

## Integrative Role of Nutraceuticals in the Control of Obesity and Metabolic Disorders

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### ABSTRACT

As obesity has escalated into a global health crisis affecting millions worldwide, the demand for effective and sustainable management strategies has become increasingly urgent. In this context, nutraceuticals—bioactive compounds derived from food sources—are emerging as potentially valuable adjuncts to conventional obesity management, even though foundational lifestyle modifications such as dietary regulation and regular physical activity remain indispensable. These naturally occurring compounds, which encompass a wide range of substances including plant extracts, fatty acids, fibers, and vitamins, are believed to contribute to weight reduction and metabolic improvement through diverse mechanisms such as the regulation of appetite, enhancement of fat oxidation, improvement of insulin sensitivity, and attenuation of inflammation. This review therefore aims to provide an in-depth exploration of the role of nutraceuticals in obesity management by examining their biological mechanisms, health-related benefits, and the scientific evidence that supports their use. Specific nutraceuticals such as green tea extract, *Garcinia cambogia*, conjugated linoleic acid (CLA), omega-3 fatty acids, probiotics, and curcumin are discussed in relation to their effects on weight loss and metabolic health. Nevertheless, despite the encouraging findings, significant challenges remain, including variability in individual response, potential safety concerns, lack of standardization in product formulation, and ongoing regulatory issues, all of which limit their reliability as stand-alone interventions. Ultimately, while nutraceuticals may provide meaningful complementary benefits when combined with traditional weight loss strategies, the most effective approach to obesity management continues to be a comprehensive and holistic one that incorporates professional medical guidance, balanced nutrition, and consistent physical activity.

**Key words:** Nutraceuticals, obesity management, weight reduction, fat oxidation

### I. INTRODUCTION

Obesity has become one of the most pressing public health challenges of the twenty-first century, with prevalence rates continuing to rise at an alarming pace worldwide. In 2022, an estimated 2.5 billion adults aged 18 years and older were overweight, of whom more than 890 million were living with obesity—a more than twofold increase compared to 1990 [1]. Projections suggest that, without urgent and effective intervention, as many as 60 % of the global adult population could be classified as overweight or obese by 2050 [2]. This growing burden underscores the need for solutions that are not only effective in the short term but also sustainable over the long term, making the exploration of complementary interventions particularly important.

One such emerging strategy is the use of nutraceuticals, defined as bioactive compounds derived from food or natural sources that provide health benefits beyond basic nutrition. While conventional approaches such as dietary modification and increased physical activity remain the cornerstone of obesity management, nutraceuticals are increasingly being investigated as supportive tools that may enhance weight loss, improve metabolic outcomes, and promote overall well-being.

Evidence from recent systematic reviews and meta-analyses indicates that certain nutraceuticals—including psyllium, *Nigella sativa*, spirulina, chitosan, curcumin, green tea, and glucomannan—can produce modest but measurable reductions in body weight, ranging from approximately one to nearly four kilograms [3]. Although these effects are insufficient to position nutraceuticals as standalone treatments for obesity, they highlight the potential role of these compounds as natural adjuncts for individuals

seeking to improve health and manage weight more effectively.

The purpose of this article is to critically examine the role of nutraceuticals in obesity management by analyzing their mechanisms of action, summarizing the available scientific

evidence, and evaluating both the benefits and limitations of their use. This approach allows for a clearer understanding of how nutraceuticals may complement conventional strategies, while also addressing the precautions and challenges that accompany their integration into clinical practice.



Fig 1.0 Global obesity ratio

### Understanding Nutraceuticals

Nutraceuticals are broadly defined as products containing bioactive compounds derived from food sources that are consumed not merely for their nutritional value but also for their therapeutic and preventive health benefits [4]. They encompass a wide range of natural supplements, including vitamins, minerals, fatty acids, fibers, and plant extracts, many of which have been investigated for their potential role in preventing and managing chronic conditions such as obesity, cardiovascular disease, and metabolic syndrome

[5,6]. Unlike pharmaceutical drugs, nutraceuticals are generally regarded as safe, non-invasive, and easily accessible, which has contributed to their growing popularity among consumers [7]. Despite these advantages, their quality, consistency, and effectiveness can vary significantly depending on the raw material, formulation, and standardization processes applied [8]. This variability underscores the importance of critical evaluation and evidence-based application of nutraceuticals within both clinical and public health settings.

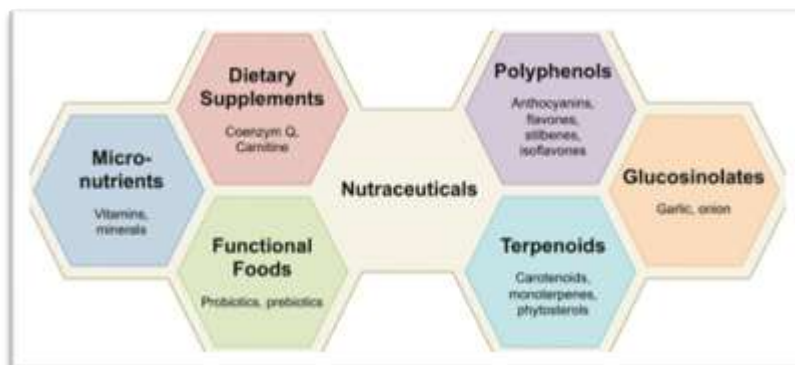


Fig:2.0 understanding nutraceuticals

### Mechanism of Action in Obesity

The mechanisms through which nutraceuticals exert their effects on obesity are multifactorial, involving appetite regulation, enhanced energy expenditure, improved insulin

sensitivity, anti-inflammatory activity, and modulation of the gut microbiome. Each pathway contributes to weight reduction and metabolic improvements through distinct yet complementary biological processes.

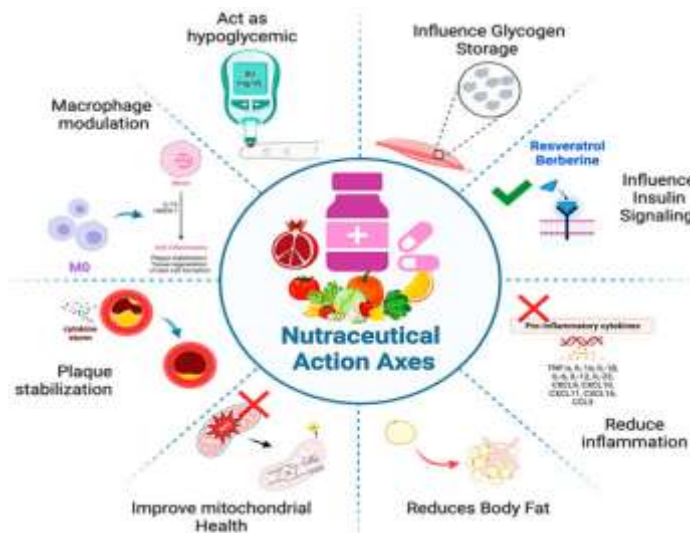


Fig: 3.0 mechanism of action of nutraceuticals

### Appetite Regulation

Several nutraceuticals influence appetite control by modulating hormones such as ghrelin and leptin, which play critical roles in hunger and satiety signaling. Dietary fibers promote gastric distension and delay gastric emptying, while green tea catechins and capsaicin have been shown to enhance satiety and reduce overall caloric intake [9,10]. These mechanisms contribute to reduced energy consumption and support long-term weight management.

### Fat Oxidation and Thermogenesis

Compounds such as caffeine and green tea extract stimulate thermogenesis—the process of heat production associated with increased energy expenditure—while conjugated linoleic acid (CLA) enhances lipid metabolism [11,12]. Together, these nutraceuticals increase fat oxidation, elevate basal metabolic rate, and promote fat mass reduction.

### Improved Insulin Sensitivity

Nutraceuticals including berberine, cinnamon extract, and omega-3 fatty acids play a role in improving insulin sensitivity. By enhancing glucose uptake and utilization, these compounds prevent excess glucose from being stored as adipose tissue and reduce the risk of insulin

resistance, a hallmark of obesity-related metabolic dysfunction [13,14].

### Reduction of Inflammation

Chronic low-grade inflammation is strongly associated with obesity and related metabolic disorders. Anti-inflammatory nutraceuticals such as omega-3 fatty acids, resveratrol, and curcumin have demonstrated efficacy in attenuating pro-inflammatory cytokine activity and improving metabolic health [15,16]. These effects not only contribute to weight management but also help mitigate cardiovascular and metabolic complications.

### Gut Microbiome Modulation

Emerging evidence suggests that the gut microbiome plays a pivotal role in regulating body weight, fat storage, and appetite. Probiotics and prebiotics enhance the growth of beneficial gut bacteria, which produce metabolites that influence energy balance, glucose metabolism, and inflammatory pathways [17,18]. A balanced gut microbiota is therefore increasingly recognized as a key mediator in effective obesity management.

### Evidence Supporting Nutraceuticals in Obesity Management

The scientific evidence regarding the use of nutraceuticals in obesity management is expanding rapidly. Numerous clinical trials and meta-analyses demonstrate that although results may vary, several compounds consistently exhibit measurable benefits in body weight regulation and metabolic health.

### Green Tea Extract (EGCG)

Green tea extract, rich in catechins such as epigallocatechin gallate (EGCG), has been shown to increase fat oxidation and stimulate thermogenesis. Clinical studies indicate that supplementation can lead to modest reductions in body weight and body fat, particularly when combined with exercise interventions [19,20].

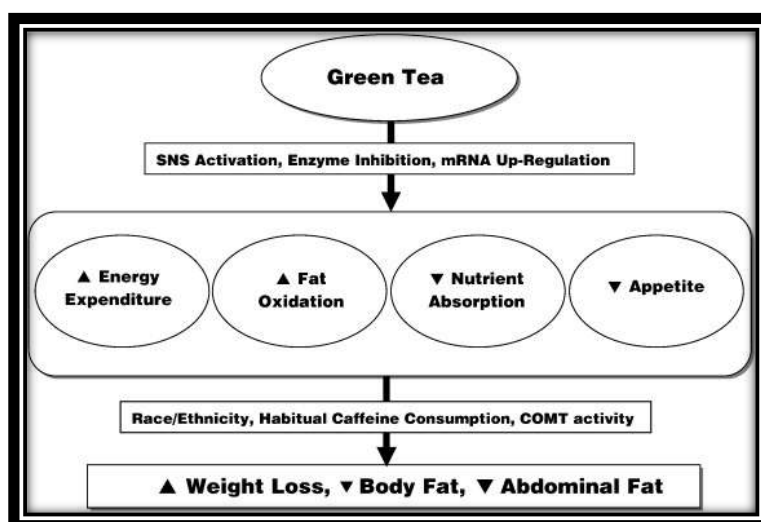


Fig : 4.1 benefits of green tea extract

### Garcinia Cambogia

Garcinia cambogia contains hydroxycitric acid (HCA), a compound proposed

to suppress appetite and inhibit fat storage by interfering with citrate lyase activity. However, systematic reviews suggest that

its effects on weight loss are generally small and inconsistent across populations [21,22].

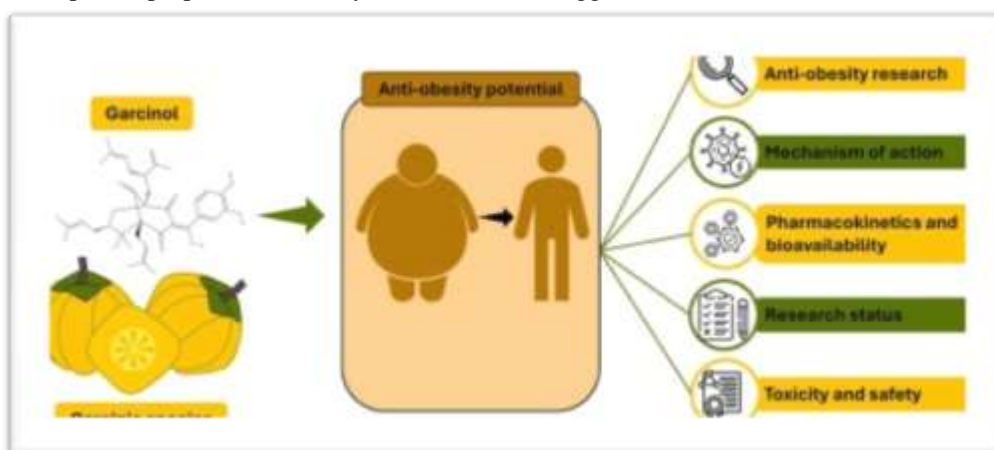


Fig 4.2Garcinol

### Conjugated Linoleic Acid (CLA)

CLA supplementation has been associated with modest reductions in body fat and potential increases in lean muscle mass. While some

randomized controlled trials demonstrate significant improvements in body composition, the overall magnitude of effect remains limited and varies considerably among individuals [23,24].

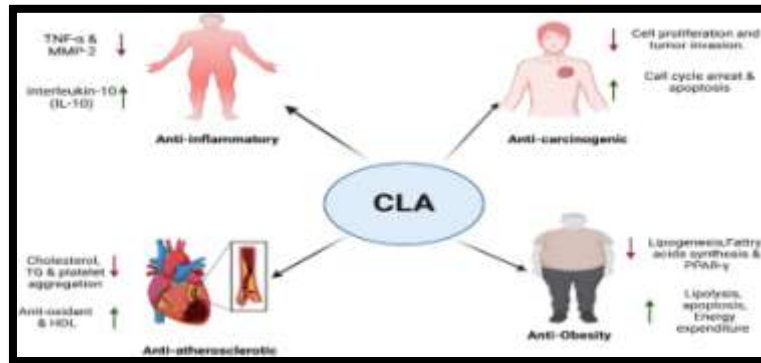


Fig: 4.3 benefits of CLA

### Omega-3 Fatty Acids

Omega-3 fatty acids, particularly those found in fish oil, contribute to improved insulin sensitivity, reduced inflammation, and enhanced

lipid metabolism. Evidence indicates that they may be especially effective in reducing visceral fat among individuals with obesity and metabolic disorders [25,26].



Fig: 4.4 benefits of omega-3 fatty acid

### Probiotics

Probiotics, especially strains from the Lactobacillus and Bifidobacterium genera, have demonstrated the ability to beneficially alter gut

microbiota composition. These changes are associated with reductions in body fat mass, improvements in insulin sensitivity, and favorable alterations in body composition [27,28].

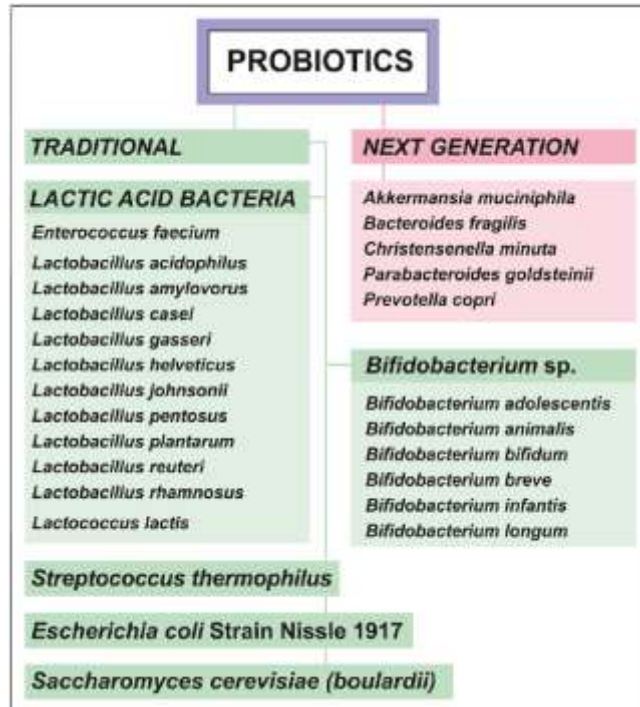


Fig 4.5 Types of probiotics

**Caffeine and Capsaicin**

Both caffeine and capsaicin are thermogenic agents that increase energy expenditure and metabolic rate. Clinical evidence

supports their role in promoting fat oxidation, reducing fat accumulation, and supporting overall weight management [29,30].

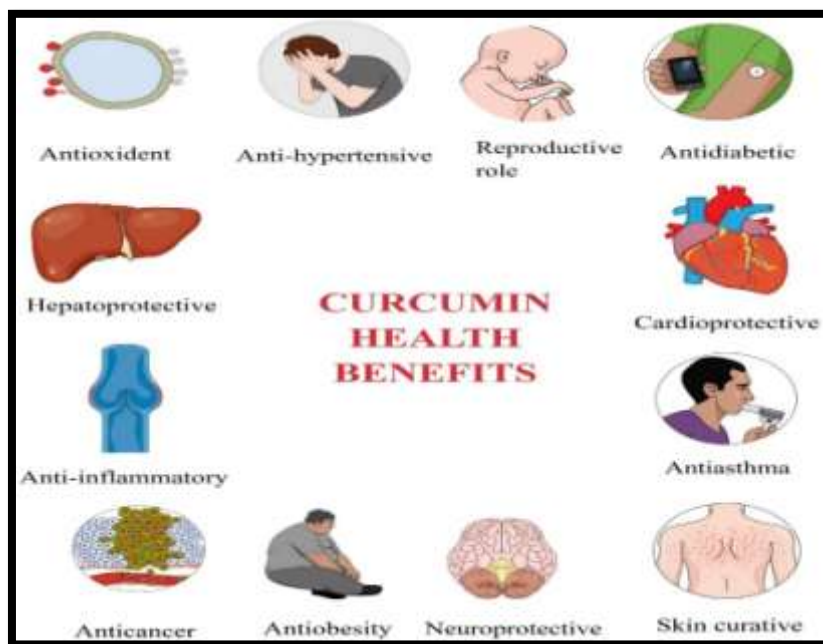


Fig:4.6 benefits of caffeine

**Curcumin**

Curcumin, the bioactive compound in turmeric, exerts potent anti-inflammatory and antioxidant effects. Evidence from clinical studies

suggests it may improve insulin sensitivity, modulate adipokine secretion, and contribute to gradual reductions in body weight and waist circumference [31,32].



**Fig: 4.7 benefit of curcumin**

**Soluble Fibers**

Soluble fibers such as glucomannan enhance satiety, reduce calorie intake, and improve digestive function. Randomized controlled trials

indicate that supplementation with glucomannan and other viscous fibers supports long-term weight management by lowering body weight and improving metabolic health markers [33,34].



**Fig: benefits of soluble fibers**

### **Benefits beyond Weight Loss**

In addition to their role in promoting weight reduction, nutraceuticals provide a wide range of additional health benefits that are particularly valuable for individuals affected by obesity, since this condition is closely associated with numerous comorbidities.

### **Cardiovascular Health**

Nutraceuticals such as omega-3 fatty acids [35], nut-derived compounds [36], and green tea catechins [37] have been shown to improve lipid profiles, lower triglyceride levels, and reduce blood pressure, thereby lowering the risk of cardiovascular disease.

### **Enhanced Insulin Sensitivity**

Compounds including berberine [38], cinnamon [39], and omega-3 fatty acids [40] assist in regulating blood glucose levels, thereby reducing the risk of developing type 2 diabetes.

### **Anti-Inflammatory Effects**

Since chronic inflammation is both a cause and consequence of obesity, nutraceuticals such as curcumin [41], resveratrol [42], and omega-3 fatty acids [43] help mitigate this condition, leading to improved metabolic and cardiovascular health.

### **Gut Health**

Probiotics such as *Lactobacillus rhamnosus* [44] and *Bifidobacterium* species [45] enhance digestion, nutrient absorption, and metabolic regulation by improving the balance of the gut microbiome, which plays an increasingly recognized role in obesity and weight management.

### **Liver Protection**

Compounds such as milk thistle [46] and turmeric [47] provide hepatoprotective effects, offering protection against non-alcoholic fatty liver disease, a condition strongly linked with obesity.

### **Mental and Cognitive Health**

Nutraceuticals such as omega-3 fatty acids [48], green tea catechins [49], and polyphenols [50] have demonstrated positive effects on mood, cognitive performance, and anxiety reduction, which may indirectly support weight control by reducing stress-related or emotional eating behaviors.

### **Challenges and Considerations**

Despite their many potential benefits, the incorporation of nutraceuticals into obesity management is associated with several important limitations and challenges that must be carefully considered.

### **Variability in Individual Response**

Individual responses to nutraceuticals can vary significantly, with factors such as genetics, lifestyle, and baseline health influencing effectiveness. Inconsistencies between study outcomes further complicate interpretation, limiting the ability to generalize findings [51,52].

### **Lack of Standardization and Quality Control**

Unlike pharmaceutical drugs, nutraceuticals are not always subject to rigorous quality control or standardization, leading to substantial variability in potency and purity, and in some cases, contamination or adulteration [53,54].

### **Potential Adverse Effects**

Although nutraceuticals are generally regarded as safe, they are not entirely without risk, as some may produce gastrointestinal discomfort, allergic reactions, or interactions with prescription medications [55,56].

### **Limited Long-Term Evidence**

Many of the demonstrated benefits of nutraceuticals are observed primarily in the short term, with limited evidence regarding their sustainability over longer periods. Weight regain is also common once supplementation is discontinued [57,58].

### **Regulatory and Marketing Challenges**

The lack of strict regulatory oversight contributes to the proliferation of misleading marketing claims, making it difficult for consumers to differentiate between evidence-based products and those with exaggerated promises [59].

### **Economic Barriers**

Cost and accessibility remain barriers for many individuals, as high-quality nutraceutical supplements can be prohibitively expensive, limiting their use among populations with fewer financial resources [60].

## Future Aspects of Nutraceuticals in Obesity Management

### Personalized Nutrition and Genomics

Advances in nutrigenomics may allow nutraceutical interventions to be tailored to an individual's genetic profile, making obesity management more precise and effective [61].

### Improved Formulations and Delivery Systems

Future research could focus on developing novel formulations, such as nanoencapsulation or slow-release systems, that increase the bioavailability and effectiveness of nutraceuticals [62].

### Combination Therapies

Integrating nutraceuticals with pharmaceuticals, lifestyle interventions, or even bariatric procedures may create synergistic effects for better long-term weight management [63].

### Gut Microbiome Targeting

With growing evidence linking gut health to obesity, future nutraceuticals may be specifically designed to modulate the microbiome in more targeted ways, using next-generation probiotics or synbiotics [64].

### Standardization and Quality Control

Research and policy efforts will likely focus on creating stricter guidelines and global standards to ensure consistency, safety, and efficacy of nutraceutical products [65].

### Digital Health Integration

Wearable devices and mobile health applications may soon track how individuals respond to specific nutraceuticals, helping researchers and clinicians optimize treatments in real time [66].

### Long-Term Clinical Trials

More robust, large-scale, and long-term clinical trials will be necessary to confirm the safety, efficacy, and sustainability of nutraceuticals for obesity management [67].

### Accessibility and Affordability

Efforts may also focus on making high-quality nutraceuticals more accessible and affordable, especially for populations disproportionately affected by obesity [68].

## II. RESULT & DISCUSSION

In summary, nutraceuticals represent a promising complementary approach to conventional obesity management strategies, offering modest benefits in weight reduction as well as important improvements in cardiovascular, metabolic, gastrointestinal, hepatic, and cognitive health. Nonetheless, their use is complicated by factors such as inconsistent effectiveness, variability in product quality, potential side effects, and regulatory shortcomings, all of which underscore the importance of careful consideration before incorporating them into a weight management regimen.

The most effective and sustainable approach to addressing obesity remains a holistic strategy that integrates professional medical guidance, balanced nutrition, regular physical activity, and long-term lifestyle modification. Within such a framework, nutraceuticals may serve as valuable adjuncts, enhancing outcomes and supporting overall health, but they should not be regarded as stand-alone solutions. To maximize benefits while minimizing risks, individuals should consult healthcare professionals before beginning supplementation, ensuring that nutraceuticals are used safely, effectively, and in conjunction with evidence-based weight management practices

## REFERENCES

- [1]. StatPearls Publishing. Psychological Issues Associated With Obesity [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 [cited 2025 Oct 3]. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK603747/>
- [2]. Institute for Health Metrics and Evaluation (IHME). The Lancet: More than half of adults and a third of children and adolescents worldwide estimated to be overweight or obese by 2035 without significant action. Seattle: IHME; 2023 [cited 2025 Oct 3]. Available from: <https://www.healthdata.org/news-events/newsroom/news-releases/lancet-more-half-adults-and-third-children-and-adolescents>
- [3]. Shahinfar H, Djalalinia S, Asayesh H, Moradi S, Heshmat R, Qorbani M. Comparative effects of nutraceuticals on body weight in adults with overweight or obesity: a systematic review and network meta-analysis of 111 randomized clinical

- trials. *Front Nutr.* 2023;10:1265432. doi:10.3389/fnut.2023.1265432
- [4]. Zeisel SH. Regulation of “nutraceuticals”. *Science.* 1999;285(5435):1853–1855. doi:10.1126/science.285.5435.1853
- [5]. Nasri H, Baradaran A, Shirzad H, Kopaei MR. New concepts in nutraceuticals as alternative for pharmaceuticals. *Int J Prev Med.* 2014;5(12):1487–1499. PMID: 25709784
- [6]. Santini A, Tenore GC, Novellino E. Nutraceuticals: a paradigm of proactive medicine. *Eur J Pharm Sci.* 2017;96:53–61. doi:10.1016/j.ejps.2016.09.003
- [7]. Brower V. Nutraceuticals: poised for a healthy slice of the healthcare market? *Nat Biotechnol.* 1998;16(8):728–731. doi:10.1038/nbt0898-728
- [8]. Martirosyan DM, Singh J. A new definition of nutraceuticals: part 1. *Funct Foods Health Dis.* 2015;5(6):209–223. doi:10.31989/ffhd.v5i6.183
- [9]. Hariri M, Ghiasvand R. Cinnamon and chronic diseases. *AdvExp Med Biol.* 2016;929:1–24. doi:10.1007/978-3-319-41334-1\_1
- [10]. Dulloo AG, Duret C, Rohrer D, et al. Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. *Am J Clin Nutr.* 1999;70(6):1040–1045. doi:10.1093/ajcn/70.6.1040
- [11]. Hursel R, Viechtbauer W, Westerterp-Plantenga MS. The effects of green tea on weight loss and weight maintenance: a meta-analysis. *Int J Obes (Lond).* 2009;33(9):956–961. doi:10.1038/ijo.2009.135
- [12]. Whigham LD, Watras AC, Schoeller DA. Efficacy of conjugated linoleic acid for reducing fat mass: a meta-analysis in humans. *Am J Clin Nutr.* 2007;85(5):1203–1211. doi:10.1093/ajcn/85.5.1203
- [13]. Yin J, Gao Z, Liu D, Liu Z, Ye J. Berberine improves glucose metabolism through induction of glycolysis. *Am J PhysiolEndocrinolMetab.* 2008;294(1):E148–E156. doi:10.1152/ajpendo.00211.2007
- [14]. Calder PC. Marine omega-3 fatty acids and insulin sensitivity: importance of the tissue fatty acid composition. *Nutrients.* 2022;14(14):2903. doi:10.3390/nu14142903
- [15]. Panahi Y, Khalili N, Hosseini MS, et al. Lipid-modifying effects of adjunctive therapy with curcuminoids–piperine combination in patients with metabolic syndrome: results of a randomized controlled trial. *Complement Ther Med.* 2014;22(5):851–857. doi:10.1016/j.ctim.2014.07.006
- [16]. Poulsen RC, Gotlinger KH, Serhan CN, Kruger MC. Identification of bioactive lipids in New Zealand green-lipped mussel extract with anti-inflammatory activity. *Prostaglandins LeukotEssent Fatty Acids.* 2008;79(6):367–373. doi:10.1016/j.plefa.2008.09.018
- [17]. Kobylak N, Conte C, Cammarota G, et al. Probiotics in prevention and treatment of obesity: a critical view. *NutrMetab (Lond).* 2016;13:14. doi:10.1186/s12986-016-0067-0
- [18]. Everard A, Cani PD. Gut microbiota and GLP-1. *Rev EndocrMetabDisord.* 2014;15(3):189–196. doi:10.1007/s11154-014-9288-6
- [19]. Dulloo AG, Duret C, Rohrer D, et al. Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. *Am J Clin Nutr.* 1999;70(6):1040–1045. doi:10.1093/ajcn/70.6.1040
- [20]. Hursel R, Viechtbauer W, Westerterp-Plantenga MS. The effects of green tea on weight loss and weight maintenance: a meta-analysis. *Int J Obes (Lond).* 2009;33(9):956–961. doi:10.1038/ijo.2009.135
- [21]. Onakpoya I, Hung SK, Perry R, Wider B, Ernst E. The use of Garcinia extract (Hydroxycitric Acid) as a weight loss supplement: a systematic review and meta-analysis of randomized clinical trials. *J Obes.* 2011;2011:509038. doi:10.1155/2011/509038
- [22]. Kim JH, Pan JH, Kim HM, Lee ES, Noh YH, Kim SH. Efficacy of Garcinia cambogia supplementation: a systematic review and meta-analysis. *Obes Res ClinPract.* 2011;5(4):e255–e266. doi:10.1016/j.orcp.2011.04.002
- [23]. Whigham LD, Watras AC, Schoeller DA. Efficacy of conjugated linoleic acid for

- reducing fat mass: a meta-analysis in humans. *Am J Clin Nutr.* 2007;85(5):1203–1211. doi:10.1093/ajcn/85.5.1203
- [24]. Gaullier JM, Halse J, Høye K, Kristiansen K, Fagertun H, Vik H, Gudmundsen O. Supplementation with conjugated linoleic acid for 24 months is well tolerated by and reduces body fat mass in healthy, overweight humans. *J Nutr.* 2005;135(4):778–784. doi:10.1093/jn/135.4.778
- [25]. Buckley JD, Howe PRC. Long-chain omega-3 polyunsaturated fatty acids may be beneficial for reducing obesity—a review. *Nutrients.* 2010;2(12):1212–1230. doi:10.3390/nu2121212
- [26]. Calder PC. Marine omega-3 fatty acids and insulin sensitivity: importance of the tissue fatty acid composition. *Nutrients.* 2022;14(14):2903. doi:10.3390/nu14142903
- [27]. Kobylak N, Conte C, Cammarota G, et al. Probiotics in prevention and treatment of obesity: a critical view. *NutrMetab (Lond).* 2016;13:14. doi:10.1186/s12986-016-0067-0
- [28]. Sanchez M, Darimont C, Drapeau V, et al. Effect of *Lactobacillus rhamnosus* CGMCC1.3724 supplementation on weight loss and maintenance in obese men and women. *Br J Nutr.* 2014;111(8):1507–1519. doi:10.1017/S0007114513003875
- [29]. Astrup A, Toubro S, Cannon S, Hein P, Breum L, Madsen J. Caffeine: a double-blind, placebo-controlled study of its thermogenic, metabolic, and cardiovascular effects in healthy volunteers. *Am J Clin Nutr.* 1990;51(5):759–767. doi:10.1093/ajcn/51.5.759
- [30]. Yoshioka M, Lim K, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M. Effects of red-pepper diet on the energy metabolism in men. *J NutrSciVitaminol (Tokyo).* 1995;41(6):647–656. doi:10.3177/jnsv.41.647
- [31]. Panahi Y, Khalili N, Sahebi E, et al. Antioxidant and anti-inflammatory effects of curcuminoid–piperine combination in subjects with metabolic syndrome: a randomized controlled trial. *Clin Nutr.* 2015;34(6):1101–1108. doi:10.1016/j.clnu.2014.12.019
- [32]. Di Pierro F, Bressan A, Ranaldi D, Rapacioli G, Giacomelli L, Bertuccioli A. Potential role of bioavailable curcumin in weight loss and omental adipose tissue decrease: preliminary data of a pilot study in overweight subjects. *Nutr J.* 2015;14:35. doi:10.1186/s12937-015-0026-9
- [33]. Birketvedt GS, Aaseth J, Florholmen J, Rytting K. Long-term effect of glucomannan on body weight in overweight and obese subjects: a randomized, double-blind, placebo-controlled trial. *Int J ObesRelatMetabDisord.* 2005;29(8):942–949. doi:10.1038/sj.ijo.0802971
- [34]. Keithley J, Swanson B. Glucomannan and obesity: a critical review. *Altern Ther Health Med.* 2005;11(6):30–34. PMID: 16320857
- [35]. Hartweg J, Farmer AJ, Holman RR, Neil A. Potential impact of omega-3 treatment on cardiovascular disease in type 2 diabetes. *Diabetes ObesMetab.* 2009;11(6):475–484. doi:10.1111/j.1463-1326.2009.01025.x
- [36]. Kim Y, Keogh JB, Clifton PM. Benefits of nut consumption on insulin resistance and cardiovascular risk factors: multiple potential mechanisms of actions. *Nutrients.* 2017;9(11):1271. doi:10.3390/nu9111271
- [37]. Kuriyama S, Shimazu T, Ohmori K, et al. Green tea consumption and mortality due to cardiovascular disease, cancer, and all causes in Japan: the Ohsaki study. *JAMA.* 2006;296(10):1255–1265. doi:10.1001/jama.296.10.1255
- [38]. Yin J, Xing H, Ye J. Efficacy of berberine in patients with type 2 diabetes mellitus. *Metabolism.* 2008;57(5):712–717. doi:10.1016/j.metabol.2008.01.013
- [39]. Akilen R, Tsiami A, Devendra D, Robinson N. Glycated haemoglobin and blood pressure-lowering effect of cinnamon in multi-ethnic Type 2 diabetic patients in the UK: a randomized, placebo-controlled, double-blind clinical trial. *Diabet Med.* 2010;27(10):1159–1167. doi:10.1111/j.1464-5491.2010.03079.x

- [40]. Calder PC. Marine omega-3 fatty acids and insulin sensitivity. *Nutrients*. 2022;14(14):2903. doi:10.3390/nu14142903
- [41]. Panahi Y, Khalili N, Sahebi E, et al. Antioxidant and anti-inflammatory effects of curcuminoid–piperine combination in subjects with metabolic syndrome: a randomized controlled trial. *Clin Nutr*. 2015;34(6):1101–1108. doi:10.1016/j.clnu.2014.12.019
- [42]. Brasnyó P, Molnár GA, Mohás M, et al. Resveratrol improves insulin sensitivity, reduces oxidative stress and activates the Akt pathway in type 2 diabetic patients. *Br J Nutr*. 2011;106(3):383–389. doi:10.1017/S0007114511000316
- [43]. Calder PC. Omega-3 fatty acids and inflammatory processes: from molecules to man. *Biochem Soc Trans*. 2017;45(5):1105–1115. doi:10.1042/BST20160474
- [44]. Kobylak N, Conte C, Cammarota G, et al. Probiotics in prevention and treatment of obesity: a critical view. *Nutr Metab (Lond)*. 2016;13:14. doi:10.1186/s12986-016-0067-0
- [45]. Sanchez M, Darimont C, Drapeau V, et al. Effect of *Lactobacillus rhamnosus* CGMCC1.3724 supplementation on weight loss and maintenance in obese men and women. *Br J Nutr*. 2014;111(8):1507–1519. doi:10.1017/S0007114513003875
- [46]. Loguercio C, Festi D. Silybin and the liver: from basic research to clinical practice. *World J Gastroenterol*. 2011;17(18):2288–2301. doi:10.3748/wjg.v17.i18.2288
- [47]. Rahmani S, Asgary S, Askari G, et al. Treatment of non-alcoholic fatty liver disease with curcumin: a randomized placebo-controlled trial. *Phytother Res*. 2016;30(9):1540–1548. doi:10.1002/ptr.5659
- [48]. Grosso G, Pajak A, Marventano S, et al. Role of omega-3 fatty acids in the treatment of depressive disorders: a comprehensive meta-analysis of randomized clinical trials. *PLoS One*. 2014;9(5):e96905. doi:10.1371/journal.pone.0096905
- [49]. Scholey A, Downey LA, Ciorciari J, et al. Acute neurocognitive effects of epigallocatechin gallate (EGCG). *Appetite*. 2012;58(2):767–770. Doi:10.1016/j.appet.2011.12.016
- [50]. Taylor MR, Murphy KS, Wright BJ. Dietary intake of green tea polyphenols and depressive symptoms in older adults: results from the English Longitudinal Study of Ageing. *J Nutr Health Aging*. 2020;24(1):94–100. doi:10.1007/s12603-019-1265-0
- [51]. Ferguson JF, Phillips CM, Tierney AC, et al. Gene–nutrient interactions in the metabolic syndrome: single nucleotide polymorphisms in ADIPOQ and ADIPOR1 interact with plasma saturated fatty acids to modulate insulin resistance. *Am J Clin Nutr*. 2010;91(3):794–801. doi:10.3945/ajcn.2009.28789
- [52]. Ordovas JM, Corella D. Nutritional genomics. *Annu Rev Genomics Hum Genet*. 2004;5:71–118. doi:10.1146/annurev.genom.5.061903.175408
- [53]. Mullie P, Guelinckx I, Clarys P, et al. Cultural, socioeconomic and nutritional determinants of dietary supplement use in the Belgian population. *Public Health Nutr*. 2011;14(8):1333–1341. doi:10.1017/S1368980010003346
- [54]. Mason P. Quality issues in dietary supplements. *Pharm J*. 2018;301(7915):45–48. doi:10.1211/PJ.2018.20205172
- [55]. Ernst E. Toxic heavy metals and undeclared drugs in Asian herbal medicines. *Trends Pharmacol Sci*. 2002;23(3):136–139. doi:10.1016/S0165-6147(00)01972-6
- [56]. Di Lorenzo C, Ceschi A, Kupferschmidt H, et al. Adverse effects of plant food supplements and botanical preparations: a systematic review with critical evaluation of causality. *Br J Clin Pharmacol*. 2015;79(4):578–592. doi:10.1111/bcp.12519
- [57]. Miller PE, Perez V. Coffee consumption and cardiovascular disease: a systematic review and meta-analysis. *Nutrients*. 2014;6(12):5048–5068. doi:10.3390/nu6125048
- [58]. Onakpoya IJ, Posadzki P, Ernst E. The efficacy of glucomannan supplementation in overweight and obesity: a systematic review and meta-analysis of randomized clinical trials. *J Am Coll Nutr*.

- 2014;33(1):70–78.  
doi:10.1080/07315724.2014.870013
- [59]. Starr RR. Too little, too late: ineffective regulation of dietary supplements in the United States. *Am J Public Health*. 2015;105(3):478–485.  
doi:10.2105/AJPH.2014.302348
- [60]. Bailey RL, Gahche JJ, Miller PE, Thomas PR, Dwyer JT. Why US adults use dietary supplements. *JAMA Intern Med*. 2013;173(5):355–361.  
doi:10.1001/jamainternmed.2013.2299
- [61]. Ferguson LR, De Caterina R, Görman U, et al. Guide and position of the International Society of Nutrigenetics/Nutrigenomics on personalised nutrition: part 1 – fields of precision nutrition. *J Nutrigenet Nutrigenomics*. 2016;9(1):12–27.  
doi:10.1159/000445350
- [62]. McClements DJ. Advances in nanoencapsulation of nutraceuticals: From microemulsions to polymeric nanoparticles. *Trends Food Sci Technol*. 2020;96:30–39.  
doi:10.1016/j.tifs.2019.12.008
- [63]. Hasani-Ranjbar S, Jouyandeh Z, Abdollahi M. A systematic review of anti-obesity medicinal plants – an update. *J Diabetes MetabDisord*. 2013;12:28.  
doi:10.1186/2251-6581-12-28
- [64]. Thursby E, Juge N. Introduction to the human gut microbiota. *Biochem J*. 2017;474(11):1823–1836.  
doi:10.1042/BCJ20160510
- [65]. Mason P. Quality, safety, and efficacy of nutraceuticals: future directions. *Nutrients*. 2022;14(14):2955.  
doi:10.3390/nu14142955
- [66]. Bashi N, Karunanithi M, Fatehi F, Ding H. Remote monitoring of patients with chronic disease: digital health technologies in clinical practice. *Med J Aust*. 2020;212(9):448–452.  
doi:10.5694/mja2.50698
- [67]. Onakpoya IJ, Heneghan CJ, Aronson JK. Post-marketing withdrawal of anti-obesity medicinal products because of adverse drug reactions: a systematic review. *BMC Med*. 2016;14:191. doi:10.1186/s12916-016-0735-y
- [68]. Bailey RL, Gahche JJ, Thomas PR, Dwyer JT. Why US children and adults use dietary supplements. *J Nutr*. 2013;143(5):817–823.  
doi:10.3945/jn.112.170993