The Influence of Plant-Based Diets on Metabolic Syndrome

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Abstract: The magnification of Western eating habits has contributed to a large increase in the development of several diseases and conditions, namely cardiovascular disease, obesity, dyslipidemia, and hyperglycemia. These are part of a cluster of metabolic factors involved in metabolic syndrome. However, there are new dietary patterns more focused on the consumption of plant-based foods. Thus, the aim of this review was to investigate the impact of plant-based diets on metabolic syndrome and to achieve the inflammatory mediators and the antioxidant effects involved in this potential health benefits effect. Advanced research was performed for articles published in the last 10 years, which were analyzed and selected according to the defined inclusion and exclusion criteria. Of the articles analyzed, the majority supported the positive impact of plant-based diets on metabolic syndrome. Furthermore, several studies also showed that these diets appear to have an anti-inflammatory and antioxidant role. Thus, plant-based diets appear to have health benefits, contributing to the prevention of metabolic syndrome, and improving the cardiovascular and metabolic markers' profile, mainly when including healthy foods. The total exclusion of animal source foods (especially meat and fish) from the diet, as well as the consumption of processed and additive plant-based foods, may contribute to an increased prevalence of metabolic syndrome.

Keywords: plant-based diets; vegan diet; metabolic syndrome; cardiovascular risk; inflammatory biomarkers

1. Introduction

In recent years, the epidemic of chronic diseases has become a growing concern worldwide. Overweight, obesity and metabolic syndrome have seen an exponential increase in their incidence [1]. Specifically, the prevalence of metabolic syndrome in the global population has reached approximately 20–25% while in the Portuguese population it is 43.1%. The occurrence of this syndrome doubles the risk of developing cardiovascular disease over the following five to ten years, increases the lifetime risk of developing type 2 diabetes mellitus (DM2) by five times, and significantly increases the risk of cancer, neurodegenerative diseases, non-alcoholic fatty liver disease (NAFLD), reproductive and vascular pathologies as well as all-cause mortality [1,2].

According to the 2009 consensus of several international societies, metabolic syndrome is defined by the presence of three or more of the following conditions: hyperglycemia, high blood pressure (hypertension), hypertriglyceridemia, low levels of high-density lipoprotein cholesterol (HDL-c) and high abdominal circumference (central obesity) (Figure 1) [2,3].

Physical exercise and diet are modifiable risk factors that play an important role in the prevention and treatment of metabolic syndrome. With the globalization of Western eating habits, fast food, processed foods, refined sugars, and the excessive consumption of red meat have become increasingly common dietary patterns worldwide, contributing to an increase in the incidence of obesity and cardiovascular diseases [4].
Several studies support the positive impact of plant-based diets in the prevention and treatment of metabolic syndrome. Studies performed in rats have shown that plant-based diets (soy diet, gluten–soy mixed diet, hemp seed and bitter vegetable diet) had significant health benefits, by decreasing total cholesterol and triglycerides levels, increasing HDL-c levels, and protecting against age-related metabolic syndrome [6,7]. Furthermore, using obese animal models, oleanolic acid, which is a natural triterpene found in olive oil, fruits and vegetables, and the brown alga Undaria pinnatifida and its bioactive compound Fucoxanthin, can have protective effects on obesity and metabolic disorders, since they have been shown to improve glucose homeostasis, decrease blood pressure, increase HDL-c and have anti-inflammatory actions [8,9]. In epidemiological studies, the positive effects of plant-based diets were shown to reduce abdominal circumference, blood pressure and glycemia. However, their impact on the lipid profile, particularly HDL-c and triglyceride values, remains controversial. These dietary patterns are rich in fruit, vegetables, cereals, nuts, and seeds, with a low-calorie index, low levels of saturated fat, and large amounts of...
These are all possible factors that contribute to the beneficial effects of plant-based diets [3–5,10].

However, the industry has had to adapt to the Westernization of these diets, so several plant-based food products high in carbohydrates, sugar, fat, and other food additives have emerged, such as some vegan equivalents of hamburgers, tuna, and sausages. Therefore, it is important to distinguish between healthy and unhealthy vegetarian diets to correctly study its impact on health and cardiovascular risk [5].

This review aims to explore the impact of plant-based diets on metabolic syndrome and on each of the associated cardiovascular and metabolic markers (hyperglycemia, hypertension, hypertriglyceridemia, low HDL-c levels, and high abdominal circumference). Furthermore, it aims to identify the inflammatory mediators and the antioxidant effects responsible for the impact of these diets. On the other hand, it attempts to explore the harmful consequences that a strict, unhealthy, and unplanned plant-based diet may have.

2. Methods

Advanced research was carried out on PubMed and Scopus with the following MeSH terms “Plant-Based Diets” AND “Metabolic Syndrome”. The results were then limited to the articles published in the last 10 years (until June 2023). This resulted in a total of 325 articles. Based on the selection criteria defined (described below), 303 articles were excluded. The remaining 18 articles were selected after a careful analysis and based on their references, a further 3 articles were added as they met the selection criteria and were available on PubMed and Scopus, despite not appearing in the first search. In total, 21 articles were included.

The inclusion criteria were the following: (1) articles from the last 10 years; (2) clinical trials, case–control studies, retrospective, longitudinal or cross-sectional studies; (3) articles written in English and Portuguese; (4) adolescents, adults or the elderly as the study population; (5) studies that include the analysis of plant-based dietary patterns and their impact on metabolic syndrome; (6) articles analyzing metabolic syndrome parameters, including anthropometric (weight, body mass index (BMI), abdominal circumference), metabolic (insulin resistance, insulinemia, glycemia) and cardiovascular (blood pressure, glycated hemoglobin (HbA1c), total cholesterol (TC), HDL-c, and low-density lipoprotein cholesterol (LDL-c)).

The exclusion criteria were the following: (1) duplicate articles; (2) review articles, systematic reviews and meta-analyses; (3) research projects/protocols; (4) articles published more than 10 years ago; (5) text with restricted access; (6) articles written in languages other than English and Portuguese; (7) research carried out on animals; (8) studies exploring the association between plant-based diets and other variables not listed in the inclusion criteria (e.g., oxidative stress and inflammation, kidney pathology, microbiota, among others).

A second advanced search was carried out on PubMed and Scopus with the following MeSH terms “Plant-based diets” AND “Inflammation Mediators”. The results were then limited again to articles published in the last 10 years (until September 2023). A total of 65 articles were obtained. After a careful analysis according to the selection criteria (described below), 54 articles were excluded. The remaining 11 articles were selected and from the bibliographical references of these, 4 more articles were added that corresponded to the inclusion criteria implemented, making a total of 15 studies. The inclusion criteria selected were the following: (1) clinical trials, case–control studies, retrospective, longitudinal or cross-sectional studies published in the last 10 years; (2) articles written in English and Portuguese; (3) adolescents, adults or the elderly as the study population; (4) studies carried out in vitro; (5) studies that focus on the practice of plant-based diets and inflammation, its biomarkers, and the factors that influence this relationship. Regarding the exclusion criteria selected, these were as follows: (1) duplicate articles; (2) research carried out on animals; (3) review articles, systematic reviews and meta-analyses; (4) research projects/protocols; (5) articles published more than 10 years ago; (6) text with restricted access; (7) articles...
written in languages other than English and Portuguese; (8) articles whose research focus does not correspond to the relationship between plant-based diets and inflammation. This literature review process is schematized in Figure 3.

![Flow diagram of the literature review process.](image)

### 3. Results and Discussion

#### 3.1. The Influence of Plant-Based Diets on Metabolic Syndrome

Of the 21 articles analyzed, 15 supported an association between plant-based diets and decreased metabolic syndrome or its conditions [11–25], and 6 did not register any significant positive association [26–31]; however, 3 of these studies also showed a link between an unhealthy plant-based diet with an increased incidence of metabolic syndrome [24,27,28].

The selected articles analyzed anthropometric (abdominal circumference, weight, BMI, fat mass, waist-to-hip ratio), cardiovascular and metabolic variables (blood pressure, lipid profile, glycemia, HbA1c, insulin resistance) according to the diet of the study population. The diets were determined by applying self-report questionnaires about the food consumed. Based on the questionnaires’ results, some studies [19,22–24,27–29,31] created three different indices to classify the diet of the participants based on the method described by Satija et al. [32,33]. These indices were created according to the food frequency obtained from the dietary data in the questionnaires and assigned positive and reverse scores for each index. The three versions of the plant-based diet are as follows: (1) PDI, plant-based diets not taking quality into account and to which positive scores were given for plant foods and reverse scores for animal foods; (2) hPDI, healthy plant-based diets which included whole grains, nuts, fruits, vegetables, legumes, oils, tea, coffee and to which positive scores were given for healthy plant-based diets while reverse scores were given for less healthy plant-based and animal foods, and (3) uPDI, unhealthy plant-based diets which can include foods such as juices and sugary drinks, refined cereals, potatoes, fried foods, sweets and to which positive scores were given for less healthy plant foods and reverse scores for healthy plant-based and animal foods [32,33]. These indices are described in Figure 4.

Several studies found that individuals who consumed a plant-based diet had lower BMI, abdominal circumference, and blood pressure [11,14,15,17,19] and that a healthy one was related with lower abdominal obesity [23]. This is in line with the results of the meta-analysis carried out by Yokoyama et al. in 2014, in which the 39 studies analyzed registered lower systolic and diastolic blood pressure values among participants who consumed a vegetarian diet when compared to omnivorous participants [34]. When comparing the impact of healthy versus all types of plant-based diets in metabolic syndrome, Jovanovic et al. found 4% reduced risk for increased waist circumference and for the prevalence of metabolic syndrome, with possible protective effects for females over the age of 60 [21].
Also, obese patients with metabolic syndrome subject to a plant protein-based dietary approach to stop hypertension (DASH) diet showed a reduction in systolic blood pressure when compared to animal-based DASH diet [20].

![Plant-Based Diets Indices](image)

**Figure 4.** Classification of plant-based diets and examples of food items in each index, according to Satija et al. [32,33]. (+) symbol represents positive scores; (−) symbol represents negative scores.

When it comes to lipid profile, several authors registered lower TC and LDL-c values among vegetarians when compared to omnivores [14,15,17]. Regarding HDL-c, the results are not consistent, since the studies by Mokhtari et al. and Jafari et al. registered higher HDL-c values in individuals who practiced a plant-based diet [19,22], while Fraser and coworkers found no significant differences in HDL-c values [15] and Gadgil et al. and Chiu et al. found lower HDL-c values among vegetarians [12,14]. The same applies to triglycerides, that were lower among vegetarians in the studies by Mokhtari et al., Navarro et al., and Jafari et al. [17,19,22], but registered no significant differences in the other studies. In line with these results, the meta-analysis carried out by Yokoyama et al., 2017 concluded that, when compared to an omnivorous diet, the vegetarian one is associated with lower TC, LDL-c and HDL-c values, with no variations in triglycerides [35]. Similar results were obtained in a study where the participants underwent a low-fat plant-based diet for 30 days, with significant reductions found for all lipid parameters. Interestingly, some participants diagnosed with metabolic syndrome at the beginning of the study lost this status after the 30-day trial; however, due to HDL-c reduction, others were diagnosed with metabolic syndrome at the end of the study. This led the authors to question the use of HDL-c levels for the syndrome diagnosis in populations that feed on plant-based foods [11].

Many of these studies also found a positive association between vegetable consumption and a better glycemic control [11–14,17–20,22,27]. The mechanism behind these findings might be the intake of polyphenols (organic compounds found mainly in fruit and vegetables) which, besides their anti-inflammatory and antioxidant properties that reduce oxidative stress and improve endothelial function, appear to alter carbohydrate metabolism, particularly sucrose digestion and glucose/fructose transport [13,19,36].

Vajdi and coworkers conducted their study on previously obese adults (BMI between 30 and 40 kg/m²), finding an improvement in anthropometric variables with the adoption of a healthy plant-based diet. However, no changes in other cardiovascular and metabolic markers were found, therefore concluding that there was no association with the incidence of metabolic syndrome [31]. The study conducted by Pandya et al. did not register a significant association between a vegetarian diet in the beginning of adulthood and an
improvement in metabolic parameters years later [30]. On the other hand, Misra and collaborators concluded that a vegetarian diet reduces the DM2 risk in 44% but has no impact on the obesity and metabolic syndrome risk [26]. Health positive effects were also found by Kim et al. that registered a lower hyperglycemia risk with a higher PDI score with no impact of the vegetarian diet in the other parameters [27]. These results are in agreement with those from Shahdadian and co-workers, in which an increased adherence to hPDI was related with decreased hyperglycemia and hypertriglyceridemia [24]. It is important to consider that the studies from Pandya et al. [30] and Misra et al. [26] only analyzed a vegetarian diet versus a non-vegetarian diet, not considering the quality of the food consumed. A poorly planned vegetarian diet rich in unhealthy plant-based foods often results in the intake of nutritionally poor foods, leading to micronutrient deficits, including vitamin B12 that rises homocysteine levels, a well-known independent cardiovascular risk factor [26]. Investigations from three different studies did not find a positive association between different values of the PDI and hPDI indices and metabolic syndrome [24,28,29]. These results support the potential benefits of a plant-based diet regarding the development of metabolic syndrome and may be related to the origin of the studies’ participants. Supporting this theory, the meta-analysis carried out by Benatar and Stewart, 2018 [37] on cardiometabolic risk factors in vegan individuals found a significant difference between the results obtained in studies carried out in Asian populations compared to others. Asians have a very healthy dietary tradition less focused on animal products such as meat, which reduces the differences in the diet quality between individuals practicing plant-based diets and omnivores. Therefore, there seems to be a favorable impact of plant-based diets on cardiovascular risk [37]. In accordance, Park and collaborators also found an inverse association between plant-based diets and the risk of insulin resistance (IR) in an Asian adult population. The authors aimed to analyze the polygenic variants regarding IR and the participants’ lifestyle, showing a connection between IR risk and genes involved in glucose metabolism and oxidative stress. Thus, this population may benefit from an antioxidant plant-based diet rich in fruit, vitamin C and flavonoids [25]. Furthermore, a study conducted by Baudry and co-workers showed that a higher organic food consumption was related with decreased odds of developing metabolic syndrome [38]. According to the studies presented, a plant-based diet may reduce the risk of developing MetS, but the quality of the diet also has an important role in MetS.

Regarding the uPDI index, Mokhtari and collaborators also found a relationship between a higher score on this index and an increased likelihood of adolescents to be metabolic unhealthy obese (MUO) [19]. In adults, two different studies from the same research group registered an approximately 50% increased probability of developing metabolic syndrome with higher scores on the uPDI index [27,28]. Furthermore, it was found that those in the highest quintile of uPDI had a higher calorie intake and a lower intake of potassium, calcium, vitamin A and C [28]. More recently, Shahdadian et al. corroborated these results, considering that a moderate and higher adherence to uPDI were related with metabolic syndrome and increased risk of hypertension, respectively [24]. Unhealthy plant-based diets are rich in added sugars and refined carbohydrates and have a high glycemic index, which produces an increase in postprandial insulin secretion. In addition, high amounts of sugar interfere with lipogenesis, increasing the hepatic production of triglycerides [27]. These mechanisms are involved in the development of obesity, DM2 and hypertension.

The systematic review and meta-analysis carried out by Picasso et al. in 2018 analyzed 71 articles (6 randomized clinical trials, 2 longitudinal studies and 63 cross-sectional studies) about the effects of vegetarian diets on metabolic syndrome and cardiovascular risk markers [39]. Similarly to our review, the study found great heterogeneity of the results between the different studies. None of the studies found an association between vegetarian diets and metabolic syndrome. However, most of the cross-sectional studies found lower values for abdominal circumference, blood pressure, fasting blood glucose and HDL-c among vegetarians [39]. These results resemble the results obtained in this review but,
unlike the present review, the studies included in Picasso’s meta-analysis do not take into consideration the quality of the foods included in vegetarian diets.

There are many variables that are not considered in the mentioned studies that might be responsible for this diversification of results, including the diet composition, the origin of the plant foods consumed, the possibility of containing substances that interfere with endocrine function, particularly obesity (obesogens), the genetic variability of each individual or population, and the impact of microbiota or psychosocial factors such as jobs or associated stress. Many of the studies did not consider the cooking method, which significantly alters the nutritional quality of foods [13,19,30].

Several mechanisms have been proposed to explain the positive impact of plant-based diets on metabolic syndrome, such as the large amount of fiber, micronutrients (potassium, calcium, vitamin A, vitamin C), antioxidants and the large amounts of unsaturated fat present in plant-based foods. In addition, a higher consumption of vegetables reduces the intake of other foods rich in sugar, saturated fat, and iron [19]. Some studies have pointed to their association with a reduction in inflammation [13,19,22,27–29]. Metabolic syndrome is characterized by a pro-inflammatory state, responsible for altering many of the cardiovascular and endocrine parameters that define it. The consumption of plant-based foods appears to have an anti-inflammatory and antioxidant effect, which has been of growing interest to both the scientific community and consumers.

Table 1 summarizes the results of each article.

<table>
<thead>
<tr>
<th>Diet</th>
<th>Metabolic and Cardiovascular Parameters</th>
<th>Results</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low fat plant-based diet for 30 days</td>
<td>Anthropometric data; BP; Lipid profile; FBG.</td>
<td>Decreased levels of BMI, BP, triglycerides, FBG, LDL-c, TC, TC: HDL-c and LDL-c: HDL-c ratios. Some participants diagnosed with metabolic syndrome at the beginning of the study lost this status after the 30-day trial, and others were diagnosed with metabolic syndrome at the end of the study due to HDL-c reduction.</td>
<td>[11]</td>
</tr>
<tr>
<td>Vegetable consumption (quantity and quality of vegetables)</td>
<td>Anthropometric data; Blood glucose; Insulin sensitivity; Acute insulin response.</td>
<td>The youth who consumed more plant-based foods had 39% lower liver fat fraction, 54% lower prevalence of NAFLD and 17% lower visceral adipose tissue, higher insulin sensitivity (by 31%) and lower acute insulin response.</td>
<td>[13]</td>
</tr>
<tr>
<td>Vegetarian and Western diet</td>
<td>Anthropometric data; Lipid profile; Blood glucose; Oral Glucose Tolerance Test; Insulin resistance; Adiponectin.</td>
<td>Vegetarians had better fasting blood glucose and HOMA-IR (homeostatic model assessment for insulin resistance) results. However, vegetarians had lower HDL-c values.</td>
<td>[12]</td>
</tr>
<tr>
<td>Vegan diet Ovo-lacto-vegetarian Pesco-vegetarian Non-vegetarian</td>
<td>Anthropometric data; BP; Lipid profile; Blood sugar.</td>
<td>Vegetarians/vegans were less likely to have hypertension, DM2, hypercholesterolemia (30% of individuals with high TC in the vegetarian/vegan group compared to 48% in the non-vegetarian group), high LDL-c and had a lower BMI and abdominal circumference. No significant differences were found in HDL-c and triglyceride levels between the different diets.</td>
<td>[15]</td>
</tr>
<tr>
<td>Pro-vegetarian diet/ DASH diet/ Mediterranean diet</td>
<td>Anthropometric data; BP; Triglycerides; HDL-c; Glycemia.</td>
<td>Moderate adherence to a Pro-Vegetarian diet was associated with a reduction in the risk of developing metabolic syndrome. This protective effect was more evident among female participants.</td>
<td>[16]</td>
</tr>
<tr>
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<tr>
<td>Vegetarian diets vs. omnivorous diet</td>
<td>Anthropometric data; BP; Lipid profile; Fasting blood glucose.</td>
<td>Decreased levels of WC, BMI, BP, FBG, TC, HDL-c, LDL-c, and TC:HDL-c ratio in vegetarians compared with non-vegetarians. Vegetarian diets showed significant beneficial effects on metabolic parameters, possibly due to the lower BMI of vegetarians.</td>
<td>[14]</td>
</tr>
<tr>
<td>Vegetarian diet vs. omnivorous diet</td>
<td>Anthropometric data; BP.</td>
<td>Vegetarians showed better results in metabolic and cardiovascular parameters (only 3 had a Framingham Risk Score higher than 10 compared to 8 omnivores), and a lower probability of developing metabolic syndrome (15.9%) compared to omnivores (52.3%).</td>
<td>[17]</td>
</tr>
<tr>
<td>PDI</td>
<td>Pre-DM2 and DM2; Insulin resistance.</td>
<td>A diet rich in plant products and low in animal foods was associated with lower insulin resistance and a lower risk of pre-DM2 and DM-2.</td>
<td>[18]</td>
</tr>
<tr>
<td>Vegetarian diet</td>
<td>Anthropometric data; BP; Triglycerides; LDL-c and HDL-c; Glycemia; Lp(a); Homocysteine.</td>
<td>The results showed that a vegetarian diet is a protective factor and reduces the risk of DM2 by 44%, but not the risk of obesity and metabolic syndrome.</td>
<td>[26]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; TC; Triglycerides; HDL-c; Glycemia.</td>
<td>Higher scores on the uPDI index were associated with a 50% greater likelihood of developing metabolic syndrome. Higher scores on the PDI index were associated with a lower risk of developing hyperglycemia.</td>
<td>[27]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; Triglycerides; HDL-c; Glycemia.</td>
<td>Higher PDI or hPDI scores were not associated with a reduction in metabolic syndrome. Higher uPDI scores were associated with a 54% increase in the risk of metabolic syndrome, especially in women.</td>
<td>[28]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; TC; Triglycerides; HDL-c; Glycemia.</td>
<td>No significant associations were found between the different indices and metabolic syndrome or its components.</td>
<td>[29]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; TC; HDL-c; Glycemia; Insulin resistance; BP; Triglycerides.</td>
<td>Higher hPDI index values were inversely related to the probability of being MUO. Higher uPDI indices were related to an increased probability of being MUO.</td>
<td>[19]</td>
</tr>
<tr>
<td>Vegetarian and Non-vegetarian diet</td>
<td>Anthropometric data; BP; Lipid profile.</td>
<td>There was no significant association between a vegetarian diet in early adulthood and improvement of metabolic parameters years later.</td>
<td>[30]</td>
</tr>
<tr>
<td>Plant-based DASH diet vs. Animal-based DASH diet</td>
<td>Anthropometric data; BP; Lipid profile; Glycemia.</td>
<td>Both groups had decreased FBG, SBP, DBP, Triglycerides levels, weight and WC. FBG, SBP levels decreased in Plant-based DASH Diet subjects compared to Animal-based DASH Diet subjects. No associations found for TC, LDL-c, HDL-c.</td>
<td>[20]</td>
</tr>
<tr>
<td>Healthy vs. all types of plant-based diets</td>
<td>Anthropometric data; BP; Triglycerides; HDL-c; Glycemia.</td>
<td>4% reduced risk for increased WC and metabolic syndrome. Protective effects for females above 60 years old.</td>
<td>[21]</td>
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</tbody>
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Table 1. Cont.

<table>
<thead>
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<tbody>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; TC; Triglycerides; HDL-c; Glycemia.</td>
<td>Higher scores on the uPDI index were associated with a higher risk of hyperglycemia. Higher scores on the hPDI index were associated with lower weight, adiposity, and waist-to-hip ratio. However, the PDI and hPDI indices were not associated with a lower risk of metabolic syndrome or its markers.</td>
<td>[31]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; Triglycerides; HDL-c.</td>
<td>Higher scores on the hPDI index were associated with a 28% lower probability of developing metabolic syndrome and a 20% lower risk of abdominal obesity. Higher scores on the uPDI index were not associated with an increased likelihood of developing metabolic syndrome.</td>
<td>[23]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; Triglycerides; HDL-c.</td>
<td>Higher PDI index values were associated with higher HDL-c values (20% lower record of low HDL-c values). Higher values on the uPDI index were associated with lower HDL-c values. Higher values on the hPDI index were associated with a lower probability of developing metabolic syndrome.</td>
<td>[22]</td>
</tr>
<tr>
<td>Korean-style balanced diet (vegetables, fermented foods, meat or seafood), Plant-based diet, Western-style diet, or rice-main diet</td>
<td>Anthropometric data; BP; Lipid profile; Glycemia.</td>
<td>IR mostly associated with BMI, fat mass and metabolic syndrome. Plant-based diet, vitamin C, and flavonoid intake inversely associated with IR risk. Participants with high polygenoc risk score positively associated with IR risk.</td>
<td>[25]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Anthropometric data; BP; Lipid profile; Fasting blood glucose.</td>
<td>Higher adherence to hPDI related with decreased hyperglycemia and hypertriglyceridemia. Moderate and higher adherence to uPDI related with metabolic syndrome and increased risk of hypertension. No association between PDI and hPDI and metabolic syndrome.</td>
<td>[24]</td>
</tr>
</tbody>
</table>

Legend: BMI, body mass index; BP, blood pressure; DASH Diet, dietary approach to stop hypertension diet; DBP, diastolic blood pressure; DM2, type 2 diabetes mellitus; FBG, fasting blood glucose; HDL-c, high-density lipoprotein cholesterol; HOMA-IR, Homeostatic Model Assessment for Insulin Resistance; hPDI, healthy plant-based diets index; IR, insulin resistance; LDL-c, low-density lipoprotein cholesterol; Lp(a), Lipoprotein A; MUO, metabolic unhealthy obese; NAFLD, non-alcoholic fatty liver disease; PDI, plant-based diets index; SBP, systolic blood pressure; TC, total cholesterol; uPDI, unhealthy plant-based diets index; WC, waist circumference.

3.2. Anti-Inflammatory Potential of Plant-Based Diets

Several studies have demonstrated the positive effect of plant-based diets on cardiovascular health, not only by altering cardiovascular risk factors (such as those linked to metabolic syndrome), but also due to their role in the inflammatory state, its biomarkers and in circulating endothelial progenitor cells [36,40]. Therefore, this review intends to correlate the inflammatory mediators and antioxidant effects of the various components of these diets.

The consumption of foods such as fruit, vegetables, olive oil and nuts has been proven to have anti-inflammatory and antioxidant effects. One of the mechanisms of these effects is the presence of polyphenols, which are secondary metabolites of plants and are the most abundant antioxidants in the diet [41,42]. These results were demonstrated by several authors in which a higher urinary polyphenol excretion was related with lower concentrations of plasma inflammatory biomarkers and a higher intake of polyphenols was inversely related to inflammation [41–43]. Furthermore, higher polyphenol intake was also associated with a better overall profile of metabolic syndrome parameters, mainly HDL-c, in an overweight or obese population [44]. These results show that the intake of polyphenols may improve the metabolic syndrome status of both men and women and is a possible therapeutic strategy to lower the incidence of this syndrome.
In 2020, Dugardin et al. sought to investigate the effect of plant protein consumption on reducing the production of inflammatory mediators and inhibiting the production of reactive oxygen species (ROS) by colon epithelial cells. However, the results of this study were inconclusive, with no pro- or anti-inflammatory effects observed for the plant proteins tested [45]. This is in contrast with other studies, where peptides from milk, seitan, eggs, and soy were found to have anti-inflammatory properties [46] and, in a different perspective, abnormal immunity was positively related with metabolic syndrome and negatively with a plant-based diet and physical activity [47].

The etiology of the inflammation associated with obesity is complex, and is characterized by many inflammatory markers, some secreted by adipocytes, called adipokines, others by the liver or leukocytes (C-reactive protein (CRP), interleukins such as IL-6, and transforming growth factor β (TGF-β)) [40,48]. Plant-based diets seem to change the adipokines profile towards an anti-inflammatory balance [40], decreased TGF-β, CRP levels [48,49] and other less known inflammatory biomarkers such as Amyloid A, TNF-related apoptosis-inducing ligand (TRAIL), TNF-related activation-induced cytokine (TRANCE), and C-X3-C motif chemokine ligand-1 (CX3CL1) [50]. Lower BMI associated with plant-based diets appears to play an important indirect role on this anti-inflammatory effect, although a direct relationship between these diets and a reduction in inflammatory biomarkers remains after BMI adjustment [51].

It is known that endothelial progenitor cells enable neovascularization, repair endothelial lesions, and improve endothelial function. A well-functioning vascular endothelium is essential for the prevention of cardiovascular diseases, particularly by reducing the risk of atherosclerosis. Some foods seem to be responsible for increasing the number of endothelial progenitor cells in circulation, such as olive oil, fruit, and vegetables [52]. However, in the study conducted by Cesari and coworkers, a vegetarian diet did not increase the number of progenitor cells in circulation, unlike a Mediterranean diet. This reduction in the vegetarian diet is possibly related with a deficit on B12 vitamin that was associated with higher levels of IL-6, CRP, and oxidative stress [52,53]. Polyunsaturated-n-3 fatty acids (omega-3 PUFA), found mainly in fish, are essential for the function and bioavailability of endothelial progenitor cells [52]. Vegans and vegetarians consume small amounts of omega-3 PUFA and great amounts of omega-6 PUFA. The study performed by Yu et al. found that vegetarians had much lower levels of omega-3 fatty acids in plasma and in erythrocytes, as well as leukotriene B4 (LTB4), cyclooxygenase 2 (COX2) and prostaglandin E2 (PGE2), and higher levels of omega-6 fatty acids and IL-6. Omega-3 PUFA appear to have a role in reducing the inflammation and improving the endothelial function [54]. In an attempt to understand if the inclusion of eggs in a plant-based diet could protect against oxidative stress and inflammation, Thomas and co-workers analyzed several oxidation and inflammation biomarkers after 2 weeks of plant-based diet consumption and 4 weeks of an egg and spinach complemented diet. The results showed that the inclusion of eggs led to a reduction in oxidative stress markers and did not increase inflammation, which may be beneficial to attenuate metabolic syndrome symptoms [55].

Trimethylamine N-oxide (TMAO) is an intestinal metabolite linked to atherosclerosis that provides a direct relationship between the microbiota and cardiovascular diseases. Intestinal bacteria produce trimethylamine (TMA) from phosphatidylcholine or carnitine, a nutrient mainly found in animal foods such as meat. TMA is oxidized by liver enzymes and transformed into TMAO [48]. In the article by Smits et al., the excretion of TMAO in the 24 h urine was significantly lower in vegans compared to individuals with metabolic syndrome. Stool transplantation altered the composition of the microbiota in some individuals but did not result in a decrease in TMAO or a change in the signs of vascular inflammation. The authors also found that autologous stool transplantation may have benefits on metabolic health, since the transplanted individuals had an increased production of IL-10 which is an anti-inflammatory cytokine; however, the pro-inflammatory cytokine IL-1β was also increased. If confirmed, this anti-inflammatory effect may be due to the benefit of
some aerobic bacteria present in the microbiota, demonstrating an important role of the microbiota in reducing inflammation [49].

Table 2 summarizes the results of the studies regarding the anti-inflammatory and antioxidant role of plant-based diets and their components.

**Table 2.** Anti-inflammatory and antioxidant effect of plant-based diets and their components.

<table>
<thead>
<tr>
<th>Diet/Diet’s Components</th>
<th>Inflammatory Parameters</th>
<th>Results</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacto-ovo-Vegetarian vs. Omnivorous diet</td>
<td>Serum omega-6 PUFA, omega-3 PUFA, IL-6, LTB4, COX2, PGE2, TNF-α.</td>
<td>Vegetarians had much lower levels of omega-3 fatty acids, LTB4, COX2 and PGE2 in plasma and in erythrocytes, and higher levels of omega-6 fatty acids and IL-6. Omega-3 PUFA appear to have a role in reducing the inflammation and improving the endothelial function.</td>
<td>[54]</td>
</tr>
<tr>
<td>Dietary intake of polyphenols and flavonoids</td>
<td>Using the INFLA-score tool, the degree of inflammation was calculated based on the synergistic effects of several biomarkers (CRP, leukocyte and platelet count and granulocyte/lymphocyte ratio).</td>
<td>A higher intake of polyphenols was inversely related to inflammation (low-grade inflammation-INFLA-score).</td>
<td>[42]</td>
</tr>
<tr>
<td>Vegetarians vs. Omnivores</td>
<td>FBG, HbA1c, lipid profile, Vitamin B-12, oxidative stress, antioxidant enzymes activity, inflammatory markers (hs-CRP, IL-6).</td>
<td>Diabetic vegetarians: Vit B-12 negatively correlated with blood glucose and oxidative stress while positively correlated with antioxidant enzymes activity. Diabetic omnivores: Vit B-12 negatively correlated with inflammation levels.</td>
<td>[53]</td>
</tr>
<tr>
<td>Dietary intake of polyphenols</td>
<td>Inflammatory biomarkers (VCAM-1, ICAM-1, IL6, TNF-α, MCP-1) in circulation and cardiovascular risk factors (BP, lipid profile, glycemia).</td>
<td>Participants with higher urinary polyphenol excretion had lower concentrations of plasma inflammatory biomarkers. There was also a decrease in BP and an increase in HDL-c proportional to the increase in urinary excretion of polyphenols.</td>
<td>[41]</td>
</tr>
<tr>
<td>Lacto-ovo-Vegetarian vs. Omnivorous diet</td>
<td>Serum Adipokines: Leptin and its receptor, Resistin, Vaspin and Visfatin, Omentin.</td>
<td>Vegetarian children had lower leptin and resistin values, as well as higher ratios of anti-inflammatory/pro-inflammatory adipokines.</td>
<td>[40]</td>
</tr>
<tr>
<td>Vegan Diet vs. Non-Plant-Based diet</td>
<td>TMA and TMAO in urine and blood. Cytokine production capacity of peripheral mononuclear cells; aortic inflammation; Microbiota composition.</td>
<td>There were differences in the composition of the microbiota between vegan and non-vegetarian obese individuals. Serum TMAO levels did not vary between the two groups. Greater urinary excretion of TMAO in obese individuals compared to vegan individuals. After fecal microbiota transplantation from vegan to obese individuals, there were no significant changes in the microbiota. There were no differences in aortic inflammation between the two groups. Autologous fecal transplantation resulted in an increase in IL-10 and IL-1β.</td>
<td>[49]</td>
</tr>
<tr>
<td>Non-vegetarian diet (NV); Partial vegetarian (PV); Lacto-ovo-vegetarian (LOV); Strict vegetarian (SV).</td>
<td>BMI; CRP, IL-6, IL-10, TNF-α.</td>
<td>BMI was indirectly associated with the effects of vegetarian diets on inflammatory markers (CRP and IL-6), accounting for 42% (SV), 67% (LOV), 52% (PV) of the association between CRP and diets. The same didn’t apply to the markers IL-10 and TNF-α. Only a direct relationship was found between an SV diet and CRP.</td>
<td>[51]</td>
</tr>
<tr>
<td>PDI, hPDI, uPDI</td>
<td>Liver enzymes; Inflammatory markers (hs-PCR, IL-1β, TGF-β).</td>
<td>Higher values in the hPDI index were related to lower amounts of hs-PCR and TGF-β, reflecting a reduction in inflammation.</td>
<td>[48]</td>
</tr>
</tbody>
</table>
### Table 2. Cont.

<table>
<thead>
<tr>
<th>Diet/Diet’s Components</th>
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<tbody>
<tr>
<td>Ovo-Lacto-Vegetarian diet (VD) vs. Mediterranean (MD)</td>
<td>Endothelial progenitor cells, circulating progenitor cells and circulating endothelial cells; CD34+/CD45−, IL-6, IL-8, MCP-1.</td>
<td>The 2 diets had no effect on endothelial progenitor cells or circulating endothelial cells. However, in the VD phase, there were significant negative changes in the number of circulating progenitor cells. In the MD phase, there were positive changes. These changes were related to a decrease in inflammatory markers in the MD phase.</td>
<td>[52]</td>
</tr>
<tr>
<td>Vegetable proteins</td>
<td>Biological activity generated by plant proteins: modulation of intestinal hormone secretion, angiotensin-converting enzyme, anti-inflammatory and antioxidant activity.</td>
<td>There were no pro- or anti-inflammatory effects of the plant proteins tested, and some lost their anti-inflammatory potential after digestion.</td>
<td>[45]</td>
</tr>
<tr>
<td>Dietary intake of polyphenols</td>
<td>BMI, WC, plasma glucose, HbA1c, HDL-c, triglyceride, LDL-c.</td>
<td>Decreased polyphenols intake in participants with higher BMI than those with lower BMI. Association between polyphenols intake with a better metabolic syndrome parameters, mainly HDL-c.</td>
<td>[44]</td>
</tr>
<tr>
<td>Increased fruit and vegetables’ consumption</td>
<td>Abdominal circumference; BP; CRP, IL-6, IL-8, MCP-1, IL-18, TNF-α, TRAIL, TRANCE, CX3CL1.</td>
<td>Increased vegetable consumption led to a significant decrease in the inflammatory markers TRAIL, TRANCE, and CX3CL1 (p &lt; 0.05). However, there was no change in BP, abdominal circumference or other inflammatory markers.</td>
<td>[50]</td>
</tr>
<tr>
<td>Plant-based diet</td>
<td>BMI, WC, BP, plasma glucose, HbA1c, Lipid profile, Liver enzymes (AST, ALT), immune status indexes (WBC, CRP).</td>
<td>Increased serum CRP levels and WBC counts (reveal an overactivated immunity) positively associated with metabolic syndrome risk and negatively related with a plant-based diet and physical activity.</td>
<td>[47]</td>
</tr>
<tr>
<td>Eggs/spinach in Plant-based diet</td>
<td>WC, BP, triglycerides, HDL-c, FBG. Liver enzymes and CRP. Cytokines (TNF-α, MCP-1, IL-6), total antioxidant capacity, Glycoprotein A, MDA, 8-Isoprostanes, oxLDL, PON-1 activity.</td>
<td>PBD with eggs/spinach led to a reduction in MDA (lipid peroxidation product) and did not increase inflammation. Attenuation of metabolic syndrome symptoms.</td>
<td>[55]</td>
</tr>
<tr>
<td>Dietary intake of polyphenols</td>
<td>Dietary inflammatory index according to the inflammatory biomarkers IL-1β, IL-4, IL-6, IL-10, TNF-α, and CRP.</td>
<td>Urinary total polyphenol excretion is a possible biomarker for the consumption of an anti-inflammatory diet in women.</td>
<td>[43]</td>
</tr>
</tbody>
</table>

Legend: ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; BP, blood pressure; COX2, cyclooxygenase-2; CX3CL1, C-X3-C motif chemokine ligand-1; FGB, fasting blood glucose; HbA1c, glycated hemoglobin; HDL-c, high-density lipoprotein cholesterol; hPDI, healthy plant-based diets index; hs-CRP, high-sensitivity C-reactive protein; ICAM-1, intercellular adhesion molecule 1; IL-1β, -4, -6, -10, -18, interleukin 1β, 4, 6, 10, 18; LDLC, high-density lipoprotein cholesterol; LTB4, leukotriene B4; MCP-1, monocyte chemoattractant protein-1; MDA, malondialdehyde; MIP-1α, -1β, macrophage inflammatory protein-1α, -1β; oxLDL, oxidized LDL; PBD, plant-based diets; PDI, plant-based diets index; PGE2, prostaglandin E2; PON-1, Paraoxonase-1; PUFA, polyunsaturated fatty acids; TMA, trimethylamine; TMAO, trimethylamine-N-oxide; TNF-α, tumor necrosis factor α; TRAIL, TNF-related apoptosis-inducing ligand; TRANCE, TNF-related activation-induced cytokine; uPDI, unhealthy plant-based diets index; VCAM-1, vascular cell adhesion protein 1; WBC, white blood cells; WC, waist circumference.

### 4. Conclusions

The various articles analyzed in this review present some disparity in the results. This might be due to their focus on different populations, representing different eating habits, lifestyles, and genetic factors. Furthermore, some of the articles do not take into account the quality of plant-based diets, which leads to a huge variability in the consumed foods and, therefore, in the results.
Despite this variability, healthy plant-based diets with greater quality of the foods seem to have health benefits, either in animal and human studies, contributing to the prevention and improvement of some parameters of metabolic syndrome, and to the reduction in the pro-inflammatory state and consequent cardiovascular risk. Their role in reducing BMI, abdominal circumference and glycemic control is corroborated by the results of most studies presented. Concerning the lipid profile, these dietary patterns seem to reduce TC and LDL-c, but also HDL-c. Plant-based diets also have a beneficial effect on blood pressure, but most likely through reducing salt intake and increasing potassium intake, rather than by excluding foods of animal origin.

These benefits have a multifactorial and complex etiology. The high consumption of healthy foods such as fruit, vegetables, olive oil and oilseeds, rich in fiber, vitamins, unsaturated fatty acids and polyphenols are the factors that most contribute to the positive impact of these diets. Plant-based diets appear to have an anti-inflammatory role, contributing to the reduction in inflammatory markers such as TGF-β, CRP, Amyloid A, IL-10, IL-6, TRAIL, TRANCE, and CX3CL1, to a better adipokine profile and to changes in the microbiota. The greatest benefit lies in adopting a moderate plant-based diet, since animal foods are a source of vitamin B12 and omega-3 fatty acids, which play a key role in regulating inflammation and vascular function.

The Westernization of plant-based diets appears to abolish their main benefits, turning them into a risk factor for the development of metabolic syndrome. It is therefore essential to plan a plant-based diet correctly, especially in restrictive diet situations, and to monitor and supplement vitamin deficits, such as vitamin B12 deficiency, which is a major cardiovascular risk factor. Furthermore, considering the antioxidant and anti-inflammatory properties of polyphenols, another approach would be to increase the consumption of polyphenol-containing foods. These bioactive compounds have been extensively studied in animal models, demonstrating a reduction in metabolic syndrome symptoms upon a dietary intake of polyphenols, which may help in preventing the onset of the syndrome or its complications [56]. Thus, new studies should be carried out to understand if the beneficial effects of polyphenolic compounds, including resveratrol, quercetin, curcumin, catechin, or other compounds, such as oleanolic acid and Fucoxanthin, could also occur in humans.

This review has some limitations, including the fact that only two databases were used, resulting in a lower number of articles, as well as the cross-sectional typology of most of them, which makes it more difficult to establish a causal connection between plant-based diets and metabolic syndrome.

A small number of narrative and systematic reviews have been published on this subject [10,57,58]. This paper analyses studies that consider the quality of plant-based diets through the different indices used (PDI, hPDI, uPDI), which is not considered in the other review articles on similar topics, possibly influencing the results, as already mentioned. Moreover, most of the articles considered in this review adjust the results to the confounding factors, which improves the quality of the results.

In the future, considering the growing adherence to plant-based diets and to consolidate the scientific evidence on the benefits of these diets, it would be important to carry out longitudinal (cohort) studies with a broad population base to obtain more reliable and consistent results. Furthermore, it would be interesting to carry out clinical trials that explore the most appropriate proportion of plant/animal foods, as well as the most and least beneficial foods, allowing the creation of nutritional plans for the optimization of cardiovascular health.

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