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THE IMPACT OF COFFEE BIOACTIVE COMPOUNDS ON OBESITY: MECHANISMS AND CLINICAL PERSPECTIVES

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ABSTRACT

Coffee is globally consumed and contains bioactive compounds such as caffeine and chlorogenic acids, which may have the potential to act on body weight mechanisms. This review will summarize the current evidence on the effects of coffee consumption on human obesity risk. Several observational studies have reported that an increase in coffee intake is associated with a decrease in BMI and waist circumference, especially in men. These changes may have been brought about by thermogenesis, fat oxidation, changes in appetite, glucose and lipid metabolism, and altered gut microbiota. However, these studies conflict with each other, possibly due to varying types of coffee, preparation methods, and population characteristics. Overall, moderate coffee intake appears to help indirectly in obesity prevention; yet, more studies assessing these effects and the mechanisms that can be involved are necessary.

Aim of study: The given sources consider the potential interaction between coffee consumption and either the development or prevention of obesity from a human-oriented perspective. Emphasis is placed on how the bioactive compounds, particularly caffeine and chlorogenic acids, affect bodily parameters linked to weight regulation and fat metabolism, while a few of these physiological effects may relate to appetite and the metabolism of gut microbiota.

Materials and methods: The review is based on a comprehensive analysis of current literature, including clinical trials and observational studies. PubMed and Google Scholar databases were consulted using keywords related to coffee, caffeine, chlorogenic acids, obesity, metabolism, appetite regulation, and gut microbiota to retrieve relevant articles.

KEYWORDS

Caffeine, Coffee, Obesity, Metabolic Syndrome, Adiposity

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1. Introduction

Coffee, primarily from Coffea arabica and Coffea canephora, is one of the most widely consumed beverages in the world. It contains several bioactive compounds, such as caffeine, chlorogenic acids, diterpenes, and polyphenols [1]. More recently, besides the composition of coffee, there is a greater focus on possible health effects, mostly concerning chronic non-communicable diseases [2].

Thus, the coffee weight control mechanism and the resistance potentially offered against obesity have constituted one of the domains of study. Caffeine remains the prime candidate for active substance; other substances include chlorogenic acids, trigonelline, and melanoidins. These substances have antioxidant, anti-inflammatory, and metabolism-regulating activities [3,4]. It is suggested that drinking coffee would affect thermogenesis, appetite, the activity of fat cells, and the gut microbiome, all of which are linked with obesity of various kinds [4,5].

A very interesting thing about caffeine, the most familiar stimulant present in coffee, is that it also exists in some other food products and medicines, such as tea, cocoa, energy drinks, dietary supplements, and, less potently, in over-the-counter drugs like analgesics and decongestants [6].

The present article attempts to summarize current research evidence on coffee and its bioactive constituents with obesity development in humans. Focus will be placed on mechanisms involved in these effects on the biological system, observational studies, and randomized controlled trials with results [4,5,7].

2. Materials and methods

A literature review of studies published from 1990 to 2025 in the PubMed database analyzed clinical trials, meta-analyses, and systematic reviews on the effects of coffee consumption and its bioactive compounds on obesity, using the following keywords: "coffee"; "obesity"; "thermogenesis"; "caffeine"; "chlorogenic acids"; "fat metabolism".

3. Results

3.1 Definition and Pathophysiology of Obesity

Obesity is a chronic condition in which fat is excessively accumulated in the body to a degree that presents a serious health hazard. The condition is most commonly assessed in clinical practice via the body mass index, or BMI, calculated as the weight in kilograms divided by the height in meters squared (kg/m²) [8]. Worldwide, obesity has become one of the most important public health challenges of the twenty-first century. The World Health Organization (WHO) considers a BMI of 30 or above to be obese [8]. The major drawbacks of using BMI include that it does not differentiate between fat and lean mass, an important factor in considering metabolic risk. Another consideration is fat distribution [9].

Thus, to make up for these deficiencies in BMI, other anthropometric indices have been developed and are used in clinical practice and research settings. One of the most widely accepted of these is the waist-to-hip ratio (WHR), which is obtained by dividing the waist circumference by the hip circumference. A WHR greater than 0.90 in men and greater than 0.85 in women is considered a sign of abdominal (visceral) obesity and predisposes one to a greater risk of metabolic syndrome and cardiovascular diseases [9]. Waist circumference alone, as well as waist-to-height ratio, are used to measure central adiposity, especially when assessing cardiometabolic risk.

The prolonged imbalance between energy intake and energy expenditure is the cause of obesity. Such an imbalance may arise from genetic predispositions or behavioral aspects, such as a sedentary lifestyle and eating habits; nonetheless, several external factors may come into play, such as socioeconomic status and access to healthy food [10]. Biologically, the processes involved in the development and maintenance of obesity are related to impaired thermogenesis mechanisms; dysregulated control of hunger and satiety; increased diameter and multiplication of adipocytes; and a changed composition of gut microbiota [10, 11].

In contrast, adipose tissue also functions as an endocrine gland, in addition to its role in energy storage. It synthesizes numerous adipokines, including leptin, adiponectin, and resistin, which all influence appetite, insulin sensitivity, lipid metabolism, and inflammation [12,13]. The disordered secretion of adipokines in obesity leads to chronic low-grade inflammation and insulin resistance, type 2 diabetes, and other associated diseases [12, 13].

3.2 Thermogenesis and the role of coffee compounds

Thermogenesis is the process of heat generation by the body, representing one of the major ways for maintaining energy balance. Approximately 10% of the daily energy expended in a human body is from thermogenesis, with many factors influencing this process, diet being one of them [14].

Caffeine, the active principle in coffee, has been conclusively proven to produce thermogenic effects. Its activity has been described as the stimulation of the central nervous system to release catecholamines, primarily norepinephrine, which subsequently activate brown adipose tissue (BAT) to carry out lipolysis and heat generation [15, 16]. A piece of investigation undertaken by Astrup et al. in 1990 through a randomized, double-blind, placebo-controlled study showed that caffeine administration increased the resting metabolic rate and the rate of fat oxidation among healthy adults [15]. Thermogenesis could have possibly occurred since the RMR values recorded were higher after caffeine ingestion in the subjects than after administration of a placebo.

According to Tajik et al., the main components of coffee, next to caffeine, were chlorogenic acid and polyphenolic compounds, from which different effects on metabolic processes have been reported [3]. The chlorogenic acids, as they stated, would then be enhancing insulin sensitivity and decreasing fat accumulation through glucose metabolism; these arguments make it reasonable to conclude that chlorogenic acids may contribute to decreasing the possibility of becoming obese by stimulating fat oxidation and coordinating metabolic efficiency.

Combined, caffeine and chlorogenic acids exert a synergistic thermogenic effect. Hursel et al. [17] showed that caffeine combined with green tea extract (which contains catechins) produced a greater increase in fat oxidation than either constituent alone. Thus, there comes an implication that these polyphenolic substances can raise the thermogenic action of coffee, thus boosting the idea of coffee as a potential agent for weight management.

Coffee contains caffeine and chlorogenic acids, affecting thermogenesis, primarily through increased energy expenditure and fat oxidation [18]. These effects are very subtle, but combined, they can aid in weight loss potential. These are very subtle effects, but in conjunction, they can be beneficial for weight-loss potential. Coffee has long been in the limelight as a metabolism-enhancing drink, particularly when consumed as part of a balanced diet; however, more studies are required to clarify long-term effects [19].

3.3 Modulation of Adipocyte Function by Coffee Bioactive Compounds

Adipocytes, or fat cells, play an essential role in energy storage and metabolic control. They absorb excess energy in the form of triglycerides and release fatty acids and glycerol when lipolysis breaks down fat. Dysfunction of adipocytes causes obesity, in which excessive fat accumulation occurs if lipolysis is blocked or fat storage is overstimulated. [20]

Dulloo et al. (1989) reported that the fat oxidation response was more intense in lean subjects and also in obese persons; thus, undoubtedly, caffeine stimulates lipolysis and the release of free fatty acids for utilization as energy [21]. This fat-directing mechanism becomes important for persons who have a higher percentage of body fat across the spectrum, since it helps to liberate and utilize that stored fat.

Chlorogenic acids present in coffee exist in fairly large quantities and may interfere with glucose metabolism in adipocytes. These polyphenols may prevent fat formation in adipose tissues and hence may pose some form of insulin sensitization. Tajik et al. (2017) referred to a preferential fat prevention effect of chlorogenic acids through increased glucose uptake in muscle cells. This means that little fat would normally be stored in excess in adipocytes. This would suggest that chlorogenic acids may inhibit fat formation and thus may be relevant for people predisposed to some kind of obesity-associated metabolic disorder [3].

Chlorogenic acids and caffeine work in tandem to affect adipocyte function. According to Lee et al. (2023), the goal of the researchers was to distinguish between the combined effect of caffeine and chlorogenic acids in coffee and the effect of these ingredients when they act separately. This finding reveals that caffeine and chlorogenic acids, together in coffee, exert slight benefits in body-fat reduction when compared with either compound alone. Caffeine is said to induce lipolysis, while chlorogenic acids influence glucose metabolism and thus may affect whether adipocytes store fat or utilize their stored fat in tissues [4].

Basically, one can say that the caffeine and chlorogenic acids in coffee could somehow influence the functioning of an adipocyte while possibly assisting in lipolysis and fat metabolism [22]. These effects could help coffee protect against obesity if combined with a good diet and a regular exercise regimen.

3.4 Appetite Regulation

Appetite regulation involves multiple coordinating factors: hormones, neural forces, and the gastrointestinal system. Dysregulation of appetite control predisposes the individual to the development of obesity; that is, an individual may start consuming an excessive amount of food. Coffee and its bioactive compounds affect appetite through various mechanisms, especially caffeine and chlorogenic acids.[23]

Caffeine is one of the most widely studied constituents found in coffee and, in some ways, has been considered an appetite suppressant. A few studies report an inverse relationship between caffeine intake and the feeling of hunger and food intake. For example, in a double-blind, placebo-controlled study by Roch et al. (2009), the participants appearing to receive caffeine before a meal had lower ratings of hunger and calorie intake when compared to those who received a placebo [24]. The mechanisms by which caffeine could reduce hunger are believed to involve an action on the central nervous system, whereby caffeine increases the concentrations of some neurotransmitters, such as serotonin and dopamine, that are involved in satiety and appetite regulation.

Chlorogenic acids found in coffee may also regulate appetite. These compounds are known to regulate the secretion of hormones involved in hunger mechanisms, like ghrelin and peptide YY. Ghrelin is an appetite-stimulating hormone, whereas peptide YY facilitates feelings of fullness. Tajik et al. (2017) showed that chlorogenic acid decreased the plasma concentration of ghrelin while stimulating the secretion of peptide YY, which could potentially minimize hunger and reduce food intake [3]. This may suggest that the chlorogenic acids present in coffee can positively affect the regulation of appetite and thus may make coffee an effective aid in weight control.

Apart from caffeine and chlorogenic acid, it also influences gastrointestinal microbiota. Due to changes in the gut microbiome affecting hunger and satiety, it has been said that coffee modulates this. According to Mills et al. (2020), this modulation of the gut microbiota by coffee had protective effects on metabolic health and appetite control [5]. Although the mechanism is yet to be clarified, it is thought that coffee's disruption of the gut microbiome can influence the mechanisms behind appetite regulation.

To conclude, caffeine and chlorogenic acid undergo different digestion patterns by gastrointestinal hormones and digestive microbiota, which affect the capacity of the stomach to stimulate appetite. Coffee is a good appetite suppressant and satiating drink, so it may be useful in the control of appetite and subsequent weight regulation.

3.5 Coffee-Derived Bioactives in the Regulation of Gut Microbiota and Obesity

The gut microbiome consists of trillions of microorganisms inhabiting the human digestive tract, carrying out various roles in digestion and metabolism, as well as other vital functions for our well-being. It has been proposed that an alteration in the bacterial composition of the gut microbiota leads to obesity and other metabolic disorders. The latest research, however, reveals that coffee and some of its bioactive compounds may alter metabolic outcomes by shaping the gut microbiome [25]

Coffee consumption is related to a greater variety and number of good gut bacteria. A study involving over 22,000 participants showed that drinking coffee regularly, including decaffeinated ones, was positively associated with levels of Lawsonibacter asaccharolyticus, an antioxidant organism formed by quinic acid, which combats oxidative stress and inflammation [26]. This indicates that some of the polyphenols present in coffee, maybe chlorogenic acid, could have prebiotic functions that help in promoting the growth of beneficial gut bacteria.

Chlorogenic acid, the primary polyphenol found in coffee, was said to promote the population of gut microflora in some models of stomach conditions [26]. In obese mice rendered obese by a high-fat diet for about a month, weight reduction, along with an improvement in lipid profile, was noted at the administration of chlorogenic acid. It was noted that there was an increase in beneficial bacterial groups like Bacteroidaceae and Lactobacillaceae, and a decrease in harmful types, such as Desulfovibrionaceae [27]. Most of the changes in the microbial community were related to enhanced metabolism and decreased inflammation.

Caffeine is yet another constituent of coffee that affects the gut microbiome. According to a study, offering caffeine to mice fed a high-fat diet ameliorated insulin resistance and adjusted the composition of the gut microbiota. Beneficial bacteria, such as Dubosiella and Bifidobacteria, were increased, while the presumably hazardous ones, such as Bacteroides and Lactococcus, were decreased. These changes were also reflected in positive variations in serum metabolomics, lipid, and bile acid metabolism [28].

Further synergistic actions of chlorogenic acid and caffeine have also been explored. The combined treatment reduces weight gain, reduces adipose tissue, and disrupts lipid metabolism in synergy with obesity. The effects correlate with AMPKα-LXRα/SREBP-1c pathway activation, which codes for the working of both substances in regulating lipid metabolism and energy homeostasis [29].

To conclude, the gut interaction with coffee and its bioactive components, primarily chlorogenic acid and caffeine, triggers changes that favor a healthy metabolic profile, less inflammation, and probably some beneficial effects of weight control. In keeping with metabolic health, coffee may be taken with other gut-friendly foods as a complementary approach.

4. Discussion and conclusions

Review studies suggest that coffee has an influence, particularly due to its bioactive compounds, including caffeine and chlorogenic acids, on several mechanisms considered in obesity development. So, while it is highly unlikely that a cup of coffee can induce dramatic weight loss, its influence, when compounded with other lifestyle choices like a balanced diet and some physical exercise, definitely should not be underestimated.

Probably the most well-known way in which coffee has traditionally been linked with obesity reduction is thermogenesis. Here, the body burns calories in the production of heat. It is believed that both caffeine and chlorogenic acids affect thermogenesis and, in the process, fat oxidation. An increase in energy expenditure, therefore, may work against weight gain as time goes on, particularly if this energy expenditure comes through an acceleration of fat oxidation, a mechanism that is indeed involved in the thermogenesis of coffee. Weight loss through this method, however, is very limited and only temporary. In the research of Astrup et al. (1990), caffeine tended to increase a person's basal metabolism and fat-burning capacity, and might have very little effect on fat loss unless combined with other factors [15].

Another point to be considered is the effect of coffee on adipocyte function. So, caffeine stimulates lipolysis, breaking down fat stored in adipocytes, whereas chlorogenic acids may slightly prevent fat formation by promoting glucose metabolism. This means that the two substances aid in the breakdown of fat for energy and prevent it from being stored in the body. Incidentally, more studies are needed to understand whether caffeine, chlorogenic acids, and coffee substances work together towards the physiological functioning of adipocytes [21].

The coffee influence on appetite regulation also deserves some focus. Caffeine has worked as an appetite suppressant for years - it reduces hunger and encourages less food consumption, at least temporarily, by stimulating neurotransmitters such as serotonin and dopamine that are involved in satiety and appetite regulation [28, 30]. Chlorogenic acids modulate gut hormones, such as ghrelin and peptide YY, which are

involved in hunger and satiety. They do reduce ghrelin and thereby increase peptide YY secretion, assisting in the regulation of appetite and food intake [3].

Another impact of coffee on one's figure may be influenced by its effect on the gut microbiome. Gut microbes assist in metabolism and appetite regulation, and overall metabolic health of the body. Based on recent developments, coffee was believed to influence the gut microbiome positively by increasing the number of beneficial bacteria and decreasing that of harmful bacteria [5].

For example, Freeze-dried coffee extract administration in high-fat diet-induced obese rats has shown increased population of Bifidobacterium spp and decreased population of Escherichia coli in their guts [31]. When acid chlorogenic compounds act on the improvement of microbial diversity, this leads to the enhancement of the metabolic status and a reduction of inflammation [32].

In conclusion, coffee may affect several pathways of obesity due to active substances in it, including thermogenesis, fat metabolism, appetite, and the gut microbiome [33] Overall, the effects of coffee on weight loss are minimal, and on-and-off consumption can be incorporated as part of a healthy lifestyle to help control weight. Further investigations need to be carried out to obtain a clearer picture of the long-term effects of coffee consumption on obesity and its strategic implications in obesity management [34, 35].

5. Disclosure

Author's Contribution

- Conceptualization: Iwona Górnicka, Magdalena Rosiewicz, Urszula Kierepka, Marcin Durowicz
- Methodology: Sylwia Bartolik, Anita Janda, Aleksandra Pastuszek
- Software: Magdalena Rosiewicz, Aleksandra Minda
- Formal analysis: Iwona Górnicka, Aleksandra Pastuszek, Jan Drzymała
- Investigation: Marcin Durowicz, Anita Janda
- Writing - rough preparation: Urszula Kierepka, Aleksandra Minda
- Writing - review and editing: Jan Drzymała, Aleksandra Minda
- Supervision: Magdalena Rosiewicz, Karolina Bieńkowska, Sylwia Bartolik, Marcin Durowicz

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