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Review article

Anti-obesity medicinal plants, spices and their bioactive phytochemicals: mechanisms and therapeutic evidence

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ABSTRACT

Obesity is a multifactorial metabolic disorder characterized by abnormal or immoderate fat accumulation that harm health and increases the risk of numerous chronic illnesses such as cardiovascular disorders, Non-alcoholic fatty liver disease, Type 2 Diabetes Mellitus (T2DM), and certain cancers. Despite the availability of pharmacological products for obesity management, their long-term use is often connected with inadequate effect and adverse effects. From The past few years, medicinal plants and culinary spices have attracted significant attention as safer and effective alternatives for obesity control due to their rich content of bioactive phytochemicals such as polyphenols, flavonoids, alkaloids, terpenoids, and saponins. These phytochemicals regulate adipogenesis, lipid metabolism, appetite, thermogenesis, inflammation, insulin signaling, and gut microbiota composition through multiple molecular targets. This article provides a comprehensive, original, and critical review of anti-obesity medicinal plants and spices, their active phytochemicals, molecular mechanisms of action, preclinical and clinical evidence, safety considerations, limitations, and future research perspectives.

Keywords: Obesity, Anti-obesity, Medicinal plants, Spices, Phytochemicals, Adipogenesis.

INTRODUCTION

One of the most significant global health issues of the twenty-first century is obesity. The World Health Organisation (WHO) reports that since 1975, the occurrence of overweight and obesity has nearly tripled globally, impacting adults and children from all socioeconomic backgrounds [1]. Many chronic illnesses, such as dyslipidemia, hypertension, atherosclerosis, cardiovascular diseases, osteoarthritis, type 2 diabetes mellitus, infertility, and various cancers, are now known to be significantly increased by obesity [2].

Current pharmacological strategies for obesity management mainly target appetite suppression, inhibition of fat absorption, or modulation of nerve stimulators. However, a number of licensed anti-obesity medications have been discontinued because of severe side effects, such as mental and cardiovascular issues [3]. Even currently available agents such as orlistat and glucagon-like peptide-1 receptor agonists are related with gastrointestinal discomfort, high cost, and limited long-term adherence.

In this context, medicinal plants and dietary spices have gained growing interest as another choice therapeutic option. Traditional medical systems such as Unani, Ayurveda and Chinese drug have long utilized plant-based remedies for body-weight control and metabolic disorders [4]. Advances in phytochemical and molecular study have shown that many of these botanicals exert scientifically measurable anti-obesity effects through multiple biochemical pathways [5]. Plant - derived phytochemicals have pleiotropic effects, providing metabolic benefits with comparatively fewer adverse effects, compare to synthetic medications that usually act on a specific molecular target.

Pathophysiology of obesity

A persistent mismatch between energy intake and expenditure leads to the development of obesity. White adipose tissue gradually accumulates fat when excess calories are consumed and physical activity is decreased. Adipocyte hypertrophy (increase in cell size), or an increase in cell size, and adipocyte hyperplasia (increase in cell number), or an increase in cell number, are the two basic methods by which adipose tissue expands [6].

Adipose tissue is now recognized as a dynamic endocrine organ that secretes numerous adipokines, cytokines, and hormones involved in energy homeostasis and inflammation. In obesity, dysregulated adipose tissue releases elevated levels of pro-inflammatory mediators such as tumor necrosis factor-α (TNF α), interleukin-6, and monocyte chemoattractant protein-1, resulting in chronic low-grade inflammation and systemic insulin resistance [7].

Adipogenesis is regulated at the molecular level by transcription factors such as sterol regulatory element-binding protein-1c (SREBP-1c), CCAAT/enhancer binding proteins (C/EBPα and C/EBPβ), and peroxisome proliferator-activated receptor-γ (PPARγ) [8]. Hepatic de novo lipogenesis is also controlled by SREBP-1c and carbohydrate-responsive element-binding protein, leading to excessive triglyceride synthesis. In addition, emerging evidence highlights the pivotal role of gut microbiota in obesity pathogenesis. Gut dysbiosis alters energy harvest from food, modulates bile acid metabolism, promotes metabolic endotoxemia, and influences systemic inflammation [9]. These complex and interconnected mechanisms collectively drive the onset and advancement of obesity.

Rationale for utilizing medicinal plants and spices in obesity management

The renewed interest in natural anti-obesity therapies is driven by several advantages offered by medicinal plants and spices. First, they act through multiple biochemical and molecular pathways, targeting lipid digestion, adipocyte differentiation, thermogenesis, insulin sensitivity, and inflammatory signaling simultaneously [10, 11]. Second, they often exhibit additional health-promoting effects such as antioxidant, anti-inflammatory, hypoglycemic, and cardioprotective activities. Third, they tend to be considered safer when used at dietary or moderate therapeutic doses.

Phytochemicals can inhibit pancreatic lipase, thus, reducing intestinal fat absorption; suppress adipogenesis by modulating transcription factors; stimulate mitochondrial biogenesis and energy expenditure; regulate appetite-controlling hormones like leptin and ghrelin; and reshape gut microbial composition toward a metabolically favorable profile [12].

Major anti-obesity medicinal plants and spices

The natural bioactive ingredients that help control hunger, increase metabolism, prevent fat buildup, and improve lipid and glucose metabolism, medicinal herbs and spices have long been used for weight management (Table 1).

Table 1: Anti Obesity medicinal plants and spices: key phytochemicals and mechanisms

Plant/Spice	Botanical name	Key phytochemicals	Mechanism of action
Green tea	*Camellia sinensis*	EGCG, catechins, caffeine	AMPK activation, thermogenesis, inhibition of lipogenesis
Turmeric	*Curcuma longa*	Curcumin	Inhibits PPARγ, C/EBPα, anti-inflammatory
Ginger	*Zingiber officinale*	6-Gingerol, shogaol	Thermogenesis, lipid metabolism regulation
Garlic	*Allium sativum*	Allicin, diallyl sulfide	Reduces lipogenesis, improves insulin sensitivity
Fenugreek	*Trigonella foenum-graecum*	Diosgenin, galactomannan	Appetite suppression, delayed glucose absorption
Cinnamon	*Cinnamomum verum*	Cinnamaldehyde	Enhances insulin signaling, lipid metabolism
Black pepper	*Piper nigrum*	Piperine	Inhibits adipogenesis, enhances thermogenesis
Chili pepper	*Capsicum annuum*	Capsaicin	TRPV-1 activation, fat oxidation
Garcinia	Garcinia gummi-gutta	Hydroxycitric acid (HCA)	Inhibits ATP-citrate lyase, suppresses lipogenesis and appetite

***Camellia sinensis* (Green tea)**

One of the most studied natural anti-obesity medicines is green tea. Catechins, especially epigallocatechin gallate (EGCG), are mostly responsible for its metabolic effect. AMP-activated protein kinase (AMPK), the main cellular energy sensor that inhibits lipid synthesis and encourages fatty acid oxidation, is activated by EGCG [13]. By activating the sympathetic nervous system and up-regulating uncoupling proteins in brown adipose tissue, green tea catechins also improve thermogenesis. Following green tea consumption, clinical trials and meta-analyses consistently show moderate but significant decreases in body weight, body fat percentage and waist circumference [14]. These effects are the consequence of both decreased absorption of fat and increased energy expenditure.

***Curcuma longa* (Turmeric)**

Turmeric is a widely used culinary spice with potent medicinal properties. Curcumin, its principal polyphenolic compound, exhibits strong anti-adipogenic, anti-inflammatory, and antioxidative activities. It suppresses preadipocyte differentiation by down-regulating PPARγ and C/EBPα while inhibiting mitogen-activated protein kinase and NF-κB signaling pathways [15, 16]. It dramatically lowers body weight gain, adipocyte size, hepatic lipid accumulation, and circulating inflammatory markers in animal models of diet-induced obesity. Clinical research shows improvements in body mass index (BMI) insulin resistance (IR), and lipid profile after curcumin intake, especially when the supplement is designed for increased bioavailability [27].

***Zingiber officinale* (Ginger)**

Bioactive substances with thermogenic, lipolytic, and antioxidative properties found in ginger rhizome include 6-gingerol, 8-gingerol, and shogaols. It enhances energy expenditure by activating transient receptor potential vanilloid-1 (TRPV1) channels and increasing sympathetic stimulation. Experimental studies show that ginger supplementation reduces body weight, plasma triglycerides, and hepatic lipid accumulation. According to human clinical trials, it speculates that Ginger consumption helps lower the fasting blood sugar, body weight, and serum triglyceride levels in overweight individuals [17, 18].

***Allium sativum* (Garlic)**

Allicin, diallyl sulfide, and ajoene are among the sulfur-containing substances found in garlic. By decreasing acetyl CoA carboxylase and fatty acid synthase and increasing fatty acid oxidation, these bioactives inhibit lipogenesis [19]. Moreover, Garlic also improves insulin sensitivity and reduces systemic inflammation. Preclinical and clinical studies have demonstrated that supplementing with garlic can reduce blood cholesterol and body weight in overweight and dyslipidemic individuals [20].

***Trigonella foenum-graecum* (Fenugreek)**

Alkaloids (trigonelline), soluble dietary fiber (galactomannan), and steroidal saponins (diosgenin) are abundant in fenugreek seeds. These components decrease intestinal fat absorption, curb appetite, and postpone stomach emptying.Additionally, fenugreek enhances insulin sensitivity and glucose homeostasis [21]. Fenugreek seed administration dramatically lowers body weight, total calorie intake, and serum triglyceride levels in overweight people, according to clinical trials.

***Cinnamomum verum* (Cinnamon)**

Cinnamon improves glucose and lipid metabolism by enhancing insulin receptor signaling and increasing glucose transporter-4 translocation. Cinnamaldehyde and polyphenolic procyanidins are the key compounds accountable for these effects [22]. Cinnamon supplementation has been revealed to lower the fasting glucose, triglycerides, total cholesterol, and body fat accumulation in both *in vitro* and *in vivo* studies.

***Piper nigrum* (Black pepper)**

The primary alkaloid in black pepper, piperine, suppresses t he production of PPARγ and C/EBPα to prevent adipocyte developm ent.

Additionally, it increases the bioavailability of other phytochemicals and promotes thermogenesis through catecholamine secretion [23].Pip erine efficiently reduces fat storage and enhances lipid metabolism, a ccording to studies.

***Capsicum annuum* (Chili pepper)**

Chili pepper contains capsaicin, a bioactive chemical that activates the transient receptor potential vanilloid 1 (TRPV1) channel. Activation of TRPV1 increases energy expenditure, promotes thermogenesis and fat burning, and inhibits adipogenesis. These benefits emphasize capsaicin's potential significance in managing and preventing obesity by reducing adiposity and improving metabolic outcomes [24].

***Garcinia gummi-gutta* (Kudambuli)**

Garcinia gummi-gutta also called Garcinia cambogia, is a well-liked natural supplement for weight loss. Its rind contains Hydroxycitric Acid (HCA), which may prevent the ATP: citrate lyase enzyme from producing fat (lipogenesis), hence decreasing hunger and boosting fat burning. Caution is advised, especially for persons with diabetes or who are pregnant or nursing, as human evidence is conflicting, with some evaluations finding no substantial weight loss and warnings of potential liver abnormalities. However, animal studies indicate promise for lowering weight and fat in high-fat diets. G gummi gutta has been shown in an in vitro investigation to lower cholesterol and inhibit lipase activity [25, 26].

Anti-obesity phytochemicals and their molecular targets

Several plant derived phytochemicals are widely recognized for their capacity to influence critical biochemical processes implicated in obesity. Catechins (especially EGCG), curcumin, resveratrol, quercetin, capsaicin, piperine, berberine, and genistein are examples of compounds that have a variety of metabolic actions that help enhance energy balance and reduce adiposity. Important targets, such as AMPK, PPARγ, SREBP1c, NFκB, and UCP1, are modulated by these bioactive compounds (Figure 1). Inhibiting fatty acid production, promoting mitochondrial β oxidation, and improving the overall cellular energy balance are all important functions of AMPK activation.

PPARγ and C/EBP transcription factors prevent adipocyte development, reducing fat tissue growth. SREBP-1c downregulation also helps to improve lipid profiles by lowering hepatic triglyceride production. Furthermore, UCP-1 stimulation increases thermogenesis in brown and beige adipose tissues, which raises energy expenditure. Together, these phytochemicals increase metabolic efficiency, control lipid metabolism, and reduce inflammation through complementary pathways. Their diverse effects highlight the medicinal potential of substances derived from plants as helpful treatments for the control of obesity [27-32].

Molecular mechanisms of action

Phytochemicals regulate obesity through multiple interconnected mechanisms:

Inhibition of adipogenesis

Suppression of PPARγ and C/EBPα prevents preadipocyte differentiation.

Enhancement of lipolysis and fat oxidation

Activation of AMPK increases carnitine palmitoyltransferase-1 activity and fatty acid oxidation.

Suppression of lipogenesis

Down-regulation of SREBP-1c and acetyl-CoA carboxylase reduces triglyceride synthesis.

Induction of thermogenesis

Up-regulation of UCP-1 increases energy dissipation as heat.

Anti-inflammatory effects

Inhibition of NF-κB reduces obesity-associated inflammation.

Modulation of gut microbiota

Phytochemicals promote beneficial microbial populations such as *Akkermansiamuciniphila* and *Bifidobacterium* species, improving metabolic homeostasis.

Preclinical and clinical evidence

Numerous laboratory-based research and animal studies show that herbal extracts and isolated phytochemicals dramatically lower inflammation, lipid accumulation,oxidative stress, adipocyte hypertrophy, and body weight increase. Green tea catechins, curcumin, resveratrol, gingerol, and piperine significantly reduce fat mass and enhance insulin sensitivity (IR) in diet-induced obese animals (Table 2) [14, 23, 33, and 34].

According to human clinical trials, fenugreek suppresses hunger and lowers calorie intake [21], ginger lowers triglycerides and fasting glucose [18, 34], Curcumin improves body mass index and lipid profile [27], and green tea extract lowers body weight and waist circumference [14]. The total metabolic changes are clinically significant even though the sum of weight reduction is frequently modest (Table 3).

Figure 1: Phytochemicals and their molecular targets in anti-obesity therapy

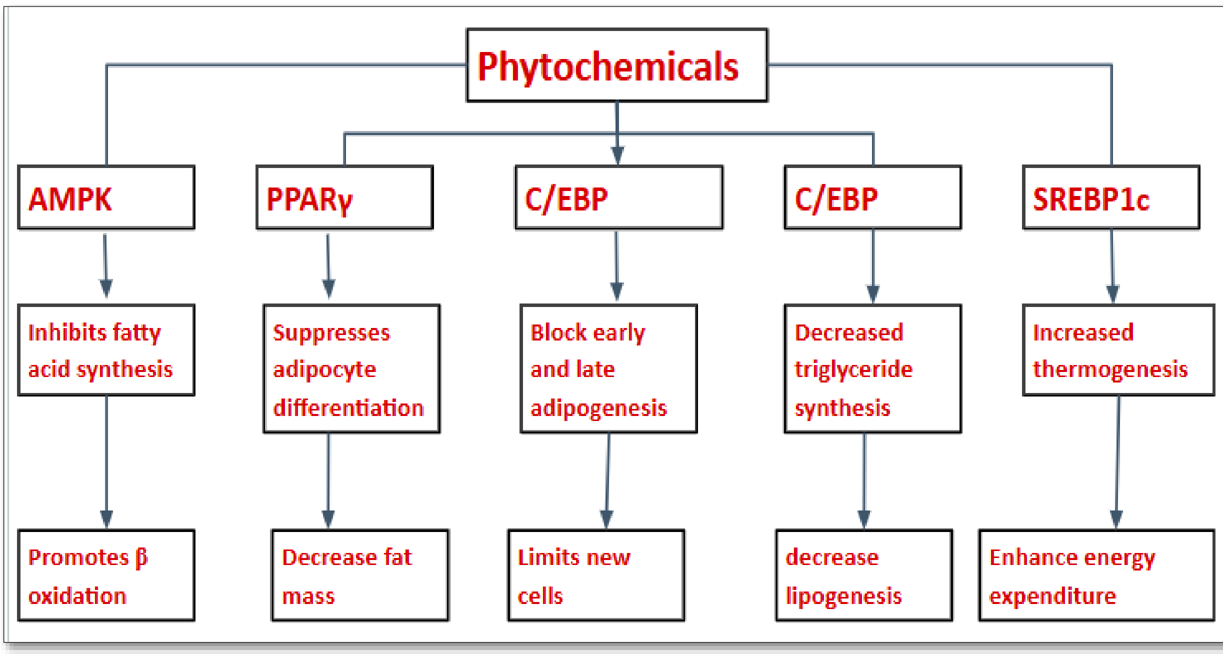

Table 2:preclinical evidence of anti-obesity activity of medicinal plants and spices

Plant/Compound	Experimental Model	Dose	Outcome
Green tea extract	High-fat diet mice	0.5% in diet	↓ Body weight, ↓ fat mass
Curcumin	Diet-induced obese rats	100 mg/kg	↓ Adiposity, ↓ TG
Piperine	3T3-L1 adipocytes	25–50 µM	↓ Lipid accumulation
Capsaicin	Obese mice	2 mg/kg	↑ Energy expenditure
Quercetin	High-fat mice	0.1% in diet	↓ Inflammation, ↓ adipocyte size

Table 3: Clinical trials of anti-obesity medicinal plants and spices

Intervention	Study Design	Participants	Dose & Duration	Outcome
Green tea extract	Randomized controlled trial	Overweight adults (n=132)	500 mg/day, 12 weeks	↓ BMI, ↓ waist circumference
Curcumin phytosome	Double-blind RCT	Obese subjects (n=44)	1 g/day, 8 weeks	↓ Fat mass, ↓ triglycerides
Ginger powder	Randomized trial	Obese adults (n=80)	2 g/day, 10 weeks	↓ Body weight, ↓ FBG
Fenugreek extract	Placebo-controlled trial	Overweight subjects (n=60)	588 mg/day, 8 weeks	↓ Appetite, ↓ fat intake
Cinnamon	RCT	Type 2 diabetic obese patients	1.5 g/day, 12 weeks	↓ Body weight, ↓ LDL

Table 4: Safety and toxicological considerations of selected medicinal plants

Plant	Reported Adverse Effects	Drug Interaction Risk	Reference
Green tea	Hepatotoxicity at high dose	Statins, β-blockers	(Stickel et al., 2011) [35]
Turmeric	GI irritation, gallbladder risk	Anticoagulants	(Williamson, 2003) [36]
Garlic	Bleeding risk	Warfarin, aspirin	(Ried, 2016) [20]
Ginger	Heartburn	Antihypertensives	(Maharlouei et al., 2019) [18]
Cinnamon	Liver toxicity (coumarin)	Antidiabetics	(Sheng et al., 2018) [22]

Safety, toxicity, and limitations

When used at standard dietary amounts, medicinal herbs and spices are generally harmless. On the other hand, hepatotoxicity, allergic reactions, gastrointestinal discomfort, and herb-drug interactions might result from excessive or prolonged consumption (Table 4) [35, 22]. While high doses of the extract of green tea have been connected to infrequent occurrences of liver damage, curcumin has poor oral absorption. The absence of standardized formulations, variations in phytochemical content resulting from processing and geographic variations and the dearth of long-term randomized controlled trials are additional significant limitations [35, 36].

The complete therapeutic integration of phytochemicals into traditional obesity therapy is now limited by these constraints.

Future perspectives

Future research should priorities

Standardization of herbal extracts and quality control

Development of nano-delivery systems to enhance bioavailability

Exploration of synergistic polyherbal combinations

Integration of gut microbiome-targeted therapies

Large, multi-centre randomized clinical trials

Application of omics technologies and systems pharmacology approaches to decipher complex phytochemical–host interactions [37, 38]. Such strategies will accelerate the translation of plant-based anti-obesity agents from bench to bedside.

CONCLUSION

Medicinal plants and dietary spices provide a rich source of natural compounds with multi-target anti-obesity potential. Their phytochemicals influence several interconnected mechanisms, including the regulation of adipogenesis, lipid metabolism, thermogenesis, insulin sensitivity, inflammatory pathways, and gut microbiota composition. Together, these actions contribute to improved metabolic balance and reduced obesity-related complications. Although growing experimental and clinical studies highlight their promise as supportive interventions, significant challenges remain. Standardization of active components, comprehensive safety assessments, and well-designed, large-scale clinical trials are crucial to ensure consistency, efficacy, and safety. Only with such rigorous validation can these plant-derived agents be reliably integrated into evidence-based obesity management strategies.

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