Review Article

Harnessing the Power of Nutraceuticals: A New Approach to Obesity Treatment

ABSTRACT

The increasing prevalence of obesity highlights the urgent need for effective and sustainable management solutions. This review explores how nutraceuticals derived from various sources can play a key role in addressing obesity and its related health issues. Compounds like curcumin, green tea extract, psyllium fibre and omega-3 fatty acids have shown promising effects in weight management by regulating appetite, enhancing metabolism, reducing inflammation, and improving insulin sensitivity. Obesity is a complex condition influenced by genetic, environmental and behavioural factors, making it difficult to treat. Nutraceuticals help by targeting specific pathways involved in inflammation, lipid metabolism and hormonal regulation, providing a safer, more natural alternative to traditional treatments. However, challenges like poor absorption, inconsistent results and the potential side effects still exist. Further advancements in exploring opportunities to enhance the effectiveness and accessibility of obesity management through nutraceuticals are yet to be undertaken. This review emphasizes the importance of rigorous clinical testing, regulatory oversight and better consumer education to enhance the benefits of nutraceuticals in obesity management. By integrating these natural compounds with comprehensive lifestyle changes, including improved diet, regular exercise andbehavioural therapy sustainable weight loss and improved overall health can be achieved.

Keywords: Nutraceuticals, Obesity, Co-morbities, Toxicity, Regulation

1. INTRODUCTION

The term Nutraceuticals combines "nutrition" & "pharmaceutical," refers to food-derived products which offers health benefits beyond basic nutrition. It was first introduced by Stephen DeFelice, founder and chairman of the Foundation for Innovation in Medicine in 1989, nutraceuticals are described as “a food or part of a food that provides medical or health benefits, including the prevention and/or treatment of disease. Nutraceuticals was further defined as food-based products presented in medicinal forms like pills or powders, making them distinct from regular foods by “Health Canada”. This concept aligns with the philosophy of Hippocrates, the father of medicine, who famously advocated, “Let food be your medicine”. Nutraceuticals encompass a wide variety of substances, including isolated nutrients, herbal extracts, dietary supplements, processed foods, and genetically engineered "designer" foods. They originate from industries like food production, pharmaceuticals, herbal remedies, and agribusiness. Over time, they have become essential in enhancing health, delaying aging, and preventing chronic diseases (Slavinet.al, 2005). Nutraceuticals are especially valued for their role in managing serious health issues and oxidative stress-related conditions, including diabetes, cardiovascular diseases, cancer, gastrointestinal and kidney disorders, allergies, alzheimer’s, parkinson’s, and obesity. Key components of nutraceuticals include phytochemicals such as terpenoids, limonoids, phytosterols, polyphenols, and isoflavonoids (Das et al., 2012). These compounds offer a range of therapeutic benefits, including anti-inflammatory, antioxidant, antibacterial, antifungal, anticancer, neuroprotective, and antiaging effects. Despite these benefits, challenges like poor bioavailability, digestion-related inefficiencies, and potential toxicity remain(Puri et al., 2022).To address these issues, advancements in nanotechnology-based delivery systems are being explored, which aim to enhance stability and effectiveness by protecting these bioactive compounds during digestion(Kim et al., 2023).

Nutraceuticals positively influence numerous biological processes, such as boosting antioxidant defences, regulating cell growth, supporting gene expression, and preserving mitochondrial function. They act as non-specific biological therapies, promoting overall health, easing symptoms, and reducing the risk of chronic illnesses. Ranging from functional foods and beverages to herbal supplements and pharmaceutical-grade formulations, nutraceuticals have become a cornerstone in healthcare, nutrition, and disease prevention(Chopra et al., 2022).Obesity is a complex, multi-factorial diseases which is influenced by multifaceted interaction of hereditary, epigenetic, and environmental and behavioral factors. A comprehensive, system wide approach is necessary for prevention and management of obesity.Environmental variables can interfere with these energy-balancing mechanisms, which can result in overeating and a higher risk of obesity, particularly in genetically predisposed individuals. The underlined pathophysiology involved is by interaction between gastrointestinal system, adipose tissue and endocrine system which regulates food intake and appetite. Recent developments in obesity treatment includes bariatric surgery in addition to pharmacological and nutritional therapies(Liu et al., 2003) .Because obesity raises inflammation and harmful cholesterol levels, it rises the risk of coronary artery disease, stroke, and elevated blood pressure. Because of factors including insulin resistance and chronic inflammation, obesity increases the risk of developing cancers and sleep arena in which excess body fat in neck and airway causes breathing problems while you sleep, which can cause exhaustion and other health problems.Osteoarthritis, back discomfort, and gout are all made more likely by obesity's effects on the bones and joints.Nutraceuticals are governed by The Food Safety and Standards Act 2006 ensuring they are safe and compliant with quality standards,Nutraceuticals must adhere to regulations for packaging, labelling, to ensure safety and efficacy, for the treatment, prevention, or cure of obesity.
In obesity management, nutraceuticals offer a natural and effective approach by addressing critical factors like appetite control, metabolism enhancement, fat storage reduction, gut health improvement, and inflammation management. Ingredients like green tea extract, omega-3 fatty acids, curcumin, fibre supplements, and probiotics not only support weight loss but also improve metabolic and cardiovascular health. Their natural origin makes them a safer and more holistic alternative to conventional weight-loss drugs, with fewer side effects. However, their effectiveness can vary, highlighting the need for better standardization and stronger scientific evidence. With innovations in delivery systems, personalized formulations, and advanced technologies like nanotechnology, nutraceuticals hold tremendous potential to play a pivotal role in comprehensive obesity management strategies(Gaskin et al., 2024).

1.1 Overview of Nutraceuticals

Nutraceuticals are described as "foods or parts of foods that provide medical or health benefits, including the prevention and/or treatment of diseases".They serve as supplements when a regular diet fails to deliver adequate essential nutrients and vitamins. Acting as an alternative solution, nutraceuticals blur the distinction between food and medicine. Individuals with nutritional deficiencies often turn to these natural products, as they are designed to align with the principles of a balanced diet.

1.2 Overview of Obesity

The World Health Organisation (WHO) defines obesity as an abnormal or excessive accumulation and storage of body fat which threatens the public health sector by prevalenceincrease across all age groups and socioeconomic strata. Obesity is now seen as a worldwide health crisis, taking a serious toll on quality of life and leading to early deaths. Anthropometric measurements such as waist circumference, skinfold thickness, and waist-to-hip ratio are increasingly utilized to evaluate an individual's risk of obesity.Obesity is a condition where the amount of fat in the body surpasses the lean mass. It is typically assessed using the Body Mass Index (BMI), which estimates body fat by dividing a person's weight in kilograms by the square of their height in meters. In children obesity and overweight is classified by Body Mass Index percentiles compared to children are specific for age and sex,BMI of 35 or higher than 40 kg/m^2 is severe obesity, BMI of greater than 35 kg/m^2 and experiencing obesity-related health conditions or greater than 40 or45 kg/m^2 is morbid obesity, BMI of greater than 45 or 50 kg/m^2 is super obesity, Table 1 and 2 represents the BMI Percentile classification for paediatrics and adults.

Table 1. Paediatric BMI Percentile Classification

Paediatric BMI Percentile Classification	Percentile
Underweight	<5th
Normal	5-84th
Overweight (Pre-obesity)	85-94th
Obesity	>95th

Table 2. Adult BMI Classification

Adult BMI Classification	kg/m^2
Underweight	<18.49
Normal	18.50-24.90
Overweight (Pre-obesity)	25-29.9
Obesity class I	30-34.9
Obesity class II	35-39.9
Obesity class III	>40

In 1997,WHO recognised obesity as a global epidemic, the prevalence of obesity doubled globally between 1980and 2014 more than 600 million adults were obese, as per the reports in 2022, more than 1 billion people worldwide were living with obesity, including 879 million adults and 159 million children. This accounts for 43% of adults aged 18 and older, with 43% of men and 49% of women affected. In India, obesity affects 13-15% of the urban population and 8-38% of the rural population, with women being more commonly impacted than men(Slavin, 2005).

2. PATHOGENESIS AND ETIOLOGY OF OBESITY

Obesity involves a complex interaction between hormones, heredity and environment. Multiple hormones, including adipokines and hormones associated to the gut. The stomach produces the peptide hormone ghrelin, which is released into the bloodstream, it peripherally acts as an orexigenic hormone which is stimulates appetite. The anorectic gut hormones are Peptide YY, Cholecystokinine18, glucagon like peptide which limits food intake to for optimal digestion and absorption, prevents the causes of hyperinsulinemia and insulin resistance (Aktar et al., 2017). Adipocytes secrete hormones called adipokines which is essential for regulating of metabolism and obesity. TNF-α, interleukin-6, leptin, and adiponectin are important adipokines.Through the disruption of insulin signalling, reduced synthesis of adiponectin and free fatty acids release, TNF-α has been linked to the development of insulin resistance. The brain receives information regarding energy stores in adipose tissue from leptin, a vital long-term regulator. It suppresses hunger by binding to receptors in the hypothalamus, particularly in neurons that regulate appetite after crossing the blood-brain barrier (Wen et al., 2022).

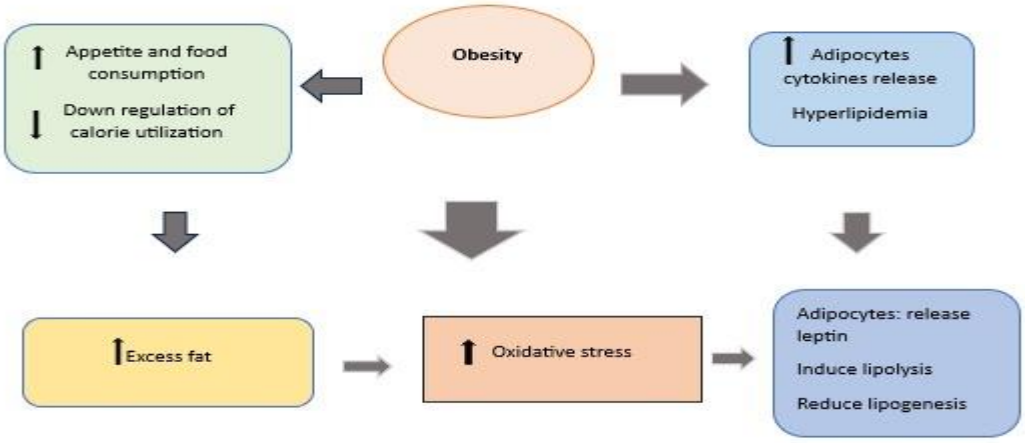

Fig. 1. Etiology of obesity

An insulin-sensitizing, anti-inflammatory adipokine with anti-atherogenic qualities is adiponectin. Its positive metabolic effects are shown by the fact that its levels are usually returned to normal after weight loss. These adipokines work together to maintain energy homeostasis(ElSayed et al., 2023). AMPK and PPAR pathways, decrease in the inflammatory response are the key objectives of obesity management. Nutraceuticals targeting inflammatory pathways have a reducing insulin resistance and modulating macrophages polarization. The complexity of these interconnected mechanisms obesosome necessitates the development of multi targeted therapies. Synergistic nutraceuticals formulation is a potential approach is an effective combination for obesity management (Sethi&Hotamisligil, 1999). Drugs and neuroendocrine disorders (pituitary, thyroid, adrenal, and hypothalamus) are secondary causes of obesity.High-energy density diet, larger portions, sedentary lifestyles, poor levels of physical activity, and eating disorders are important factors that leads to the development of obesity. The behavioural and environmental factors that causes alteration in adipose tissue structure (adipocyte hypertrophy and hyperplasia, inflammation) and secretion (adipokine) (Heymsfield&Wadden, 2017).

3. NUTRACEUTICALS CLASSIFICATION

Nutraceuticals are bioactive substances obtained from natural sources such as plants, animals, microbes, and marine organisms. These sources offer a wide array of nutrients and bioactive compounds that support health, prevent diseases, and provide therapeutic advantages.

Table 3. Classification of nutraceuticals based on source

Source	Examples	Key Bioactive components	Benefits
Plant-Based Sources	Fruits and Vegetables	Vitamin C, flavonoids (citrus fruits), anthocyanins (berries), lycopene (tomatoes), glucosinolates (cruciferous vegetables)	Antioxidant, anticancer, anti-inflammatory, and cardiovascular health benefits.

	Whole Grains and Cereals	Dietary fiber, lignans, phenolic acids	Supports gut health and reduces the risk of cardiovascular diseases
	Herbs and Spices	Curcumin (turmeric), gingerols (ginger), catechins (green tea)	Anti-inflammatory, antioxidant, and metabolic benefits
		Isoflavones (soybeans), omega-3 fatty acids, vitamin E (almonds, walnuts	Supports bone health, cardiovascular health, and reduces inflammation
	Medicinal Plants	Ginsenosides (ginseng), anthraquinones (aloe vera)	Immune-boosting, skin health, digestive health
Animal-Based Sources	Dairy Products	Whey protein	Muscle repair and protein supplementation
	Eggs	Choline, lutein, zeaxanthin	Benefits brain and eye health
	Meat	Bioactive peptides, essential amino acids	Supports growth, repair, and metabolic functions
Microbial Sources	Probiotics	*Lactobacillus*, *Bifidobacterium*, *Saccharomyces boulardii*	Improves gut health, boosts immunity, supports digestion

	Prebiotics	Inulin, fructooligosaccharides (FOS)	Enhances the growth of beneficial gut bacteria
	Enzymes	Lactase, bromelain, amylase	Aids digestion and metabolic processes
Marine Sources	Algae and Seaweed	Protein, antioxidants, essential fatty acids (Spirulina, Chlorella), fucoidans (brown algae)	Anti-inflammatory, antioxidant, anticoagulant properties
	Fish and Seafood	Omega-3 fatty acids (DHA, EPA), vitamin D	Supports brain and heart health
	Marine Collagen	Collagen peptides	Supports skin health, joint health, and tissue repair
Synthetic and Fortified Sources	Fortified Foods	Calcium (orange juice), iron and folic acid (cereals), vitamin D, omega-3 fatty acids (milk and dairy)	Enhances nutrient intake, supports bone health, reduces nutritional deficiencies
	Recombinant Nutraceuticals	Insulin, bioactive peptides, fortified yeasts	Delivers targeted health benefits through biotechnology

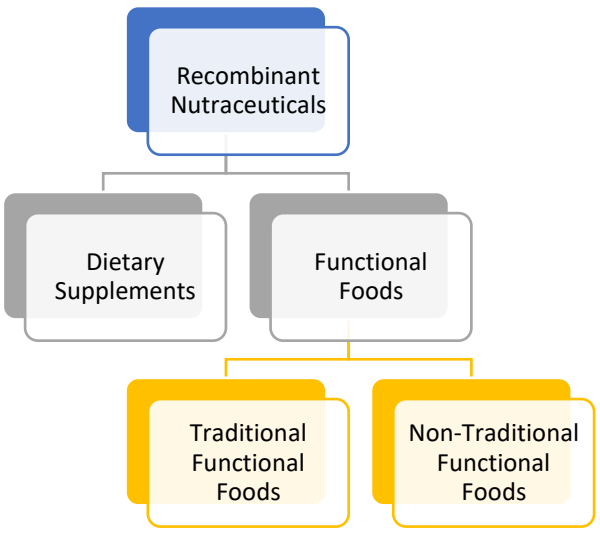

Fig.2. Classification of recombinant nutraceuticals

3.1 Dietary Supplements

These are specially formulated products containing bioactive compounds extracted from food sources, made into convenient forms for consumption. They include amino acids, vitamins, minerals, herbs, metabolites, and enzymes, designed to combat the nutritional gaps or provide additional nutrients that might be needed in higher amounts(Shick et al., 1998). These supplements come in various forms such as tablets, capsules, powders, liquids, gummies, and even energy bars, offering flexibility to suit individual preferences. They aim to support overall health, address nutritional deficiencies, and assist in managing specific health conditions(Yeh et al., 2003).

3.1.1 Key Components of Dietary Supplements

Table 4. Key Components of Dietary Supplements

Component	Examples	Key Functions
Vitamins and Minerals	Vitamin C, Vitamin D, Calcium, Magnesium	Support immune function, strengthen bones, aid in energy production
Amino Acids and Proteins	L-arginine, Whey Protein	Promote muscle repair, support heart health, regulate metabolism
Probiotics and Prebiotics	*Lactobacillus*, *Bifidobacterium*, Inulin	Improve gut health, enhance digestion, boost immunity, and aid nutrient absorption
Herbal Extracts	Curcumin (turmeric), Ginseng, Ashwagandha	Provide antioxidants, reduce inflammation, combat oxidative stress, and manage stress with adaptogenic effects
Fatty Acids	Omega-3 (Fish oil, Algae)	Support heart and brain health, reduce inflammation, and promote cognitive function
Antioxidants	Coenzyme Q10, Resveratrol, Flavonoids	Protect against oxidative stress, prevent cellular damage, and promote overall well-being

3.1.2 Functional Foods

These are everyday foods or ingredients that provide additional health benefits beyond basic nutrition. These include both natural whole foods and foods that are fortified, enriched, or modified to improve human health. When regularly taken as part of a balanced diet, functional foods can enhance overall well-being. Common examples include pasta, cereals, whole grains, yogurt, and snacks, which are often enriched with nutrients to offer specific health benefits. By incorporating dietary supplements and functional foods into the routine, one can support a healthier lifestyle, address specific health needs and optimize overall nutrition(Inbathamizh et al., 2022).

3.1.2.1 Classification of Functional foods

Functional foods are those foods that provide health benefits beyond basic nutrition, having bioactive components which strengthen or modulate good health and specific health conditions.Functional

foods can be classified into two categories, namely Traditional Functional Foods and Non-Traditional Functional Foods, according to their sources and the method of preparation(Shahidi, 2020).

A. Traditional Functional Foods

Traditional functional foods are natural, nutrient-rich foods that deliver additional health benefits alongside their basic nutritional value(Kobyliak et al., 2018). These are further classified into subcategories based on their composition.

Table 5. Classification of Traditional Functional Foods

Classification	Category	Examples	Benefits
Based on Chemical Constituents	Nutrients	Vitamins: Vegetables, whole grains, dairy, fruits.	Address heart disease, stroke, cataracts, diabetes.
		Minerals: From plant, animal, and dairy sources.	Strengthen bones, teeth, muscles; improve nerve impulses, regulate heart rhythm.
		Omega-3 Fatty Acids: Flaxseed, salmon.	Control inflammation, support brain function, lower cholesterol
	Herbs	Willow Bark (*Salix nigra*): Contains salicin	Anti-inflammatory and pain-relieving properties
		Parsley (*Petroselinum crispum*): Rich in flavonoids	Diuretic and antipyretic.
		Peppermint (*Mentha piperita*): Contains menthol	Treats colds and flu

		Lavender (*Lavandula angustifolia*): Contains tannins.	Reduces stress, depression, asthma symptoms.
		Cranberries (*Vacciniumerythrocarpum*): Contain proanthocyanidins.	Useful for urinary tract infections, ulcers, cancer prevention.
	Phytochemicals	Carotenoids: Fruits, vegetables, egg yolk	Anti-carcinogenic properties, UV protection.
		Flavonoids: Berries, legumes, vegetables.	Antioxidant activity, prevention of breast and prostate cancer
		Phenolic Acids: Blueberries, tomatoes.	Antioxidant activity, reduction of harmful mutations
		Glucosinolates: Broccoli.	Antitumor effects.
Probiotic Microorganisms	Probiotics	*Lactobacillus*, *Bifidobacterium*, *Saccharomyces boulardii*.	Improve gut health, boost immunity, prevent pathogen adhesion, and reverse effects of lactose intolerance
Nutraceutical Enzymes	Enzymes	*Lactase, bromelain, amylase.*	Aid in digestion and metabolism, manage hypoglycemia, obesity, and digestive issues.

B. Non-Traditional Functional Foods

These are foods modified or fortified using advanced technologies to enhance their nutritional and health benefits(Miglani et al., 2015).

Table 6. Classification of Non-traditional Functional Foods

Category	Examples	Benefits
Fortified Nutraceuticals	Orange juice fortified with calcium	Enhances bone health.

	Iron-enriched cereals	Prevents anemia.
	Milk fortified with vitamin D	Addresses vitamin D deficiency.
	Probiotic-enriched milk with *Bifidobacterium lactis*	Combats diarrhea and respiratory infections
	Bananas fortified with the soybean ferritin gene	Addresses iron deficiency.
Recombinant Nutraceuticals	Bread, yogurt, cheese, vinegar, and fermented starch produced using fermentation technologies.	Provides energy and specific health benefits.
	Probiotics and bioactive components created using biotechnological methods	Enhances gut health and delivers targeted therapeutic benefits.

4. OBESITY-RELATED COMORBIDITIES

Cardiovascular diseases

According to epidemiological research, obesity raise the potential of cardiovascular diseases which elevates BP, stroke, heart attack, obese people develop cardiovascular diseases due to high BP, unhealthy cholesterol levels and inflammation. It is primary risk factor for development of type 2 diabetes a chronic condition which is characterized by elevated sugar levels (Poirirp et al., 2022).

Cancer

Obesity increases the chances of developing several types of cancer including colorectal, breast, endometrial, and pancreatic cancer. The mechanism underlying this are intricate and includes a number of variables such as insulin resistance, hormonal imbalance and chronic inflammation(Flynn et al., 2006).

Sleep apnea

Obesity is a major risk factor, a disorder which is characterized by pause of breathing during sleep, excess fat accumulated around neck and airways which cause difficulty in breathing that disrupt the sleep and fatigue during daytime and other health issues. Loss of weight, life style modification along with medical intervention can improve the sleep apnea symptoms (Kasbia, 2005).

Disorders related to musculoskeletal

Obesity significantly strainthe bones and joints, leading to an increase in the musculoskeletal disorders such as osteoarthritis, low back pain and gout. Excess weight causes mechanical stress that deteriorates cartilages and joints, which resulting in pain inflammation and limited mobility.Weight loss and physical therapy can help manage musculoskeletal disorders.

Obesity significantly lowers a person's quality of life, epidemiological research has linked obesity to the onset and progression of chronic metabolic disorders, such as insulin resistance, abnormal glucose, lipid metabolismand persistent inflammatory conditions(Farooqi & O'Rahilly, 2006).

Fig. 3. Obesity related co-morbidities

Obesity leads to medical conditions including endocrine disorders such as hypothyroidism, hypercortisolism, and growth hormone deficiency, damages the central nervous system including hypothalamic-pituitary damage from surgery, and post-malignancy conditions such as acute leukaemia. Several pharmacological agents such as glucocorticoids, insulin, several antiepileptic medications like sodium valproate, and a few atypical antipsychotics including risperidone, olanzapine, and clozapine, are linked to excessive weight gain(Rosenheck, 2008).

5. COMPREHENSIVE STRATERGIES FOR OBESITY MANAGEMENT

5.1 Life style modification

Obesity management primarily depends on weight loss by reducing the caloric intake rather than precise proportion of carbohydrates, fats and proteins in the diet. Consulting a dietitian fornutrition therapy is beneficial, as a promoting collaborative care and encouraging self-management of obesity.Weight management can also be facilitated by incorporating meal replacements which are intended provides essential nutrition within a set of caloric limits(Wadden et al., 2012).

5.2 Dietary management

Dietary advice should focus on promoting healthy eating habits, including the consumption of vegetables, grains, cereals and fibre. While opting for low-fat dairy products and lean meats over high-fat alternatives. Enhanced seafood intake is also encouraged for its health benefits. On the other hand,to prevent consuming too many caloriesone should limit consumption of foods that contain refined sugar, fatty foods, sweet drinks, and alcoholic beverages. Prioritizing healthy eating habits promotes long-term weight loss and general health (Yanovski & Yanovski, 2014).

Type of Diet: The amount and caloric content of the diet should be taken into consideration. The diet must be classified as high-calorie, high-carb, high-fat, or low-fibre based on dietary recall.

Meal Pattern: Analyse the type and quantity of meals consumed. It should ideally eat five to six small meals frequently. It is important to address unhealthy eating habits including skipping meals, having long gaps between meals(Yannakoulia et al., 2019).

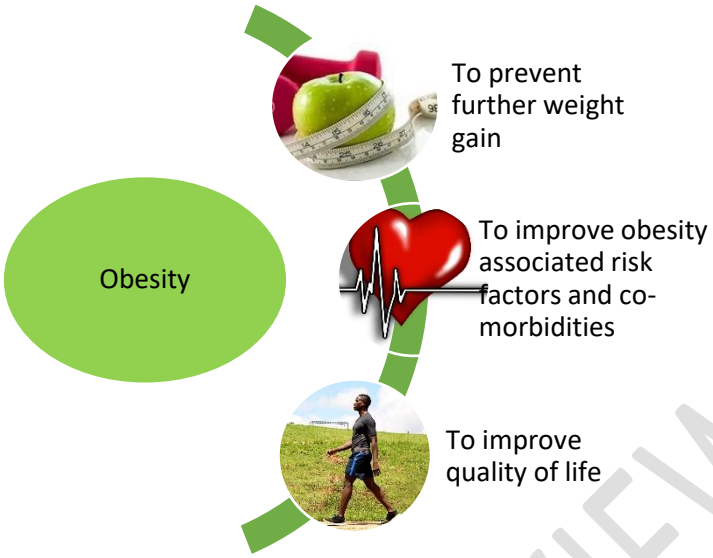

Fig. 4. Life style modifications for obesity

Portion Size: Consider how much food each meal requires. Large portions and energy dense meals contributes to excessive calorie intake.
Consumption of carbohydrates: Focus on the items that contain carbohydrates in the diet, especially those that have a high glycaemic index (such as processed foods, refined flour, white rice, noodles, and pasta), as well as confections and baked goods. It's important to monitor on how much sugar is in tea, coffee and sugary drinks(Wadden et al., 2012).
Fat Consumption: Monitor the consumption of red and processed meats, fried foods, baked goods, margarineand fatbased dressings. It is also important to evaluate how often they are consumed as well as the quantity and amount of cooking oils utilized.
Fibre Consumption: Ensure to eat the diet including more servings of fruits and vegetables each day. It is important to evaluate the consumption of foods high in fibre, such as salads, whole grains, legumes, nutsand seed(Pillitteri et al., 2008).
Beverage's consumption: Drinking too much alcohol and sugary drinks (more than one drink for women and two for men per day) might lead to weight gain and should be monitored.
MealPreparation: The frequency of consuming ready-to-eat, convenienceand restaurant meals as well as the use of high-calorie home-cooked recipes. Unhealthy eating habits may be influenced by these variables. By analysing these aspects of a patient's diet, practitioners can provide personalized guidance for healthier eating patterns and more effective weight management(O'Neil et al., 2010).
Studies show that even a small weight loss of 5–10 kgor a caloric deficit of 35,000–70,000 kcal, can have substantial health advantage. Weight loss objectives should aim for a weekly reduction of 0.5 to 1 kg, as 1 kg of body weight is equivalent to a 7,000-kcal deficit. Rapid weight reduction raises the risk of rapid weight gain and physiological strain. One can also produce net energy deficit by directly lowering caloric intake. The daily energy intake limit for low-calorie diets is 800-1600 kcal, and for very low-calorie diets (LCD and VLCD), it is 800 kcal(Shahinfar et al., 2023).

5.3 Physical Activity

Sedentary lifestyles are linked to obesity. Exercise increases energy expenditure which leads to lipolysis and the release of free fatty acid from fat-stored triglycerides for muscle usage.In addition, exercise improves mood, lowers blood pressure, decreases visceral fat, increases attention and concentration, and has numerous other positive health effects. Frequent exercise lowers the risk of metabolic disorders & lowers mortality in obese individuals. Typically, lifestyle modification programs recommend 150–180 min of moderately intense aerobic exercise, like brisk walking, each week (Kushner & Ryan, 2014).Numerous advantages are linked toregular aerobic exercise, such as improvements in mental and physical health (e.g., anxiety, depression, blood pressure, lipids). Additionally, increased fitness is linked to physical exercise, which may reduce the risk of mortality associated with obesity. Exercise is an effective way to lose weight when combined with dietary

changes, suggested that it can reduce BMI by 2% to 3% on its own (Strychar, 2006). According to most of the research, exercise by itself either doesn't help people lose weight at all or just causes small weight reduction of a few kg. Nonetheless, exercise can support the maintenance of weight loss over the long period (Rippe, 2018).

5.4 Sleep

Sleep is a treatment for paediatric obesity, particularly in older children's and adolescents. Sleep interventions in preschool-aged children associated with reduced weight growth. Improvement in healthy sleeping habits, such as normal sleep-wake schedules, a regular bedtimeand less evening screen timeare probably going to have numerous additional advantages and favourable impacts on other weight-related behaviour (Richman & Rittenberg, 2024).

5.5 Behavioural therapy

Behavioural therapy on a continuous basis with ongoing communication from healthcare professionals has been incorporated into behavioural techniques and greatly improved the chances of long-term weight loss. It assists customers in navigating the numerous obstacles that stand in the way of behaviour change, which could lead to continuous changes. Boost your behaviour strategy to enhance your eating and exercise habits and help you get rid of obstacles that prevent you from sticking to your weight control plan. These methods' main constituents include the following: Self-monitoringawareness and identification of which ones would benefit improvement by tracking patterns of eating, physical activity and body weight.Stress management improving methods to avoid overindulging in food. Cognitive restructuring is the process of self-correcting erroneous beliefs and expectations regarding body image and weight loss. Using friends and family as a source of accountability and encouragement is known as social support. Preventing relapses involves sticking to a plan in the face of a setback, such as overeating or gaining weight(Yanovski&Yanovski, 2014). In order to address specific psychological factors that contribute to specific eating behaviours and outcomes, which include inadequate physique perception, negative affectstatesor an incentivecontrol, psychological interventions are used either alone or in combination with other forms of therapy in the treatment of obesity. This lowers barriers to behavioural change.Bariatric surgery for individuals with Obesity Class II or Class III those are unsuccessful in reducing their initial weight goals in 6 months. The least intrusive surgical technique is called adjustable gastric banding (AGB), which entails encircling the stomach's fundus with an inflated silicone band to form a tiny pouch. The band's diameter can be changed by adding or removing saline via a subcutaneous port(Dyson, 2010).Hormones and intestinal anatomy are unaffected by this limiting surgery. At three years, AGB causes a median weight loss of about 15.9% of starting weighA strong, permanent inhibitor of pancreatic and stomach lipases, orlistat lowers the systemic breakdown of fats from food by 30%. A 3 kg weight loss or a 3% greater reduction in bodyweight than when a placebo is consumed is the result of randomized clinical trials. Along with delaying diabetes, improving glycaemic control in diabetic patientsand considerably lowering systolic and diastolic blood pressure, it also decreasedcholesterol and low density lipoprotein levels independently of body weight lossCognitive-behavioural therapy, or CBT, has been the most widely used psychological intervention. It typically seeks to link the traits between the three aspects of thoughts, feelings, and behaviours. The method modifies nonadaptive habits using both behavioural and cognitive strategies(Snitker et al., 2009). CBT has been shown to be helpful in lowering BMI and waist circumference, particularly in children and adolescents, as well as in enhancing eating behaviours, psychological healthand self-esteem. ACT has shown promise in treating adult obesity.Preliminary research suggests that it will probably be both practical and acceptable to adult obesity it is more feasible and acceptable it is potential empirically(Mead et al., 2017).

6. KEY NUTRACEUTICALS FOR OBESITY MANAGEMENT

Several nutraceuticals exhibit anti-obesity properties and offers natural way to manage weight and related health complications. Below is an overview of key nutraceuticals and their roles in combating obesity.

6.1Curcumin

Curcumin, a yellow compound from turmeric (*Curcuma longa*, family Zingiberaceae)is widely known for its health benefits, particularly in managing inflammation—a major contributor to obesity and

metabolic disorders(Manjunatha & Srinivasan, 2006).Curcumin targets inflammatory pathways by interacting with cyclooxygenase-2 (COX-2), cytokines (e.g., TNF-α), and other molecules involved in insulin resistance. It also modulates transcription factors like AP-1, STAT proteins, and PPARγ, while inhibiting enzymes such as CYP-450 and UDP-glucuronosyltransferase (Shehzad et al., 2012).

6.2 Bottle Gourd (*Lagenaria siceraria*)

Bottle gourd, a member of the Cucurbitaceae family, contains essential nutrients, including vitamins, minerals, and fiber.Bottle gourd (*Lagenaria siceraria*) helps manage obesity by reducing calorie intake with its low-calorie, high-water content and fiber, promoting satiety. It improves cholesterol levels, lowering total cholesterol and LDL while boosting HDL, supporting heart health. Its antioxidants combat oxidative stress, and its diuretic properties reduce bloating. Additionally, its anti-inflammatory effects improve insulin sensitivity, reduce inflammation, and lower the risk of obesity-related conditions like type 2 diabetes(Cicero & Colletti, 2016).

6.3Fenugreek (*Trigonellafoenum-graecum)*

Fenugreek seeds, rich in galactomannans, steroidal sapogeninsand diosgenin, helps in reducing plasma glucose and cholesterol levels. Fenugreek polysaccharides absorb water, forming viscous solutions that slow glucose absorption in the stomach, helping manage blood sugar and cholesterol levels.Pregnant women should avoid fenugreek due to its uterine-stimulating properties(Das et al., 2012).

6.4 Amla (*Emblica officinalis*)

Amla, widely used in traditional Indian medicine, contains antioxidants that combat oxidative stress and age-related hyperlipidaemia.Regular consumption lowers cholesterol and triglyceride levels while increasing HDL cholesterol.Amla (*Emblica officinalis*) helps manage obesity through its antioxidant, anti-inflammatory, and lipid-regulating properties. It lowers cholesterol, triglycerides, and LDL while boosting HDL, supporting cardiovascular health. Amla also reduces inflammation, improves insulin sensitivity, and helps regulate blood sugar levels, preventing fat accumulation. Its high fibre content promotes satiety, aids digestion, and supports gut health, while enhancing liver function and detoxification. These combined effects make amla an effective natural supplement for weight management and metabolic health(Nijhawan & Behl, 2020).

6.5 Curry Leaves*(Murraya koenigii)*

Curry leaves are rich in antioxidants and possess anti-inflammatory, hypoglycaemicand hepatoprotective properties.Curry leaves reduce gluconeogenic enzyme activity and enhance hepatic glycogen levels, aiding in blood sugar regulation(Cicero & Colletti, 2016).

6.6 Black Gram (*Vigna mungo*)

Black gram, a protein-rich legume, supports cardiovascular health, diabetes management, and weight regulation.It produces satiety, delays carbohydrate absorption by inhibiting α-amylaseand helps maintain healthy body weight.

6.7 Green Tea (*Camellia sinensis*)

Green tea, containing catechins like epigallocatechin gallate (EGCG), is globally consumed for its weight-reducing properties. It reduces body weight and cardiovascular risk factors and increases fat oxidation and improves insulin sensitivity(Wang et al., 2010). Green tea helps manage obesity by harnessing the power of catechins, especially EGCG, which naturally boost metabolism and promote fat burning. These compounds enhance thermogenesis allowing the body to burn more calories even when at rest. Additionally, green tea improves insulin sensitivity, which helps reduce fat storage and supports weight loss(Sae-tan et al., 2011).Its antioxidant fight oxidative stress and inflammation together contributes to obesity. By regulating blood sugar levels and aiding in fat breakdown, green tea serves as a powerful, natural ally in maintaining a healthy weight and supporting overall metabolic health(Thielecke&Boschmann, 2009).

6.7 Capsaicin

Capsaicin, found in chili peppers, is a secondary metabolite with potential anti-obesity effects.Regular consumption of capsaicin reduces fat accumulation and supports weight management. Capsaicin, the compound found in chili peppers, supports obesity management by naturally boosting metabolism and increasing fat burning. It helps the body burn more calories, even while at rest, by enhancing thermogenesis. Capsaicin also aids in breaking down stored fat and curbing appetite by influencing hormones that regulate hunger. Furthermore, its anti-inflammatory effects may help reduce the chronic inflammation often linked to obesity. By promoting fat loss, increasing calorie expenditureand preventing fat buildup, capsaicin serves as a powerful, natural tool in managing weight and supporting overall health(Rains et al., 2011).

6.8 Calcium-Rich Foods

Calcium from milk, yogurt, and cheese helps regulate body weight by reducing fat mass and promoting a healthier metabolic state.

6.9 Psyllium Fibre

Psyllium fibre, extracted from plant seed husks, reduces LDL cholesterol and supports heart health.

6.10 Bitter Melon *(Momordicacharantia*)

Bitter melon is rich in flavonoids with antiviral and anti-inflammatory properties. It reduces fat deposition, enhances insulin sensitivity and prevents obesity progression (Nijhawan & Behl, 2020).

6.11 Ginger Components

Active components in ginger, such as 6-gingerol and 6-shogaol, have anti-inflammatory effects(HAN et al., 2005). Ginger reduces triglycerides and LDL cholesterol while increasing HDL levels, promoting weight loss and combating inflammation(Das et al., 2012).

6.12 *Carallumafimbriata*

This traditional Indian plant is known for its appetite-suppressing properties.Pregnane glycosides reduce hunger and food intake, leading to weight reduction and fat deposition control(Ammendola& Scotto d'Abusco, 2022).

6.13 *Garcinia cambogia*

Garcinia cambogia supports weight loss through multiple mechanisms, primarily driven by its active compound, hydroxycitric acid (HCA). HCA inhibits the enzyme ATP-citrate lyase in the liver, reducing the production of acetyl-CoA, a critical molecule for fat synthesis. This inhibition decreases the formation of fatty acids, cholesterol, and triglycerides, leading to reduced fat storage. Additionally, lower acetyl-CoA levels result in decreased malonyl-CoA, which enhances fat oxidation and promotes fat burning, particularly during physical activity. HCA also impacts appetite regulation by increasing serotonin levels in the brain, potentially curbing hunger and enhances the feeling of fullness. These combined effects help in reduced food intake, lower body fat and supports overall weight management. Beyond its weight-loss benefits, *Garcinia cambogia* extract demonstrates other health-promoting properties, including improved blood sugar control, anti-inflammatory activity, and potential anticancer effects. These attributes make it a versatile nutraceutical for obesity management and metabolic health(Haber et al., 2018).

7. TOXICITY CONCERNS OF NUTRACEUTICALS

Nutraceuticals, often derived from natural sources, are generally perceived as safe and beneficial for promoting health and wellness. However, their growing use has highlighted concerns regarding potential toxic effects. Unlike pharmaceutical drugs, nutraceuticals often lack comprehensive safety testing, leading to uncertainties about their risks. Toxicity can arise from the properties of the active ingredients, contamination, or interactions with medications. This section examines the sources, mechanismsand strategies for managing nutraceutical toxicity(Aggarwal, 2010).

7.1 Sources of Nutraceutical Toxicity

Toxic effects associated with nutraceuticals can arise from a variety of factors, including:

7.1.1 Contamination

Heavy Metals: Contamination with lead, mercury, cadmium, or arsenic can occur during cultivation or manufacturing. These metals pose significant health risks,including damage to the nervous system (neurotoxicity), kidneys (nephrotoxicity), and an increased risk of cancer.
Pesticides and Mycotoxins: Residues of pesticides or fungal toxins like aflatoxins and ochratoxin A can contaminate herbal supplements. These contaminants are associated with liver damage, immune suppression, and carcinogenic effects.
Microbial Contamination: Poor storage and handling may result in bacterial or fungal contamination, leading to infections or digestive issues.

7.1.2 Adulterants

Some products are intentionally mixed with pharmaceutical drugs or banned substances to enhance their effects, potentially causing severe side effects.Example: Weight-loss supplements adulterated with sibutramine, a prohibited substance have been linked to cardiovascular complications.

7.1.3 Quality Control Issues

Inconsistent manufacturing practices, including incorrect dosing or lack of standardization, can result in product variability and unexpected toxic effects.

7.2 Inherent Toxicity of Nutraceutical Ingredients

Certain nutraceuticals contain natural compounds that may cause harm, particularly when consumed in excess or by vulnerable populations.

7.2.1Plant-Derived Compounds

Ephedra (*Ma Huang*): Contains ephedrine alkaloids that can lead to cardiovascular issues such as high blood pressure, rapid heartbeatand even fatal events.
Ginkgo Biloba: Contains ginkgolic acids and ginkgo toxins, which may cause spontaneous bleeding, seizures, and liver toxicity.
Aloe Vera: Non-decolorized aloe vera contains anthraquinones, which have genotoxic properties and have been linked to cancer in animal studies.
St. John's Wort: Interferes with the metabolism of certain drugs by activating liver enzymes, potentially altering the drugs' effectiveness or increasing their toxicity(Taroncher et al., 2021).

7.2.2 Marine and Animal-Derived Products

Fish Oils: While beneficial in moderate amounts, excessive omega-3 fatty acid intake may increase bleeding risks and weaken the immune system.
Green Tea Extracts: High doses of catechins like epigallocatechin gallate (EGCG) have been linked to liver and kidney toxicity in some animal studies.

7.3 Interactions with Medications

Nutraceuticals can alter how therapeutic drugs are absorbed, metabolizedor eliminated, potentially leading to adverse effects.Examples:Ginseng: Enhances the effect of blood-thinning medications, increasing the risk of bleeding.Grapefruit Juice Inhibits liver enzymes, causing certain drugs to accumulate to toxic levels.

7.4 Vulnerable Populations

Certain groups are more prone to experiencing toxic effects from nutraceuticals:
Pregnant Women and Foetuses: Ingredients like caffeine or bitter melon may cause miscarriages or developmental issues.

Elderly Individuals: Aging affects metabolism, and the use of multiple medications increases the likelihood of harmful interactions. Children's underdeveloped detoxification systems make them particularly vulnerable to adverse effects from nutraceuticals(Booth et al., 2005).

7.5 Managing and Preventing Nutraceutical Toxicity

To minimize the risks associated with nutraceuticals, several measures can be implemented:
Regulation and Quality Control:Adopting standardized manufacturing practices and rigorous quality checks can help reduce contamination and adulteration risks.Regulatory frameworks, such as those in the European Union for herbal medicines, ensure that products are safe and effective.
Pharmacovigilance: Continuous monitoring of adverse effects and toxicities can help identify and address high-risk products(Bose et al., 2008).
Education and Awareness: Healthcare providers and consumers should be educated about proper dosing, potential interactions, and warning signs of toxicity.
Advanced Testing Methods: Using biomarkers and laboratory models to predict toxicity can help identify risks early and ensure safer products.

8 REGULATORY ASPECTS OF NUTRACEUTICALS IN OBESITY MANAGEMENT

8.1 Regulatory Entry Requirements in India

Its objectives include creating economically viable systems, ensuring fair trade between states and internationally, harmonizing well-being, and protecting consumer's health. The nutraceutical sector has two major challenges: regulatory uncertainty and the credibility of labelling claims. Regulatory Entry Requirements in India(Jose et al., 2024).The Food Safety and Standards Authority of India (FSSAI) serves as the sole regulatory agency overseeing the production, delivery, and marketing of nutraceuticals in India. Established under the Food Safety and Standards Act2006, FSSAI plays a crucial role in ensuring that nutraceutical products meet safety and quality standards to protect public health. The number of nutrient contents should not be higher than the Indian Council of Medical Research's (ICMR) Recommended Dietary Allowance (RDA). The usage of licensed additives and colouring agents are allowed as per the schedules, as permitted in the food safety and standards regulations 2011(Inbathamizh et al., 2022).

8.2 Regulatory requirements for evaluation of the product

- Construction& authentication of samples of records by the concerned body
- Collecting samples
- Sample dispatch by the authorized body
- Food testing and analysis
- Proceeding in adjudication

Packaging and Labelling: Articles 23 and 24 outline the specifications for nutraceutical packaging and labelling, including limitations on the claims and advertising that these products may make. Claims pertaining to the treatment, prevention or cure of particular illnesses or ailments are prohibited.A clear list of ingredients, the health benefits claimed, with evidence to support them. A statement clarifying that the product is not designed to diagnose, treat, or cure obesity.A warning or advisory statement, especially if there is a risk of side effects or interactions with medications(Bansal & Dhiman, 2019).Nutritional information, including calorie content, serving size, and key nutrients. GMP Compliance: Nutraceuticals must be manufactured according to stringent quality control standards. Safety: The products must be safe for consumption, with no harmful side effects, and clinical trials may be and necessary for certain claims(Rippe, 2018).

8.3 Regulation process

- Submit the form under form A to the state licencing authority of the registration of the site.
- The request shall deal with for a limit time of seven days by the body.
- Inspection is done for 30 days and the site acceptance is done and if not of the proposal.
- Manufacture must request for manufacturing licence in the form and within 60 days Application number is issued.
- Queries shall be communicated within 60 days on the incomplete application.

- After 30 days approval or deny of the licence is done.

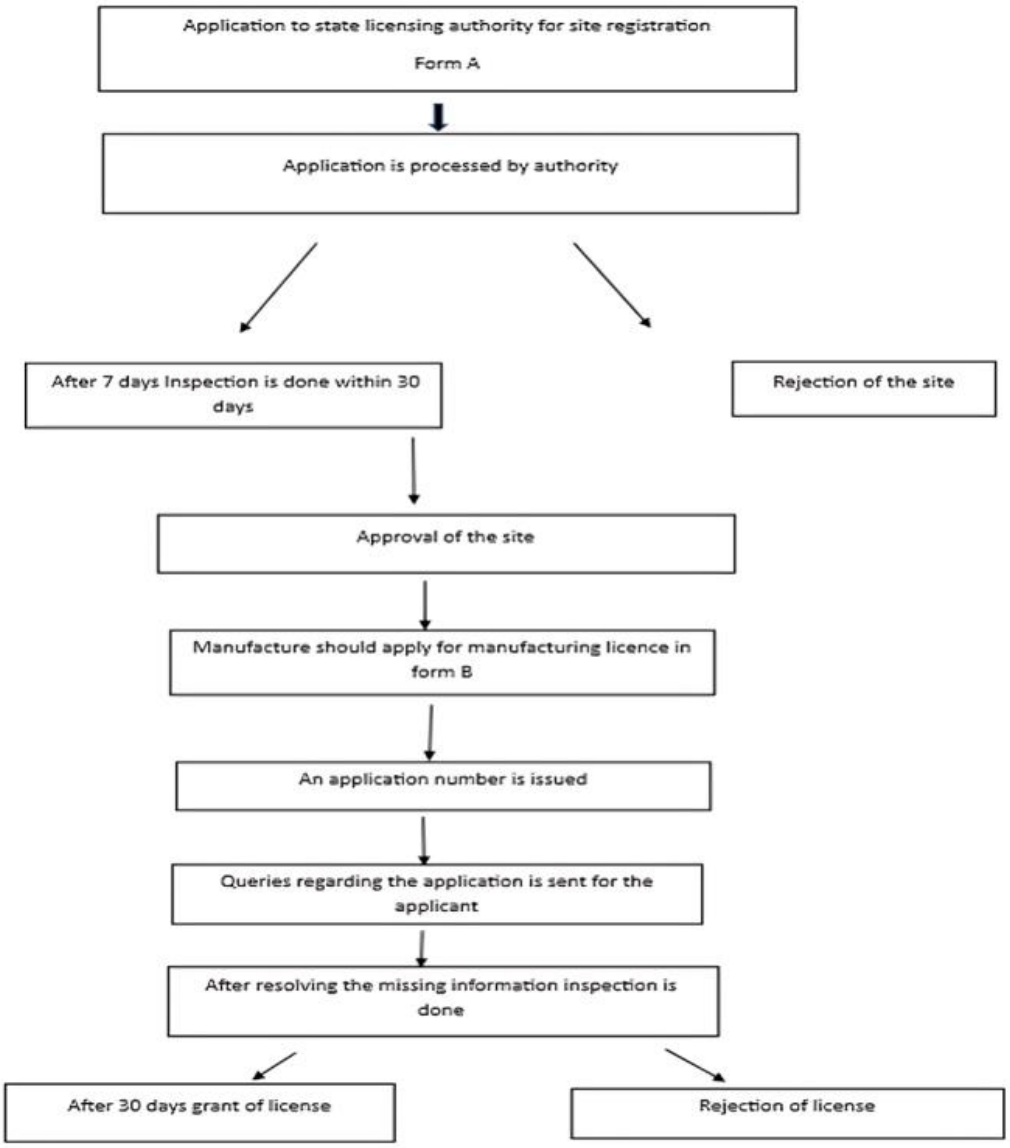

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Fig. 5. Regulation process of Nutraceuticals in India

9 MARKETED NUTRACEUTICALS FOR OBESITY MANAGEMENT

These nutraceuticals are designed to aid in weight management by boosting metabolism, improving fat oxidation, and addressing appetite regulation.

Table 7: Marketed Nutraceuticals for Obesity management

Products	Key ingredients	Manufacturer
Capsimax	Capsaicinoids (from chili peppers)	OmniActive Health Technologies
MetaVive	Salacia extract	OmniActive Health Technologies
CurcuWIN	Curcumin	OmniActive Health Technologies

10 Future Aspects

The growing prevalence of obesity highlights the need for innovative and integrative solutions, including the use of nutraceuticals. Moving forward, promoting lifestyle changes alongside the use of nutraceuticals or FDA-approved weight-loss medications could play a crucial role in reducing the risk of obesity-related conditions such as diabetes, hypertension, fatty liver, and sleep apnea. Early intervention with nutraceuticals may help prevent the progression of these serious health issues. Future research should focus on understanding the complex interactions between nutraceuticals, food, and medications to optimize their effectiveness and safety. Additionally, the impact of various processing and delivery methods on the bioavailability and efficacy of nutraceuticals must be explored. Consumer education on the link between diet and health will also be critical to drive demand and ensure informed choices. To fully integrate nutraceuticals into obesity management, it is essential to implement stricter regulations, similar to those for pharmaceuticals, to ensure the safety, consistency, and efficacy of these products. These measures will pave the way for nutraceuticals to become a reliable and effective tool in combating the global obesity epidemic.

11 CONCLUSION

This review underscores the pivotal role of nutraceuticals in managing obesity and its associated metabolic dysfunctions. Compounds such as curcumin, green tea extract, psyllium fibre**,** omega-3 fatty acids, fenugreek, bitter melon, and capsaicin demonstrate significant therapeutic potential by targeting various pathways linked to obesity. These nutraceuticals work through diverse mechanisms, including reducing inflammation, enhancing insulin sensitivity, regulating appetite, improving gut health, and promoting fat oxidation.Innovations like nanoparticle-based delivery systems have further amplified the bioavailability and efficacy of these compounds. However, despite their promising benefits, nutraceuticals face challenges such as variable absorption, inconsistent outcomes, and a lack of standardized formulations. To bridge these gaps, rigorous clinical studies, personalized formulations, and strong regulatory frameworks are essential. Nutraceuticals, when integrated with lifestyle modifications such as balanced diets, physical activity, and behavioural therapy, provide a sustainable and natural approach to combating obesity. As research progresses, the synergistic potential of combining multiple nutraceuticals could unlock new opportunities for obesity management, paving the way for a healthier and more sustainable future in combating this global health crisis.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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