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Review

A Review of foods and food supplements increasing testosterone levels

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Abstract

Androgens are essential for male physical activity. Age-related androgen deficiency, known as late-onset hypogonadism (LOH), is considered a risk factor for several diseases. There are many men's health supplements on the market. Therefore, the purpose of this review is to summarize the food ingredients that have been suggested in published literature to increase testosterone levels. A review of previously reported animal studies suggested that 5 representative nutritional components, 7 food ingredients, and 25 supplements were associated with testosterone. Some food and supplements influence testosterone levels in various animals by directly increasing testosterone or suppressing the decrease in testosterone production due to testicular toxicity. There are three mechanisms by which foods or supplements increase testosterone production: 1) regulating luteinizing hormone, the hormone that stimulates testosterone production, 2) regulating testosterone synthase in the testis, and 3) regulating testosterone-degrading enzymes. In contrast, suppressing the decrease in testosterone depends on the antioxidant effect of the foods. Although detailed mechanistic studies and clinical trials are required to validate these findings, the use of food to regulate testosterone levels is a promising therapeutic option.

Keywords

Testosterone; Nutrition; Supplement; Basic science

1. Introduction

Androgens are essential for male physical activity [1–5]. Age-related androgen deficiency, known as late-onset hypogonadism (LOH), is considered a risk factor for erectile dysfunction (ED) [1, 2]. Several studies have reported that androgen replacement therapy mitigates the symptoms of LOH and ED.

Testosterone deficiency has been reported to be associated with a variety of diseases. In recent years, epidemiologic studies have suggested that obesity is associated with multiple alterations in the gonadal endocrine system and low testosterone levels [6–8]. Type 2 diabetes mellitus (T2DM) is also a risk factor for testosterone deficiency [9, 10]. Interestingly, androgen replacement therapy was effective in restoring testosterone levels in both clinical and basic research [11–13].

There are many men's health supplements for increasing testosterone in the market, some of which have proven useful in human meta-analyses [14, 15]. These health supplements have also been tested in animal studies. Besides, many reports indicate that forages for cows and roosters affect testosterone levels. Therefore, the purpose of this review is to summarize the food ingredients that have been suggested in published literature to increase testosterone levels.

2. Methods

To conduct this review, we performed a search of PubMed.gov (National Library of Medicine) for all English-language literature published on or before June 2020 using the following search terms and their combinations: testosterone, food, and supplement.

TABLE 1. Relationship between Testosterone and Food/Supplement

	Promoting T-production	Inhibiting T-degradation	Alleviating testicular toxicity
Garlic	+[16–17]	-	+[18–21]
Ginger	+[25]	-	-
Lactic acid bacteria	+[26–28]	-	+[26–27,29–30]
Soybeans	+[31]	-	+[32]
Amino acid	+[34–36]	-	+[36]
L-arginine	+[38–39]	-	+[39–42]
L-carnitine	+[43]	-	+[43–44]
Linoleic Acid	+[45]	-	-
Selenium	+[47–49]	-	+[50–52]
Vitamin (C/E)	+[53–57]	-	+[58–62]
Zinc	+[63–65]	-	+[66–68]
β-caryophyllene	-	+[70]	-
Chrysin	-	+[71]	-
Coenzyme Q10	+[74–76]	-	+[77–79]
Cordyceps Militaris	+[80]	-	-
Curcumin	-	-	+[81]
Cuscuta chinensis	-	-	+[82]
Emu oil	-	-	+[84]
Fish oil	+[85–91]	-	-
Fucoxanthin	+[92]	-	-
Geranylgeraniol	+[95]	-	-
Guarana	+[96]	-	+[96]
Hazelnut	+ **(Aged only)**[97]	-	-
Lutein	-	-	+[99]
Maca	+[100]	-	+[101–102]
Melatonin	+[103–108]	-	+[109–112]
Milk thistle seed and rosemary leaf	+[118]	-	-
Moringa	+[119]	-	+[119–120]
N-acetyl-cysteine	-	-	+[121–125]
Oleuropein	+[126]	-	-
Piperine	+[127]	-	-
Propolis and Royal Jelly	+[128]	-	+[129–132]
Resveratrol	+[135]	-	+[136–141]
Rooibos	+[142–142]	-	-
Saccharomyces cerevisiae	+[145]	-	-
Taxifolin	-	-	+[146]

+ : reported in papers. - : no report.

3. Results

A total of 4158 and 1756 papers were retrieved using the search terms "testosterone and food" and "testosterone and supplement," respectively. These papers included duplicates, which were excluded. We further excluded human clinical trials, cell experiments, and drug-based experiments, and remained with 216 papers on animal experiments. From these papers, we extracted the papers that showed the effect of increasing testosterone (Table 1).

4. Testosterone and food

4.1 Protein and fat

Nutritional status affects testosterone, and nutritional deficiency lowers testosterone levels [16, 17]. Schoech *et al.* reported that feeding male jays a high-protein, high-fat diet increased testosterone levels, whereas estrogen levels did not change in females [18].

4.2 Garlic

Garlic, used in many cuisines around the world, also affects testosterone regulation. Oi *et al.* reported that garlic supplementation increased testosterone levels in mice by raising luteinizing hormone (LH) [19]. McVey *et al.* also reported that garlic increased testosterone in rats [20]. They also reported that garlic has protective effects against lead-mediated oxidative damage, apoptosis, and downregulation of CYP19 gene expression in rat testes. Besides, garlic reduces testicular toxicity and suppresses the decrease in testosterone [19–21].

In contrast, crude garlic-feeding decreased testosterone in rats [22–24]. Hassan *et al.* discussed the effect of crude garlic-feeding on Leydig cells and decreased testosterone levels in

rats [20].

4.3 Ginger

Ginger is also used in many cuisines worldwide, and Kandeil *et al.* reported that ginger supplementation increased testes weight and testosterone levels in rabbits [25]. They also reported that a combination of ginger and thyme aqueous extracts increased testosterone and reproductive performance.

4.4 Lactic acid bacteria

Lactic acid bacteria are present in yogurt and are consumed worldwide. Among lactic acid bacteria, *Lactobacillus reuteri* and *Lactobacillus rhamnosus* have been reported to increase testosterone [26–28]. Lee *et al.* reported that *Lactobacillus reuteri* had a protective effect against inflammation in aged mice [26]. Poutahidis *et al.* also reported that *Lactobacillus reuteri* affected Leydig cells and increased testosterone levels in mice [27]. Dardmeh *et al.* reported that *Lactobacillus rhamnosus* increased testosterone and improved sperm motility in obese mice [28].

Moreover, Tian *et al.* reported that *Lactobacillus plantarum* alleviated diethylhexylphathalate-induced testicular damage and suppressed the decrease in testosterone [29]. Xie *et al.* reported that bifidobacteria reversed ciprofloxacin-induced testosterone reduction by alleviating oxidative damage and inflammatory response [30].

4.5 Soybeans (isoflavones/lecithin)

Soybeans are grains containing proteins and various nutrients (isoflavones and lecithin) that are consumed globally. McVey *et al.* reported a dose-dependent increase of testosterone following the consumption of isoflavones by rats [31]. Attia and Kamel reported that soybean lecithin upregulated antioxidant constituents and increased testosterone levels in rabbits [32]. However, Simon et al. reported that both low and high isoflavone levels did not affect testosterone levels in monkeys [33].

5. Testosterone and nutrient

5.1 Amino acid (valine / leucine / isoleucine / threonine)

Branched-chain amino acids (BCAAs), which include valine, leucine, isoleucine, and threonine, have some physical effects. They increase post-exercise testosterone levels in humans [34, 35]. Bahadorani *et al.* reported that BCAA supplementation has a synergistic effect on sperm function and testosterone production in mice [36].

Threonine, an essential amino acid, is associated with the regulation of testosterone. Although there is no study on the direct effect of threonine on testosterone levels, Lin *et al.* reported that threonine protected against testosterone decrease in mice infected with pseudorabies virus [37].

5.2 L-arginine

L-arginine is a semi-essential amino acid that is abundant in eels and garlic. Abbaspour *et al.* reported that L-arginine increased testosterone in old broiler breeder roosters [38]. Stefani *et al.* reported that L-arginine increased testosterone in rats [39]. They also showed that L-arginine alleviated resistance training promoted oxidative stress [39]. Therefore, they reported that L-arginine and resistance training has a synergistic effect on testosterone. Additional studies have reported the effects of L-arginine in reducing testicular toxicity and suppressing the decrease in testosterone [40–42].

5.3 L-carnitine

L-carnitine is a vitamin-like substance that is abundant in meat. El-Sherbini *et al.* reported that L-carnitine increased testosterone in rats [43]. Elokil *et al.* reported that supplementation of food with L-carnitine improved the reproductive activity of aged cock by increasing the expression of gonadotropin-releasing hormone 1 (GnRH1) and melatonin receptors (MT1 and MT2) activities [44]. These studies showed that L-carnitine also had anti-oxidant effects [43, 44].

5.4 Linoleic acid

Linolenic acid is one of the essential fatty acids present in sesame oil and walnuts. Barone *et al.* reported that conjugated linoleic acid upregulated CYP17A1 and stimulated testosterone biosynthesis in mice [45]. In contrast, Abdelatty indicated that high-dose of conjugated linoleic acid might induce testicular tissue apoptosis and reduce sperm quality in male rabbits [46].

5.5 Selenium

Selenium is one of the essential trace elements of living organisms. Selenium supplementation increases goat testosterone levels [47, 48]. Erkekoglu *et al.* reported that selenium deficiency decreased testosterone levels, and selenium supplementation increased testosterone in rats by regulating LH levels [49].

Cao *et al.* reported that selenium had protective effects against aflatoxin-induced testicular toxicity and suppressed the decrease in testosterone in mice [50]. Some studies also reported that selenium maintained testosterone levels in animals by alleviating testicular toxicity [51, 52].

5.6 Vitamin (C/E)

Vitamins are nutrients that are necessary in trace amounts for the survival and growth of living organisms. Some vitamins are associated with testosterone. Harikrishnan *et al.* reported that vitamin C (ascorbic acid) increased testosterone by upregulating LH in pigs [53]. Sonmez *et al.* reported that vitamin C increased testosterone levels and epididymal sperm concentration in rats [54]. Amer reported that vitamin C and glutathione increased testosterone and modulated age-related biochemical changes in aged rats [55]. In contrast, vitamin E in combination with flaxseed oil, increases testos-

terone in roosters [56, 57].

Vitamin C is an antioxidant vitamin, and some studies have reported that vitamin C suppresses the decrease in testosterone associated with testicular toxicity [58, 59]. Mohasseb *et al.* reported that the combination of vitamin C and vitamin E suppressed diabetes-induced testosterone decrease in rats through an anti-oxidant effect [60]. The combined antioxidant effect of vitamins C and E in improving testosterone levels has also been demonstrated in other studies [61, 62].

5.7 Zinc

Zinc is present in many organs and is a component of different enzymes. Kumar *et al.* reported that zinc supplementation led to a dose-dependent increase in testosterone levels in bulls [63]. The effect of zinc supplementation in raising testosterone levels in various animals has also been demonstrated in more studies [64, 65]. Interestingly, some studies reported the effect of zinc in increasing testosterone levels and protecting Leydig cell from damage [66–68].

6. Testosterone and supplement

6.1 β-caryophyllene

β-caryophyllene is a sesquiterpene contained in spices, herbs, and essential oils of various spices and fruits. β-caryophyllene acts as a selective agonist of the cannabinoid receptor type 2. It is approved by the United States Food and Drug Administration and European agencies as a food additive, taste enhancer, and flavoring agent and termed phytocannabinoid [69]. Fiorenzani *et al.* reported that β-caryophyllene increased testosterone by inhibiting 5α-reductase in rats [70].

6.2 Chrysin

Chrysin is a flavonoid extracted from *Passiflora coerulea* or honeycombs. Altawash *et al.* reported that chrysin increased testosterone in roosters by inhibiting aromatase activity [71]. However, chrysin affects thyroid function [72]. Besides, chrysin can cause cellular toxicity and inhibit DNA synthesis [73]. Due to these side effects, consuming chrysin to increase testosterone levels may not be recommended.

6.3 Coenzyme Q10 (CoQ10)

CoQ10 is a coenzyme that is abundant in the mitochondria and cell membranes. Sharideh *et al.* reported that CoQ10 increased testosterone and improved testicular function in aged roosters [74]. CoQ10 also increased testosterone levels in other animals by increasing LH [75, 76]. Besides, CoQ10 has antioxidant activity, hence suppresses the decrease in testosterone associated with testicular toxicity in rats [77–79].

6.4 Cordyceps militaris

Cordyceps militaris is a fungus belonging to the genus Nomushitake. *Cordyceps militaris* is consumed in East Asia as a crude drug in Chinese medicine or as a medicinal ingredient in Chinese cuisine. Chang *et al.* reported that *Cordyceps militaris* increased testosterone without changing LH, FSH, or prolactin in rats [80].

6.5 Curcumin

Curcumin is a polyphenol compound present in turmeric. Curcumin has antioxidant activity. Ahmed-Farid *et al.* reported that curcumin improved testosterone in rats with reduced testosterone on a protein-restricted diet [81].

6.6 Cuscuta chinensis

Cuscuta chinensis is a parasitic plant in the family Convolvulaceae and is used as a Chinese herb. Wei *et al.* reported a dose-dependent increase in testosterone in rats with reduced testosterone due to the negative effect of bisphenol A on testicular development [82]. They also showed that *Cuscuta chinensis* reduced the methylation level of related genes and protected reproduction.

6.7 Emu oil

Emu, a bird native to Austria, is the source of Emu oil used as a medicine in Austria. Emu oil is obtained from subcutaneous and retroperitoneal fat of the emu, *Dromaius novaehollandiae*, and comprises nearly 98% lipids and 1%–2% natural antioxidants. The major fatty acids present in emu oil are oleic acid (43%–46%), linoleic acid (6%–9%), linolenic acid (6%), palmitic acid (5%–23%), and stearic acid (9%) [83]. Kamalakkannan *et al.* reported that emu oil led to a dose-dependent increase in testosterone levels in diet-induced obese rats with reduced testosterone [84]. The high content of oleic acid in emu oil could have orchestrated inhibition of atheromatous plaque formation in diet-induced obese animals.

6.8 Fish oil(DHA/EPA)omega-3 and omega-6 polyunsaturated fatty acid

Fish oil is rich in omega-3 fatty acids, which are unsaturated fatty acids. Among the omega-3 fatty acids, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) are widely used as supplements. Fish oil increases testosterone levels in some animals [85–87]. Rossi *et al.* reported that unsaturated fatty acids increased testosterone in bulls [88]. Omega-3 fatty acids also increase testosterone levels in various animals [89, 90]. Kapourchali *et al.* reported that DHA increased serum testosterone and sperm normal morphology in rats [91].

6.9 Fucoxanthin

Fucoxanthin is a major xanthophyll compound obtained from edible brown seaweeds, such as *Sargassum heterophyllum* [92]. and *Sargassum horneri* [93]. Wang *et al.* reported that

fucoxanthin increased testosterone levels in rats [94].

6.10 Geranylgeraniol

Geranylgeraniol is a diterpene found in vegetables, fruits, and grains. Ho *et al.* reported that geranylgeraniol increased testosterone levels by up-regulating cAMP in testis-derived I-10 tumor cells [95].

6.11 Guarana (Paullinia cupana var. sorbilis)

Guarana is a plant native to the Amazon basin, and its seed extracts are used in health foods. Leite *et al.* reported that guarana increased testosterone in rats [96]. They also showed that guarana protected against the cadmium-induced testis damage.

6.12 Hazelnut

Hazelnuts are the fruits of deciduous shrubs of the genus Hazel in the family Betulaceae. Kara *et al.* reported that a hazelnut-supplemented diet increased testosterone levels and semen quality parameters in aged rats [97]. In contrast, hazelnut did not change testosterone levels in young rats, implying that this effect might be related to the antioxidant action of hazelnut.

6.13 Lutein

Lutein is one of the most abundant carotenoids in fruits and vegetables with antioxidant properties [98]. Fatani *et al.* reported that lutein could suppress the decrease in testosterone due to testicular toxicity in streptozotocin-induced diabetic rats [99].

6.14 Maca (Lepidium meyenii)

Maca is a perennial plant of the Brassicaceae family that grows in Peru. There are three varieties of Maca, recognizable through their external color (Maca Negro or Black Maca, Yellow Maca, and Red Maca). Ohta *et al.* reported that maca increased testosterone levels by enhancing the steroidogenic ability of Leydig cells in rats [100]. Other studies indicated that maca increased testosterone levels and protected against the testis damage caused by cyclophosphamide in rats [101, 102].

6.15 Melatonin

Melatonin is a hormone present in animals, plants, and microorganisms and is also used as a supplement. Melatonin increases testosterone levels in various animal species [103–108]. Melatonin suppresses the decrease in testosterone levels due to testicular toxicity [109–112]. Interestingly, human clinical trials have reported an increase in testosterone levels following melatonin supplementation [113–116].

6.16 Milk thistle seed and rosemary leaf

Milk thistle seeds contain a type of flavonoid called silymarin. Rosemary is another phytogenic plant, rich in active metabolites such as caffeic acid and rosmarinic acid [117]. Attia *et al.* reported that milk thistle seed and rosemary leaves increased testosterone and sperm quality in rabbits [118].

6.17 Moringa

Moringa is native to the southern foothills of the Himalayas and is widely cultivated in tropical and subtropical regions. Moringa is ingested as a health food. El-Desoky *et al.* reported that moringa increased testosterone in rabbits. Besides, moringa suppresses the decrease in testosterone due to testicular toxicity [119, 120].

6.18 N-acetyl-cysteine

N-acetyl-cysteine is a derivative of L-cysteine. L-cysteine is a natural antioxidant amino acid found in peppers, garlic, and onions. Elnagar *et al.* reported that N-acetyl-cysteine does not increase testosterone, but it suppresses the decrease in testosterone due to testicular toxicity [121]. Some studies have also demonstrated the protective effect of N-acetyl-cysteine for testosterone production [122–125].

6.19 Oleuropein

Oleuropein is a polyphenol contained in olives and privet. Oi-Kano *et al.* reported that oleuropein increased testosterone levels by raising LH in rats [126].

6.20 Piperine

Piperine is a type of alkaloid contained in pepper. Chen *et al.* reported that piperine increased testosterone synthase in the testis and increased testosterone in rats [127].

6.21 Propolis and Royal Jelly

Propolis is a solid substance made by mixing herbs and tree sprouts collected by honeybees with saliva containing enzymatic components. Kumari *et al.* reported that propolis suppressed mitomycin-induced decline in testosterone levels in rats through an anti-oxidant effect [128].

Royal jelly is a substance made by honeybees. Almeer *et al.* reported that royal jelly increased testosterone levels by raising FSH in mice [129]. Royal jelly also suppressed the decrease in testosterone due to testicular toxicity [130–134].

6.22 Resveratrol

Resveratrol is a polyphenolic compound naturally found in peanuts, grapes, red wine, and some berries. Shati reported that resveratrol increased testosterone by raising LH in rats [135]. Resveratrol is an antioxidant [136]. and can suppress the decrease in testosterone due to testicular toxicity [137–141].

6.23 Rooibos

Rooibos is a herb of the genus Aspalathus and the subfamily Papilionoideae native to South Africa. Rooibos contains a large number of flavonoids. Schloms *et al.* reported that

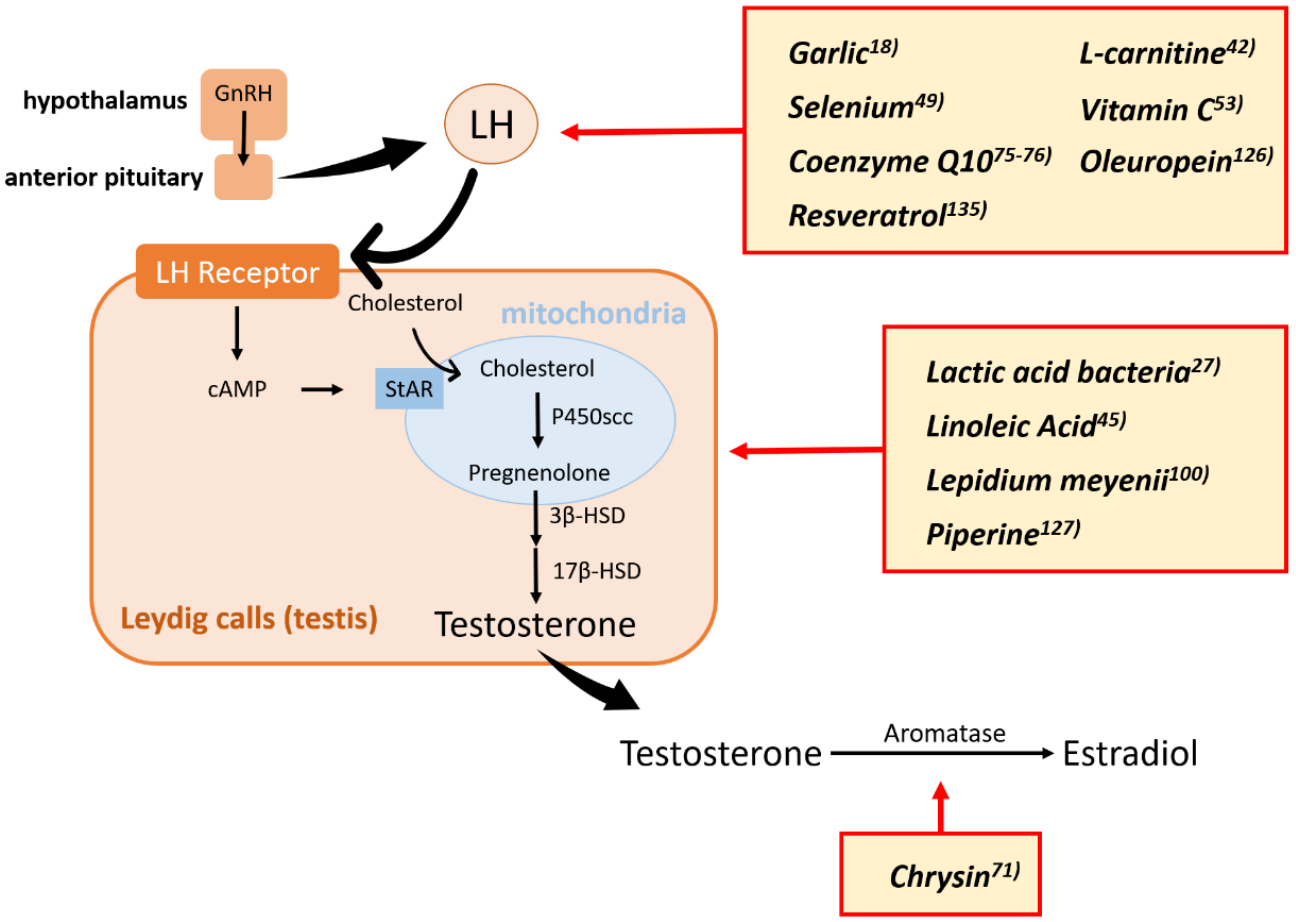

FIG. 1. Targets of testosterone production effected by food or supplements. GnRH: Gonadotropin-releasing hormone, LH: Luteinizing hormone, cAMP: Cyclic adenosine monophosphate, StAR: steroidogenic acute regulatory protein, 3β-HSD: 3β-hydroxysteroid dehydrogenase, 17β-HSD: 17β-hydroxysteroid dehydrogenase.

rooibos increased testosterone and decreased corticosterone levels in rats [142]. Noh *et al.* also reported that rooibos and dandelion increased testosterone and improved sperm quality in rats [143]. Through a clinical trial, Noh demonstrated the effect of MR-10 (a complex of dandelion and rooibos) in increasing testosterone levels [144].

6.24 Saccharomyces cerevisiae

Saccharomyces cerevisiae is a baker's yeast that is widely used as a medicine or supplement. Mannaa *et al.* reported that *Saccharomyces cerevisiae* increased testosterone levels in rats [145].

6.25 Taxifolin

Taxifolin is a flavonoid, usually found in red onions, milk thistle seeds, and Chinese yew. Taxifolin has an anti-oxidant effect. Li *et al.* reported that taxifolin suppressed the decrease in testosterone due to testicular toxicity induced by di-n-butyl phthalate in rats [146].

7. Conclusions

Some foods and supplements influence testosterone levels in various animals. The two main mechanisms are the direct increase in testosterone levels or suppression of the decrease in testosterone production due to testicular toxicity. Foods or supplements raise testosterone production in three ways: 1) regulating LH, the hormone that stimulates the production of testosterone, 2) regulating testosterone synthase in the testis, and 3) regulating testosterone-degrading enzymes (Fig. 1). In contrast, suppression of the decrease in testosterone depends on the antioxidant effect of the foods and supplements.

LH is a gonadotropin that is released by the pituitary glands [147]. Garlic, l-carnitine, selenium, vitamin C, CoQ10, qleuropein, and resveratrol regulate the LH secretion [16, 42, 49, 53, 75, 76, 126, 135]. Secreted LH acts on testis receptors and is involved in the synthesis of testosterone from cholesterol [147]. Lactic acid bacteria enhance testosterone production by increasing Leydig cells in the testis [27]. Linoleic acid, maca, and piperin raise testosterone levels by increasing the levels of enzymes involved in testosterone synthesis [45, 100, 127]. These two pathways of testosterone production would be a promising target for treatment. Foods or supplements that have been shown to increase testosterone might act on these pathways. In contrast, testosterone is metabolized to estradiol by aromatase [148]. Chrysin increased testosterone levels by inhibiting aromatase activity [71]. Although detailed mechanistic studies and clinical trials are required to

validate the findings, the effects of these foods on testosterone provide potential therapeutic options.

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Conflict of interest

The authors report no conflicts of interest.

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