



International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

Dolna 17, Warsaw,
Poland 00-773
+48 226 0 227 03
editorial_office@rsglobal.pl

ARTICLE TITLE

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ARTICLE INFO

Julia Kuszneruk, Katarzyna Krzemińska, Maria Kubas, Julia Czerwik, Patrycja Felisiak. (2025) A Narrative Review: Impact of Dietary Polyphenols on Metabolic Syndrome Management. *International Journal of Innovative Technologies in Social Science*. 3(47). doi: 10.31435/ijitss.3(47).2025.3689

DOI

[https://doi.org/10.31435/ijitss.3\(47\).2025.3689](https://doi.org/10.31435/ijitss.3(47).2025.3689)

RECEIVED

23 July 2025

ACCEPTED

03 September 2025

PUBLISHED

11 September 2025

LICENSE



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A NARRATIVE REVIEW: IMPACT OF DIETARY POLYPHENOLS ON METABOLIC SYNDROME MANAGEMENT

Julia Kuszneruk

Medical University of Lublin, Poland

ORCID ID: 0009-0001-5508-5027

Katarzyna Krzemińska (Corresponding Author, Email: krzeminskakasiaa@gmail.com)

Medical University of Lublin, Poland

ORCID ID: 0009-0004-4988-7295

Maria Kubas

Medical University of Lublin, Poland

ORCID ID: 0009-0005-1306-9132

Julia Czerwik

Medical University of Lublin, Poland

ORCID ID: 0000-0001-7241-194X

Patrycja Felisiak

Medical University of Lublin, Poland

ORCID ID: 0009-0004-4968-0331

ABSTRACT

Introduction and purposes: Metabolic syndrome includes central obesity, insulin resistance, dyslipidemia, and hypertension. Studies have explored polyphenols for their potential to prevent or manage these issues through antioxidant and metabolic effects.

Materials and Methods: A comprehensive literature review was carried out utilizing PubMed and Google Scholar. The search incorporated keywords such as 'polyphenols', 'metabolic syndrome', 'visceral adipose tissue', 'insulin resistance', 'hypertension', 'atherogenic dyslipidemia'. The search included articles published from 2020 to 2025.

Results: Although many studies suggest that polyphenols may help to manage central obesity, the effects of polyphenols on carbohydrate metabolism, blood pressure and lipid profiles are inconsistent and inconclusive. These conflicting results are probably due to small sample sizes and a lack of robust, high-quality human clinical trials.

Conclusion: The review indicates a potential connection between dietary polyphenols and the individual elements of MetS, highlighting the need for further investigation in this area. Overall, due to the variability in study design and sample size, conclusions should be interpreted with careful consideration.

KEYWORDS

Polyphenols, Metabolic Syndrome, Visceral Adipose Tissue, Central Obesity, Insulin Resistance, Hypertension, Atherogenic Dyslipidemia

CITATION

Julia Kuszneruk, Katarzyna Krzemińska, Maria Kubas, Julia Czerwik, Patrycja Felisiak. (2025) A Narrative Review: Impact of Dietary Polyphenols on Metabolic Syndrome Management. *International Journal of Innovative Technologies in Social Science*. 3(47). doi: 10.31435/ijitss.3(47).2025.3689

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Introduction and purpose

In recent decades, significant transformations in global health trends, eating behaviors, and lifestyle patterns have been observed. These include an increased consumption of energy-dense foods and sugar-laden drinks, alongside a growing prevalence of sedentary lifestyles and diminished levels of physical activity. The growing rates of overweight and obesity, along with associated chronic illnesses such as cardiovascular disease and type 2 diabetes (T2D), are no longer issues limited to adults. These health problems are now being reported more frequently among children and adolescents as well. Consequently, recent years have seen a marked rise in the incidence of metabolic syndrome (MetS), with estimates indicating that by 2020 it affected around 3% of children, 5% of adolescents, and more than 20% of the adult population.[1,2,3]

Metabolic syndrome (MetS) is a widespread yet often overlooked condition that significantly strains global public health. Defined in 2009, its diagnosis requires at least two of the following: elevated waist circumference (population-specific), triglycerides ≥ 150 mg/dL, low HDL cholesterol (< 40 mg/dL in men, < 50 mg/dL in women), systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg, and fasting glucose ≥ 100 mg/dL. [4] MetS is clearly linked to an increased likelihood of developing serious cardiovascular events such as heart attacks, strokes, thrombotic complications, and sudden cardiac death.[5,6,7,8,9] Although the exact causes of metabolic syndrome remain unclear, strong evidence points to physical inactivity and poor dietary habits as key contributors to its development. [10] Polyphenols are a diverse group of plant-based compounds that have attracted increasing interest from researchers due to their ability to reduce oxidative stress and modulate inflammation. They may also help to prevent chronic conditions such as obesity, type 2 diabetes, cardiovascular disease and hypertension. [11,12,13]. Polyphenols are a structurally diverse group of phytochemicals classified into flavonoids and non-flavonoids; the latter includes phenolic acids, lignans, and stilbenes, while flavonoids share a core structure of two aromatic rings linked by a heterocyclic ring and are further divided into subgroups like flavones, flavonols, isoflavones, flavanones, anthocyanins, and flavanols (catechins). In plant-based foods, polyphenols often exist in conjugated forms—bound to sugars, acids, or alcohols—and can also form complex structures like tannins, which include hydrolysable types (from ellagic and gallic acids) and condensed forms (procyanidins from catechins). These compounds are widely found in fruits, vegetables, tea, coffee, red wine, cocoa products, whole grains, and even some food processing by-products. [14,15,16,17]

This review aims to explore how dietary polyphenols affect different aspects of metabolic syndrome, highlighting their potential role in its prevention and management, especially since no definitive cure currently exists.

Methods

A structured literature review was conducted using databases such as PubMed and Google Scholar. The search strategy involved the use of targeted keywords, including: polyphenols, metabolic syndrome, visceral adipose tissue, insulin resistance, hypertension, and atherogenic dyslipidemia, to ensure a comprehensive assessment of the relevant scientific literature. Studies published between 2020 and 2025 were prioritized, though seminal works frequently cited in the field—published prior to this period—were also considered. Eligible materials included peer-reviewed articles, case reports, and case series that investigated the effects of polyphenols in individuals with metabolic syndrome components, as well as experimental studies involving cellular and animal models. Only articles published in English were included in the final analysis.

Central obesity

Central obesity, a key factor in the development of metabolic syndrome, has been steadily increasing since the late 20th century and is projected to affect up to 55.6% of adult men and 80.0% of women worldwide by 2030. [18] A distinguishing factor between metabolically healthy and unhealthy individuals with obesity lies in the degree of visceral adipose tissue (VAT) accumulation, which plays a decisive role in metabolic stability or dysfunction. [19,11]

The mobilization of free fatty acids from adipose tissue plays a significant role in the development of insulin resistance by disrupting normal insulin signaling pathways. Additionally, this process negatively affects pancreatic beta-cell function, leading to a reduction in insulin secretion.[20] Increased concentrations of free fatty acids interfere with glucose uptake in skeletal muscle tissue, while concurrently promoting hepatic gluconeogenesis and lipid synthesis via the activation of specific protein kinase pathways. The coexistence of insulin resistance and elevated circulating fatty acids is strongly implicated in the pathogenesis of hypertension, enhanced thrombotic risk, and persistent low-grade inflammation.[21] VAT secretes numerous biologically active substances, including pro-inflammatory cytokines and metabolic mediators such as C-reactive protein,

leptin, and resistin. These molecules contribute to the maintenance of chronic low-grade inflammation, a condition that is believed to play a central role in the pathogenesis of various complications associated with metabolic syndrome.[22] In this context, polyphenols have attracted considerable scientific interest due to their potential modulatory effects on adipose tissue metabolism. Evidence from in vitro studies and animal models suggests that polyphenols may exert anti-obesogenic properties through multiple mechanisms, including the inhibition of adipocyte differentiation, stimulation of fatty acid oxidation, suppression of lipogenesis, and enhancement of thermogenesis and overall energy expenditure.[23,24,25,26,27,28,29]

In the 18-month DIRECT-PLUS trial by Zelicha et al., 294 participants were assigned to one of three diets—healthy dietary guidelines (HDG), a traditional Mediterranean diet (MED), or a green Mediterranean diet (green-MED)—all combined with physical activity; while both MED groups consumed 28g of walnuts daily (~440 mg polyphenols), the green-MED group also consumed 3–4 cups of green tea and a duckweed shake (~800 mg additional polyphenols) while limiting red meat. The green-MED group achieved over twice the reduction in visceral adipose tissue (VAT) compared to the other groups, a result associated with increased levels of plasma polyphenol metabolites like hippuric acid and greater urinary excretion of urolithin A. [30] A randomized clinical trial involving 70 women with metabolic syndrome examined the effects of green tea consumption, with participants assigned to either a green tea group (200 ml, three times daily) or a control group consuming warm water over eight weeks. Compared to the control, the green tea group showed significantly greater reductions in body weight, BMI, waist circumference, and waist-to-hip ratio, alongside assessments of diet, physical activity, blood pressure, glucose, and lipid profiles. [31] Adding to this body of evidence, Kiyimba et al. conducted a meta-analysis involving 2,494 adults with metabolic risk factors (mean age 53.3 years) to assess the impact of polyphenols on cardiometabolic health. The findings showed that polyphenol supplementation, especially in purified extract form, led to a significantly greater reduction in waist circumference—around 3.04 cm—compared to polyphenols from whole food sources. [32] Further evidence on the role of polyphenols in modulating adiposity comes from animal and cellular studies. For instance, Chong Tian et al. examined the effects of green tea polyphenols (GTPs) on fat accumulation and adiponectin levels in rats subjected to a high-fat diet. Their results demonstrated that GTPs were effective in reducing fat deposition and reversing the decline in adiponectin concentrations, a hormone closely linked to insulin sensitivity. Moreover, in vitro experiments confirmed that GTPs could counteract the suppression of adiponectin expression triggered by high glucose levels in visceral adipose tissue. [33] Complementing these findings, Jung Yeon Kwon et al. conducted an in vitro study investigating how resveratrol, a polyphenolic compound, affects adipose tissue at the cellular level. The results showed that resveratrol induced apoptosis in mature fat cells, halted their proliferation through cell cycle arrest, and suppressed preadipocyte differentiation and fat synthesis in a dose-dependent manner. These findings underscore the complex molecular actions of polyphenols on fat tissue regulation. [34]

In conclusion, existing research suggests that polyphenol supplementation may offer therapeutic benefits in addressing CO as part of dietary interventions. However, the overall strength of this evidence remains limited, primarily due to the small sample sizes in human studies and the relatively low number of high-quality clinical trials conducted to date.

Insulin resistance

Type 2 diabetes (T2D) is a chronic metabolic disorder that poses a growing global health burden. More than two decades ago, the International Diabetes Federation (IDF) published the first edition of its Diabetes Atlas, estimating that approximately 151 million adults worldwide were affected by this condition.[35]. By 2019, the number of individuals diagnosed with T2D had escalated to approximately 463 million globally, representing nearly a threefold increase in prevalence over the past two decades. [36] Polyphenols have been shown to modulate carbohydrate metabolism through mechanisms such as safeguarding and restoring pancreatic beta-cell function, promoting insulin release, and improving glucose utilization efficiency [37]. Furthermore, multiple studies have suggested that consumption of polyphenol-rich fruits may potentiate the therapeutic effects of metformin in managing T2D [38, 39, 40]. Furthermore, inflammatory cytokines worsen insulin resistance in skeletal muscle, liver, and adipose tissue by interfering with the insulin signaling pathways in these organs. Notably, tumor necrosis factor-alpha significantly contributes to the development of insulin resistance by inactivating insulin receptors within skeletal muscles. [41] Insulin resistance, in turn, promotes the activation of inflammatory cytokines and increases blood clot formation through elevated fibrinogen concentrations. [42] Insulin resistance (IR) contributes to microvascular damage, thereby increasing susceptibility to conditions such as endothelial dysfunction, heightened vascular resistance, hypertension, and

inflammation of the vascular endothelium. Damage to the endothelial lining disrupts vascular homeostasis and may promote the development of atherosclerosis and the onset of hypertension.[43] In a prospective cohort study by Bondonno et al., 54,787 Danish adults (median age 56) were tracked for a median of 20.8 years, during which 6,700 developed diabetes; participants in the highest flavonoid intake quintile (~1,202 mg/day) had 1.52 kg less body fat and a 19% lower diabetes risk compared to those in the lowest quintile (~174 mg/day), with fat reduction explaining 57% of this association. Higher intake of flavonoid subclasses—including flavonols, flavanol monomers, oligomers/polymers, and anthocyanins—was linked to reduced diabetes risk across all demographic and lifestyle groups, with the strongest benefits observed in individuals with obesity. [44] In an eight-week randomized controlled trial by Fatemehbanoo M. et al., 70 women aged 40–70 with metabolic syndrome (per IDF criteria) were assigned to consume three daily 200 ml cups of green tea containing 12.6% polyphenols, resulting in a significant reduction in blood glucose levels—an outcome that contrasts with findings from some earlier studies. [45] In contrast, Bajerska J. et al. Conducted a study involving 55 obese men and women, supplementation of rye bread with green tea extract (GTRB) was assessed for its impact on weight loss, maintenance and metabolic syndrome markers, but the findings showed no significant difference in blood glucose levels between the GTRB group and those consuming regular rye bread. [46] A similar conclusion was reached in a separate study by Basu A. et al., which examined the effects of green tea beverages and extracts over eight weeks in 41 obese adults diagnosed with MetS. This study reported no significant alterations in fasting blood glucose, insulin resistance, or HbA1c levels compared to the control group. [47] The inconsistency between these findings and those reported by Fatemehbanoo M. et al. could potentially be explained by the fact that baseline fasting blood glucose levels in the studies by Bajerska J. et al. and Basu A. et al. were lower than those observed in the Fatemehbanoo M. et al. trial. In a six-week study by Stull et al. involving 32 obese, insulin-resistant (non-diabetic) individuals, those who consumed blueberry polyphenol-rich smoothies twice daily showed improved insulin sensitivity, while no changes were noted in inflammatory markers compared to the placebo group. [48]

Polyphenols, which are found in many plant-based foods and drinks, may help to improve insulin resistance by supporting glucose uptake and insulin signalling, as well as reducing inflammation. However, more well-designed studies are needed to confirm these effects, establish the optimal intake and provide dietary guidance, particularly for individuals at a higher risk of metabolic disorders.

Hypertension

Hypertension, the leading modifiable risk factor for cardiovascular disease, negatively impacts various physiological systems by increasing vascular resistance and decreasing arterial elasticity, which can lead to peripheral vascular disorders, cardiac remodeling (such as left ventricular hypertrophy and cardiomyopathy), and ultimately impaired kidney function. [49] Despite the availability of diverse therapeutic strategies, achieving optimal BP control remains a significant clinical challenge.[50] A substantial body of research has suggested a possible association between polyphenol consumption and reduced hypertension risk or enhanced regulation of BP. Godos J. et al. conducted a systematic review and meta-analysis of 15 cross-sectional and 7 prospective cohort studies on dietary polyphenols and hypertension risk. While analysis of five cohorts (200,256 participants, 45,732 hypertension cases) showed no overall association between total flavonoid intake and hypertension, higher anthocyanin consumption was linked to a lower risk in specific subgroups. [51] Moreover, other observational research indicated that individuals consuming greater amounts of phenolic acids, such as hydroxycinnamic acids [52,53], as well as phytoestrogens including isoflavones [54,55], were less frequently diagnosed with hypertension. [51] A meta-analysis by Kiyimba et al. found that consuming polyphenol-rich whole foods led to significant reductions in both systolic (3.69 mmHg) and diastolic (1.44 mmHg) blood pressure. Similar benefits were observed when whole foods were combined with extracts. These results suggest that consuming polyphenols in either form may help to lower cardiometabolic risk factors. [32] A meta-analysis by Godos et al. revealed a clear dose-response link between long-term coffee consumption—rich in polyphenols—and reduced hypertension risk. The analysis involved seven cohort studies with 205,349 participants and 44,120 hypertension cases. [56] In their review, Russo et al. explored the potential of quercetin—the most common flavonoid found in the human diet—in preventing various diseases. [57] Their analysis showed that quercetin supplementation had no measurable effect on cardiovascular biomarkers or risk factors when administered to healthy subjects. Conversely, in individuals suffering from hypertension, supplementation with quercetin led to significant reductions in both systolic and diastolic BP. [57,58,59] Notably, similar BP-lowering effects were reported among overweight or obese individuals considered at risk for hypertension. [57] The relationship between polyphenol intake and hypertension was the focus of studies by Grosso et al. and Miranda

et al., who examined Polish and Brazilian populations, respectively. [60,61] Using food frequency questionnaires in tandem with data from the Phenol-Explorer database, both teams assessed the quantity and types of polyphenols consumed by participants. In the Brazilian study, higher intake of certain polyphenol subclasses—such as tyrosols, alkylphenols, lignans, and stilbenes—was significantly associated with a lower prevalence of hypertension. However, this association did not extend to total polyphenol intake, which showed no statistically significant effect. [60] In contrast, in the Polish cohort study found that higher overall polyphenol intake was associated to a 31% reduced hypertension risk in women—but not in men—with hydroxycinnamic acids and flavonoids identified as key protective polyphenol groups. [61]

Although some polyphenols show promise for blood pressure control, a meta-analysis of randomized trials with 577 participants found that hesperidin, a citrus-derived flavanone, did not significantly affect systolic or diastolic BP. [62] A similar pattern was observed with genistein, an isoflavone derived from soy products. Although short-term intake did not influence BP, longer interventions extending beyond six months—particularly in individuals with metabolic syndrome—suggested a potential for improved effectiveness. [63] Resveratrol, a polyphenol from the stilbene group found in red wine and grapes, has also been extensively studied. A comprehensive review and meta-analysis of randomized controlled clinical trials revealed no significant impact of resveratrol on systolic, diastolic, or mean BP. [64] These conclusions were reinforced by Akbari M. et al., who conducted a separate meta-analysis including 28 trials selected from 831 screened publications. While the supplementation led to a measurable increase in flow-mediated dilatation (FMD)—a marker of endothelial function—no significant effect was observed on either systolic or diastolic BP. [65]

Atherogenic dyslipidemia

Dyslipidemia involves abnormal lipid levels—such as high total cholesterol, LDL, or triglycerides, and/or low HDL—and in 2008, the WHO reported that about 39% of adults aged 25 and over had elevated total cholesterol globally. [66] Moreover, research has demonstrated that high circulating levels of LDL cholesterol contribute to over 33% of mortality cases attributed to ischemic heart disease and ischemic stroke. [67] Preclinical studies using in vitro and animal models suggest that polyphenols can modulate lipid metabolism and improve lipid imbalances. This has fuelled interest in their potential to prevent non-communicable diseases. However, despite consistent results in experimental settings, evidence in humans, especially with regard to dyslipidaemia, remains inconclusive, highlighting the need for more robust clinical trials. [68,69] A substantial body of research to date suggests that polyphenol-rich dietary sources may contribute to the reduction of cholesterol concentrations. A critical review by Francis Feldman et al. analyzed 49 clinical trials examining polyphenol intake and lipid outcomes, finding that most showed improvements—especially in cases of hypercholesterolemia, hypertriglyceridemia, MetS, T2D, and postprandial dyslipidemia—often linked to phospholipid-based interventions. However, the review also highlighted inconsistencies across studies, attributed to factors such as small sample sizes, differences in polyphenol types, dosages, intervention durations, and various methodological limitations. [70] In a meta-analysis by Kiyimba et al., purified polyphenol extracts were found to significantly reduce total cholesterol by 9.03 mg/dL and triglycerides by 13.43 mg/dL. However, no significant changes were observed in LDL or HDL levels. Combining data from whole food sources and extracts revealed a consistent reduction in total cholesterol and triglycerides, suggesting that polyphenols may improve lipid profiles regardless of their form. [32] Conflicting results have been reported by two human studies investigating the influence of green coffee extract on cholesterol levels, conducted by Ochiai et al. and Kozuma et al. Notably, the two studies differed considerably in both participant numbers and intervention duration: Ochiai et al. examined a small group of 20 subjects over four months, while Kozuma et al. included a larger cohort of 117 individuals but limited the intervention to just 28 days. Regarding outcomes, Ochiai et al. observed a significant modification in homocysteine concentrations but did not detect statistically significant changes in total cholesterol, HDL, or LDL levels. In contrast, the study by Kozuma et al. demonstrated a significant decrease in total cholesterol, although HDL and LDL cholesterol values remained statistically unchanged relative to baseline measurements [71,72]. Jurgoński A. et al. explored the health effects of a diet enriched with blackcurrant pomace extract, derived from *Ribes nigrum* L., a berry native to temperate regions like Europe and New Zealand. Rich in anthocyanins from the skin and γ -linolenic acid from the seeds, blackcurrants offer antioxidant, phytoestrogenic, and circulatory health benefits. [73–76]. In a four-week study involving 20 white New Zealand rabbits, which were divided into four dietary groups, researchers investigated the impact of incorporating a blackcurrant polyphenol extract (1.5% of the diet) that was high in anthocyanins (48.9%) and flavonols (17.9%) into either standard or high-fat diets. The extract was found to significantly lower serum triglycerides, total cholesterol,

non-HDL cholesterol, and free fatty acids, while also boosting serum antioxidant capacity. [77]. In a human study by Nanashima et al., 12 healthy young women took blackcurrant extract for approximately one month. This resulted in significant reductions in total and VLDL cholesterol levels, as well as a consistent, albeit non-significant, decrease in LDL cholesterol levels. [78].

Conclusions

Recent scientific findings increasingly suggest that polyphenols—natural compounds found in many plant-based foods—may play a supportive role in counteracting several features of metabolic syndrome. Their influence appears to extend across key areas such as abdominal obesity, impaired insulin sensitivity, abnormal lipid profiles, and elevated blood pressure. Mechanistically, polyphenols are thought to modulate metabolic processes by enhancing insulin action, regulating fat storage, reducing inflammation, and improving vascular health.

Although a number of studies point to their potential health benefits, results across clinical trials remain somewhat mixed. This inconsistency is often attributed to differences in research protocols, the diversity of polyphenol sources and forms, as well as the characteristics of study populations. Therefore, while the therapeutic promise of polyphenols is considerable, current evidence is not yet strong enough to formulate universal recommendations. Future high-quality studies involving larger and more diverse populations are essential to clarify their exact role and to determine how these compounds might be best used in the dietary management of metabolic disorders.

Disclosure

Conceptualization, JK, and KK; methodology, JK; software, KK; check, MK, JC, PF; formal analysis, MK; investigation, JC; resources, PF; data curation, JC, MK; writing- rough preparation, PF; writing- review and editing, KK; visualization, JK, KK, MK, JC, PF; supervision, MK; project administration, JK; receiving funding, PF. All authors have read and agreed with the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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