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 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.

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

<table>
<thead>
<tr>
<th>Promoting T-production</th>
<th>Inhibiting T-degradation</th>
<th>Alleviating testicular toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garlic</td>
<td>-</td>
<td>+18–21)</td>
</tr>
<tr>
<td>Ginger</td>
<td>+25)</td>
<td>-</td>
</tr>
<tr>
<td>Lactic acid bacteria</td>
<td>+26–28)</td>
<td>-</td>
</tr>
<tr>
<td>Soybeans</td>
<td>+31)</td>
<td>+32)</td>
</tr>
<tr>
<td>Amino acid</td>
<td>+34–36)</td>
<td>-</td>
</tr>
<tr>
<td>L-arginine</td>
<td>+38–39)</td>
<td>+39–42)</td>
</tr>
<tr>
<td>L-carnitine</td>
<td>+43)</td>
<td>+43–44)</td>
</tr>
<tr>
<td>Linoleic Acid</td>
<td>+45)</td>
<td>-</td>
</tr>
<tr>
<td>Selenium</td>
<td>+47–49)</td>
<td>+50–52)</td>
</tr>
<tr>
<td>Vitamin (C/E)</td>
<td>+53–57)</td>
<td>+58–62)</td>
</tr>
<tr>
<td>Zinc</td>
<td>+63–65)</td>
<td>+66–68)</td>
</tr>
<tr>
<td>β-caryophyllene</td>
<td>-</td>
<td>+70)</td>
</tr>
<tr>
<td>Chrysine</td>
<td>-</td>
<td>+71)</td>
</tr>
<tr>
<td>Coenzyme Q10</td>
<td>+74–76)</td>
<td>+77–79)</td>
</tr>
<tr>
<td>Cordyceps Militaris</td>
<td>+80)</td>
<td>-</td>
</tr>
<tr>
<td>Curcumin</td>
<td>-</td>
<td>+81)</td>
</tr>
<tr>
<td>Cuscuta chinensis</td>
<td>-</td>
<td>+82)</td>
</tr>
<tr>
<td>Emu oil</td>
<td>-</td>
<td>+84)</td>
</tr>
<tr>
<td>Fish oil</td>
<td>+85–91)</td>
<td>-</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>+92)</td>
<td>-</td>
</tr>
<tr>
<td>Geranylgeraniol</td>
<td>+95)</td>
<td>-</td>
</tr>
<tr>
<td>Guaraná</td>
<td>+96)</td>
<td>+96)</td>
</tr>
<tr>
<td>Hazelnut</td>
<td>+ (Aged only)87)</td>
<td>-</td>
</tr>
<tr>
<td>Lutein</td>
<td>-</td>
<td>+99)</td>
</tr>
<tr>
<td>Maca</td>
<td>+100)</td>
<td>+101–102)</td>
</tr>
<tr>
<td>Melatonin</td>
<td>+103–108)</td>
<td>+109–112)</td>
</tr>
<tr>
<td>Milk thistle seed and rosemary leaf</td>
<td>+118)</td>
<td>-</td>
</tr>
<tr>
<td>Moringa</td>
<td>+119)</td>
<td>+119–120)</td>
</tr>
<tr>
<td>N-acetyl-cysteine</td>
<td>-</td>
<td>+121–125)</td>
</tr>
<tr>
<td>Oleuropein</td>
<td>+126)</td>
<td>-</td>
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<tr>
<td>Piperine</td>
<td>+127)</td>
<td>-</td>
</tr>
<tr>
<td>Propolis and Royal Jelly</td>
<td>+128)</td>
<td>+129–132)</td>
</tr>
<tr>
<td>Resveratrol</td>
<td>+135)</td>
<td>+136–141)</td>
</tr>
<tr>
<td>Rooibos</td>
<td>+142–142)</td>
<td>-</td>
</tr>
<tr>
<td>Saccharomyces cerevisiae</td>
<td>+145)</td>
<td>-</td>
</tr>
<tr>
<td>Taxifolin</td>
<td>-</td>
<td>+146)</td>
</tr>
</tbody>
</table>

+ : 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 diethylhexylphthalate-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 cannabinoïd 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 Nostoc. 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]. Kouroghli 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 antioxidiant 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
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. Manna 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, oleuropein, 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

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

Acknowledgements

This review was supported in part by Grants-in-Aid for Scientific Research (KAKENHI, 20K09563) from The Japan Society for the Promotion of Science (JSPS).

We would like to thank Editage (www.editage.com) for English language editing.

Conflict of interest

The authors report no conflicts of interest.

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