This indicated that nut preferences and consumption patterns may vary across different regions and cultures (20).

Nuts are indeed a significant source of natural plant fats, following vegetable oils. The total fat content in nuts varies significantly and is calculated based on their weight. For instance, cashews have a total fat content of around 45%, while macadamias have a higher fat content of approximately 75%. Nuts provide essential energy, offering 20 to 30 kJ/g of energy (21). Nuts generally have lower levels of

saturated fatty acids (SFAs) compared to animal-derived saturated fats, ranging from 4% to 15%. The predominant type of fat found in nuts is unsaturated fatty acids, which contribute to their positive effects on human health. Unsaturated fatty acids in nuts can be categorized into two groups of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) (22). The ratio of these unsaturated fatty acids differs among various types of nuts. For instance, walnuts have higher levels of PUFA compared to MUFA, while pine nuts have a higher proportion of MUFA (15) (Table 1).

In addition to being a source of fat, nuts are also a good source of protein and contain various amino acids. Proteins and amino acids play essential roles in cellular signaling and are involved in numerous physiological processes within the body. Furthermore, nuts contain beneficial substances that promote antioxidant activity, thereby increasing the overall antioxidant levels in the body (22). Nuts are also rich in dietary fiber, which contributes to their overall nutritional value. The fiber content in nuts can range from 5% to 30% of the daily fiber requirements, depending on the specific type of nut. Dietary fiber is important for maintaining digestive health, promoting satiety, and regulating blood sugar levels. Including nuts in the diet can be an effective way to increase fiber intake and support a healthy digestive system (15).

Nuts contain a variety of important micronutrients, including vitamins and antioxidants such as vitamin B, folate, and vitamin E. These micronutrients play crucial roles in maintaining overall health and supporting the body's defense mechanisms (23). Certain nuts, such as almonds, pistachios, and hazelnuts, are particularly rich in vitamin E and exhibit high levels of antioxidants. Adequate levels of antioxidants are necessary for the body as they help prevent the negative effects of oxidants and free radicals. When oxidative stress (OS) and reactive oxygen species (ROS) levels increase in the body, they can compromise the antioxidant defense system. This can have detrimental effects on various systems in the body, including the reproductive, cardiovascular, and immune systems. Consuming nuts, which are abundant in antioxidants, can help counteract oxidative stress and maintain the balance of the body's antioxidant defense system (24) (Figure 1). Nuts have very low cholesterol content, and some nuts do not contain any cholesterol at all. Instead of cholesterol, nuts contain non-cholesterol sterols known as phytosterols. These plant sterols play a similar role to cholesterol in human cell membranes (25). Phytosterols have been found to have a negative effect on cholesterol absorption in the intestine. When the level of phytosterols reaches 1 gram or more in the intestine, it can help control blood cholesterol levels and significantly reduce cholesterol levels in the body. Phytosterols are hydrophobic and have hydrocarbon molecules that have a higher affinity for absorption into micelles compared to cholesterol. This characteristic allows phytosterols to outcompete cholesterol in absorption process (26) (Table 2).

Indeed, nuts are a good source of various minerals, including calcium, potassium, sodium, and magnesium. However, the sodium content in nuts is generally very low (27). The antioxidant effects of nuts on the male reproductive system, semen parameters, and sperm quality have been demonstrated (28). Several researchers have extracted vitamin E from different nut oils and found that hazelnut oil to have the highest levels of vitamin E followed by almond, peanut, pistachio, and walnut oils, respectively (29). The effects of chronic nut intake on male fertility potential, including sperm parameters and seminal fluid quality were examined before enrolling two groups, while one group consumed the routine diet and the other group received an additional 60 grams of nuts along with their routine diet for 14 weeks.

Table 1: Average nutrient composition of tree nuts and peanuts (per 100 g) (23).

Nuts	Phytosterols (g)	Fat (g)	SFA (g)	MUFA (g)	PUFA (g)	ALA (g)	LA (g)	Fiber (g)
Pistachios	272	47	5.4	25	14	0.25	13.2	10
Pine nuts (dried)	120	68.4	4.9	18.8	34.1	0.16	33.2	3.7
Hazelnuts	115	60.8	4.5	45.7	7.9	0.09	7.8	9.7
Pecans	113	72	6.2	40.8	21.6	1	20.6	9.6
Peanuts	126	49.2	6.2	24.4	15.6	0	15.6	8.5
Walnuts	143	65.2	6.1	8.9	47.2	9.08	38.1	6.7
Macadamias	119	76	11.9	58.9	1.4	0.21	1.3	8
Brazil nuts (dried)	72	66.4	15.1	24.5	24.4	0.05	20.5	7.5
Cashews	120	46.4	9.2	27.3	7.8	0.15	7.7	3
Almonds	162	49.9	3.9	31.5	12.2	0	12.2	12.5

Data for raw nuts, except when specified. ALA: α–linolenic acid; LA: Linoleic acid; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; SFA: Saturated fatty acids.

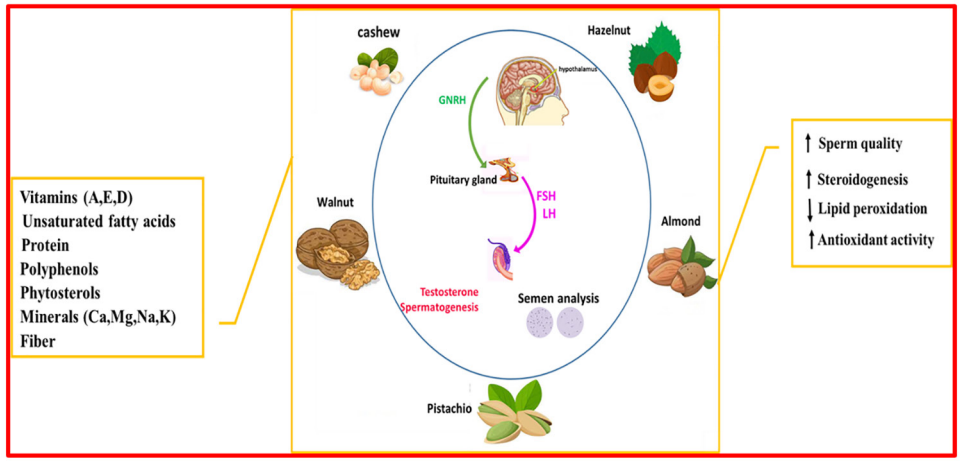

Figure 1: Schematic picture for the effect of nuts on male fertility confirming nuts (cashew, walnut, pistachio, almond and hazelnut) to contain several nutritional factors including vitamins, fatty acids, proteins, polyphenols, phytostrols, minerals and fibers. Nuts in daily diet can have various positive effects on male reproductive system and increase spermatogenesis, sperm parameters quality, antioxidant activity and decrease lipid peroxidation.

Table 2: Average composition of selected micronutrients in tree nuts and peanuts (per 100 g) (23).

Nuts	Polyphenols (mg)	Sodium (mg)	Magnesium (mg)	Calcium (mg)	Potassium (mg)	Folate (µg)
Pistachios	1420	6	106	104	977	49
Pine nuts	58	2	251	16	597	34
Hazelnuts	671	0	163	114	680	113
Pecans	1284	0	121	70	410	22
Peanuts	406	18	168	92	705	240
Walnuts	1579	2	158	98	441	98
Macadamias	126	4	118	70	363	10
Brazil nuts	244	3	376	160	659	22
Cashews	233	16	260	45	565	69
Almonds	287	1	270	269	733	44

Sperm parameters, including concentration, motility, morphology, and vitality were compared between the two groups. The findings revealed that the nut-consuming group showed improvements in sperm parameters compared to the control group. Biochemical tests also revealed higher levels of fatty acids, vitamin E, and omega-3 in the group that consumed nuts. These results suggest that regular nut consumption may have positive effects on male fertility and sperm quality (30).

Nuts are indeed rich in fatty acids, including both MUFA and PUFA. These fatty acids may play a role in preventing sperm DNA fragmentation and improving sperm quality. However, the exact relationship between fatty acids and seminal fluid quality is still not fully understood (31). There are additional evidences supporting the positive effects of other components found in nuts, such as vitamins and omega-3 and omega-6 fatty acids on sperm quality (32). The levels of omega-3 and omega-6 fatty acids in human blood were exhibited to be directly related to male fertility, seminal fluid quality, and sperm parameters (33, 34). Moreover, antioxidants and omega-3 fatty acids have been reported to decrease sperm DNA fragmentation (SDF), which is an important parameter for assessing sperm chromatin quality (35). SDF is a main parameter to diagnose the sperm chromatin quality (36). It was shown that nuts are a significant source of vitamin E and omega-3 fatty acids (30). By evaluating the effects of supplements and antioxidants on male fertility, scientific evidences indicated the improvement of sperm quality in infertile patients following the use of antioxidants (37). Furthermore, several researchers have illustrated that vitamins and antioxidants can increase testosterone levels in the human body. Testosterone is an essential hormone for sperm maturation and seminal fluid quality, making it an important factor in the fertility potential of human spermatozoa (38).

Cashew

Nuts, including cashews (*Anacardium occidentale*) are often recommended as part of a healthy daily diet. Cashews, in particular, have been suggested for improving sexual impotency (39). It was

shown that cashew oil could enhance sexual libido and fertility potential in male rats (40). Additionally, it was suggested that cashew nuts might be able to increase sexual hormones, especially testosterone, in infertile men (41). Cashews are rich in various nutrients such as fiber, iron, magnesium, calcium, phosphorus, fat, and zinc. These nutrients play important roles in different biological systems within the human body. For example, fiber is beneficial for the digestive system, iron is important for the blood system, calcium and magnesium are essential for the musculoskeletal system, and fat and zinc are vital for the reproductive system (40). Cashew zinc, in particular, has been documented as an essential factor for sperm production and maturity, potentially increasing fertility potential in men. Including cashews in a balanced diet can provide a range of important nutrients that support various bodily systems, including reproductive health (41). Several studies have demonstrated that zinc deficiency can have negative effects on male fertility by decreasing testosterone levels and impairing sperm quality (41, 42) (Figure 1).

A recently published paper evaluated the effects of a combination of cashew and clomiphene citrate on male fertility in rats revealing that the diet containing cashew along with clomiphene citrate could have a moderating effect on male reproductive function biomarkers. The authors proposed that this combination could be used as a potential treatment for infertility in patients, addressing certain infertility issues (43). Researchers have conducted a study using an extract obtained from *Anacardium occidentale* leaves and tested the effect of extract on stress-induced infertility in rats by evaluating fertility parameters demonstrating that the extract could decrease male sexual dysfunction. It was shown that the polyphenolic compounds present in the extract might be responsible for targeting and improving fertility potential in rats (44). These studies highlight the potential benefits of cashew and its components in addressing male fertility issues and improving reproductive function. However, further researches are needed to fully understand the mechanisms of action and to determine the efficacy and safety of these interventions in human subjects.

Walnuts

Walnuts are indeed a highly valued nut due to their nutritional composition and health benefits. They belong to the genus Juglans and have several species distributed worldwide. The Food and Agriculture Organization (FAO) has recognized the nutritional value of walnuts and classified them in the list of priority plants (45). In terms of antioxidant activity, walnuts have been found to possess the highest activity among various nuts, followed by pistachios and hazelnuts. Walnuts are rich in various beneficial components, including tocopherols (a form of vitamin E), essential fatty acids such as linolenic, palmitic, oleic, and stearic acids, polyphenols, tannins, folate, dietary fiber, protein, melatonin, and sterols (45). The presence of these compounds in walnuts contributes to their potential health benefits. For example, the high content of essential fatty acids, particularly omega-3 alpha-linolenic acid, may have positive effects on cardiovascular health. The polyphenols and antioxidants in walnuts are believed to provide protective effects against oxidative stress and inflammation. Additionally, walnuts are a good source of dietary fiber, which can support digestive health and help regulate blood sugar levels. Overall, walnuts are recognized for their rich nutritional profile and are considered a valuable addition to a healthy diet (45).

Walnut oil has been recommended for use in certain types of foods, as it provides a distinct flavor and nutritional benefits. Additionally, the consumption of whole walnuts in various forms has been suggested to potentially improve semen quality (46). IN Several animal studies, the effects of walnuts on the reproductive system have been explored revealing an increase in sperm count and interstitial cells in the testes of adult male rats, as well as an increase in sex hormones in diabetic male rats (34, 47). Initial positive results regarding the use of walnuts in improving sperm motility and morphology were demonstrated in men seeking care for infertility. It was found that consuming 42 grams (approximately 1.5 ounces) of walnuts per day had the potential benefits (48). The presence of PUFAs and antioxidants in walnuts is believed to contribute to their potential effects on sperm development. PUFAs, such as omega-3 fatty acids, have been associated with improved sperm quality and function (49).

The walnut supplement, enriched in PUFAs and antioxidants, may help counteract the lipid peroxidative damage and oxidative stress in Pmca4 null sperm. The antioxidants present in the walnuts could potentially mitigate the negative effects of oxidative stress and contribute to improved sperm motility (50). It appears that researchers have found a potential benefit of walnut supplementation in enhancing Pmca4 null sperm, particularly in relation to motility and oxidative stress. The presence of PUFAs in the sperm membrane is indeed crucial for maintaining its integrity and function. However, PUFAs are susceptible to lipid peroxidation, which can lead to oxidative damage and destabilization

of the sperm membrane, which makes them highly susceptible to lipid proxidative damage and membrane destabilization. It is important to note that these findings are specific to the context of Pmca4 null sperm and may not directly apply to individuals without this genetic condition (51). Further researches are needed to explore the broader implications and potential benefits of walnut supplementation on sperm quality and male fertility in various populations.

Lipid peroxidation refers to the oxidative damage caused to lipids, including PUFAs, in cell membranes. This process can lead to the production of reactive by-products such as malondialdehyde (MDA) and 4-hydroxynonenol (51, 52). An increase in these radical by-products is often associated with membrane damage and reduced sperm quality. It appears that the consumption of walnut oil in rats led to increased testosterone levels compared to control groups after 30 days (53). This suggests the potential effect of walnut oil on testosterone regulation in animal models. In another study examining the impact of nut consumption on sperm parameters, including vitality, motility, morphology, and total sperm counts, administering 75 grams of walnuts for 12 weeks resulted in improvements in sperm vitality, motility, and morphology (54). However, there was no significant effect on total sperm counts (54) (Figure 1). These findings suggest that walnut consumption, whether in the form of walnut oil or whole walnuts, may have positive effects on certain sperm parameters such as vitality, motility, and morphology. It is important to note that the specific dosage, duration, and population studied may influence the results, and further researches are necessary to better recognize the mechanisms and long-term impacts of walnut consumption on male fertility.

Pistachio

Pistachios are indeed native to mountainous regions and have a long history of consumption. They have been estimated to have existed for about 80 million years, and their use as food dates back to at least 7000 BC. Western Asia, in particular, is a region known for consuming a significant amount of pistachio nuts (54). Pistachios are not only enjoyed for their taste, but also valued for their nutritional composition. They are a good source of proteins, dietary fibers, and various vitamins, including pyridoxine (vitamin B6), thiamin (vitamin B1), and alpha-tocopherol (vitamin E). They also contain antioxidants and have a high content of unsaturated fatty acids, while being relatively low in saturated fatty acids (55). These nutritional qualities make pistachios a nutritious food choice. They can be consumed raw or roasted, either on their own as a snack or in combination with other ingredients in various dishes. Pistachio oil, derived from the nuts, is also popular and known for its potential properties in enhancing libido and improving semen quality (46).

It appears that oral consumption of pistachio oil has shown some positive changes in rat's testes (56). Additionally, pistachio consumption was indicated to improve erectile dysfunction (57). In an experiment conducted on adult male Wistar rats, phytosterols in pistachio oil were exhibited to reduce spermatogenesis at doses of 10 and 50 mg/kg. On the other hand, fatty acids in pistachio oil boosted spermatogenesis at a low dose of 10 mg/kg, but impaired it at a high dose of 50 mg/kg. The interaction between different doses of phytosterols and fats showed that low doses (5 mg/kg) of both phytosterols and fatty acids improved spermatogenesis, but when used together at high doses (25 mg/kg), the spermatogenesis process was disrupted. These findings suggest that the effects of pistachio oil on spermatogenesis in rats may depend on the dosage and the specific components present in the oil, such as phytosterols and fatty acids. It is important to note that these findings are specific to animal models and further researches are essential to determine the potential influences of pistachio oil on human spermatogenesis (58).

Zinc is an essential element for sperm production and overall reproductive health. It plays a crucial role in various aspects of male reproductive function, including sperm development, motility, and hormone regulation (59). In another study, researchers compared the levels of testosterone, selenium, and zinc in two groups of men, while one group consisted of infertile men, and the other group consisted of fertile men. The study found a significant difference in the mean serum levels of zinc, selenium, and testosterone between the two groups (60). This finding suggested that there might be an association between zinc deficiency or altered zinc levels and male infertility. However, this study alone cannot establish a direct cause-and-effect relationship, and further researches are demanded to better describe the role of zinc in male infertility and the potential benefits of zinc supplementation.

Certain compounds found in pistachio oil, including zinc and linoleic acid, have been shown to inhibit nitric oxide production. Nitric oxide is involved in various physiological processes, including the regulation of steroidogenesis in Leydig cells. By inhibiting nitric oxide synthesis, these compounds in pistachio oil may potentially enhance steroidogenic activity in Leydig cells. This, in turn, could lead to increased testosterone levels. Testosterone is an

important hormone involved in male reproductive function, including sperm production and sexual health (61). The findings from the study conducted before showed that male Wistar rats administered individually with different doses of pistachio for 28 days (1 mg/kg, 2 mg/kg, and 4 mg/kg) did not have any significant difference for Sertoli and Leydig cells, spermatogonia, spermatocytes, or spermatid count between the experimental groups. However, there was an increase in sperm density within the seminiferous tubules over time (56).

An investigation undertaken to determine the potential effects of pistachio by-products (PBP) on sperm quality parameters and fatty acid composition in Farahani rams showed the inclusion of 12.5% PBP in the diet not to have a negative effect on sperm parameters (62). The findings from the study regarding the effects of bene powder (derived from *Pistacia atlantica*) on infertility in mouse model demonstrated that the infertile mice were treated with a dose of 10 mg/kg for duration of 35 days of bene powder. Also in the treated mice, a significant increase in sperm viability, a normal morphology and motility were observed in comparison to the infertile group. The findings suggested that administration of bene powder had a positive impact on sperm quality parameters. Additionally, the researchers reported that bene powder declined MDA levels; while increasing the levels of superoxide dismutase and catalase enzymes in the infertile mice. MDA is a marker of lipid peroxidation, and its reduction suggests a potential protective effect on sperm membrane integrity. Furthermore, the increase in superoxide dismutase and catalase enzymes revealed an improved antioxidant defense mechanism in the infertile mice. These enzymes play a role in scavenging free radicals and protecting cells from oxidative damage (63) (Figure 1). Taken together, the findings suggested that bene powder derived from *Pistacia atlantica* may have beneficial effects on sperm quality, potentially by reducing oxidative stress and enhancing antioxidant defense mechanisms. Further investigations are crucial to evaluate the effects of bene powder on human fertility and sperm parameters.

Almond

Almonds are widely distributed throughout the world, with major cultivation regions including California, Australia, and Mediterranean countries. Almonds are known for their nutritional value and contain various beneficial compounds (64). Almonds are an excellent source of vitamin E, which is a powerful antioxidant that helps protect cells from oxidative damage. The skin of almonds, in particular, contains a concentration of compounds such as flavonols (kaempferol, quercetin, and catechin), flavanones (naringenin), anthocyanins (cyanidins), and phenolic acids (caffeic acid, ferulic acid, and P-coumaric acid). These compounds have been associated with potential health benefits due to their antioxidant and anti-inflammatory properties. In addition to these compounds, almonds also contain phytosterols, which are plant-derived compounds that have a structure similar to cholesterol and may help reduce cholesterol absorption in the intestines. Almonds also contain oils, including oleic acid (a MUFA), linoleic acid (an omega-6 fatty acid), and palmitic acid (a PUFA) (65).

Almonds and almond products are often recommended in traditional medicine and popular culture for their potential benefits on semen quality and libido. However, it is of great importance to note that scientific evidences supporting such claims are limited and further researches are needed to establish a direct link between almond consumption and these specific effects. Almonds are indeed a nutritious food, rich in various beneficial compounds, including vitamin E, flavonoids, phenolic acids, phytosterols, and healthy fats. These components contribute to the overall nutritional value of almonds and may have positive effects on overall health, including reproductive health (66).

Nutritive analysis of almonds and their polyphenolic content showed that almonds, both the drupe (fruit) and seed, contain various phenolic acids and flavonoids. Polyphenols are a class of compounds known for their antioxidant properties and potential health benefits. The presence of polyphenols in almonds, including gallic acid, catechin, chlorogenic acid, caffeic acid, ellagic acid, epicatechin, rutin, quercetin, isoquercitrin, and kaempferol, suggests that almonds may possess antioxidant activity due to these compounds. Ellagic acid, rutin, and quercetin, specifically, have been associated with potential aphrodisiac properties in the study conducted on male rats (67). However, it is necessary to note that these studies were conducted on animal models, and the direct effects on human sexual health or libido are not yet well-established. While the presence of these polyphenolic compounds in almonds suggests potential health benefits, it is important to consider that the concentration and bioavailability of these compounds can vary depending on factors such as almond variety, processing methods, and individual digestion and metabolism.

Several amino acids commonly present in almond fruits, including glutamine, arginine, tryptophan, tyrosine, and phenylalanine have been shown to enhance the sexual activities of male

Wistar rats (68). In another study, researchers reported that combination of glutamine and inositol could produce gamma-aminobutyric acid (GABA), which encourages orgasm and inhibits excitatory neurotransmitters that cause sexual craving and consequently, sexual dysfunction (69). As well, arginine facilitates blood flow to the penile tissue and is a precursor to nitric oxide (NO). In addition to enhancing arterial elastic properties, NO also lowers blood pressure and improves erections and sexual function (70). It was found that hydroxylation of phenylalanine produces L-tyrosine, a precursor for L-3,4-dihydroxyphenylalanine, norepinephrine, and epinephrine that can increase libido in male Wistar rats (71). Glutathione is an antioxidant that can protect the cells against oxidative damage that causes many diseases, such as diabetes and complications such as erectile dysfunction. Glycine, glutamic acid, and cysteine were shown to be precursors to glutathione (71). An experiment conducted before demonstrated that almond oil improved the sperm quality of diabetic rats (72).

According to findings from the study conducted before, almond-supplemented diets were found to enhance erection biomarkers in diabetic rats. This suggests that almonds, both the seeds and drupes, may have potential benefits in treating erectile dysfunction caused by diabetes. Erectile dysfunction is a common complication of diabetes, and finding cost-effective and readily available option for its treatment is of interest (73). In addition to modulating libido, testosterone regulates the synthesis and release of nitric oxide synthase, which promotes sexual synchronization (73). In diabetic rats undergoing sexually compromised states, almond-supplemented diets could restore the levels of reproduction hormones (testosterone, follicle-stimulating hormone, and luteinizing hormone) that contributed to an improved sexuality. In addition to the increase in testosterone level (73), an increase in gonadotropin level was illustrated. This was due to the functional effects of almond-supplemented diets on the pituitary gland, which induced the release of both follicle-stimulating hormone (FSH) and luteinizing hormone (LH) (74). Almond seeds are an excellent source of vitamin E, calcium, magnesium, and potassium, which play crucial roles in testosterone production (75). Testosterone level in the blood can influence sexual behavior and reproduction in men (76). It was noticed that supplementing diets with almond powder (*Prunus amygdalus* dulcisseed) could enhance the growth and improve the gonadosomatic index, as well as reproductive indexes in male African catfish (77) (Figure 1).

Hazelnut

Hazelnuts are indeed considered nutritious foods that offer various health benefits due to their bioactive compounds and nutrient profiles. Here are some key aspects of hazelnuts that contribute to their reputation as a healthy food. Hazelnuts are a good source of several essential nutrients. They contain healthy fats, including MUFA like oleic acid, which can have a positive impact on heart health. Hazelnuts also provide dietary fiber, vitamins (such as vitamin E, thiamin, and folate), and minerals (including magnesium, phosphorus, and potassium). They contain bioactive compounds with antioxidant properties, such as vitamin E, phenolic compounds (including flavonoids and phenolic acids), and phytosterols. These antioxidants help combat oxidative stress, reduce inflammation, and protect cells from damage caused by harmful free radicals. Phytosterols and dietary fibers were detected in hazelnut kernels and skins, as well as high phenolic content (gallic, vanillic, and syringic acids). In addition to having oil, hazelnut seeds contain mostly unsaturated fatty acids, which generally account for about 60% of the total weight. Consumption of hazelnut in the diet of humans can also increase the concentration of alpha-tocopherol. A diet rich in hazelnut is recommended in Canon as a means to increase sexual potency (78). A link of hazelnut consumption to male fertility was shown revealing hazelnut's nutrients and health promoting components to be important for male fertility (79). A serving of hazelnut (1.5 ounces=42.25 grams) contains 72.7% of the daily recommended amount of vitamin E for adults (80).

Furthermore, hazelnuts have been found to possess *in vivo* and *in vitro* antioxidant efficacy because of their high content of vitamin E and phenolic compounds (80, 81). The MUFA found in hazelnuts have a lower oxidation rate than long chain PUFA. It was found that hazelnuts had high antioxidant properties, which may prevent membrane oxidation, a crucial step in sperm maturity and membrane function (10). Some polyphenolic bioactive substances were detected in several tissues following acute consumption of hazelnut extract, including thymus, intestine, lung, kidney, spleen, and testis tissue (82). Hazelnut oil was found to contain 40.4 mg/100 g of α-tocopherol (83). The α-tocopherol content in hazelnut oil has been determined to be 40.4 mg/100 g. Furthermore, hazelnuts contain antioxidants, particularly polyphenols, which act as antioxidants (84).

Various positive and negative feedback systems regulate the hypothalamus-pituitary-testicular axis (85). Nitric oxide (NO) is one of these factors, and

hazelnut ingredients contain high levels of arginine, which is converted to NO by neurons in the pituitary, which further activates the NO synthesizing enzyme and increases gonadotropin release (86). Hazelnut supplemented diets can improve the reproductive health of both young and old male rats. Aging was shown to significantly increase sperm quality and reduce the amount of histopathological damage. The hazelnut supplemented diet was demonstrated to be effective in enhancing histopathological variables, sperm quality, seminal plasma oxidative stress, seminal plasma vitamin E, and serum testosterone. In an old male rat, testicular antioxidant function and semen quality were significantly enhanced by a hazelnut-supplemented diet (86).

To determine hazelnut supplementation effects on testosterone-induced testicular and epididymal tissue damage in male rats in response to doxorubicin treatment, four groups of eight rats were enrolled revealing that added supplement of hazelnuts to the diet and drinking water reversed the side effects of doxorubicin as well as testicular and epididymal tissue injuries, testosterone levels, epididymis oxidative stress index, and lipid peroxidation. Based on these results, hazelnut appears to be a promising supplement for reducing testicular toxicity induced by doxorubicin in male rats (87).

It was reported in a review article that hazelnuts were among two major foods recommended by Avicenna and there is also evidences that they increase testosterone production and improve several sperm parameters, including sperm count, motility and morphology (88) (Figure 1). Consuming nuts (walnuts, almonds, hazelnuts) can enhance the total sperm count, vitality, motility, and morphology when compared to the control group. Hazelnut has been able to reduce sperm fragmentation (30). Hazelnut antioxidant properties were demonstrated to affect sperm maturation and reduce the degradation of sperm cell membranes (89).

Conclusion

Nut consumption has been associated with better semen quality and fertility in men. Additionally, regular consumption of nuts has been found to improve lipid stability, reduce oxidative stress, decrease inflammation indicators, and enhance endothelial function in both healthy individuals and those with chronic diseases. These findings suggest the beneficial effects of nut consumption to extend beyond reproductive health and to have broader impacts on overall health. The improvement in lipid stability, oxidative stress, inflammation indicators, and endothelial function can potentially contribute to better reproductive health, particularly in relation to age-dependent decreases in sperm quality and fertility.

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Authors' Contribution

AN and SP: Conceptualization; SP and ZA: Writing and original draft preparation; NGK: Final editing and revision.

Conflict of Interest

None declared.

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