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# Impact of Apple Cider Vinegar on Insulin Resistance and Related Conditions: Benefits, Mechanisms, and Potential Risks - Literature Review

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## Abstract

**Introduction and purpose:** The topic of apple cider vinegar supplementation and insulin resistance is becoming increasingly widespread, especially on the internet, which carries many potential risks. There is a need to understand both how apple cider vinegar reduces insulin resistance and improves metabolic parameters, as well as the potential risks of its use.

**Material and methods:** Medical databases like PubMed, Google Scholar, and Embase were searched for scientific papers on the safety, benefits, mechanisms, and risks of apple cider vinegar in insulin resistance and related conditions. These were analyzed and summarized in a single review.

**State of knowledge:** Apple cider vinegar supplementation contributes to a reduction in insulin resistance, which is reflected in parameters such as decreased postprandial insulin secretion, lower levels of triglycerides (TG) and total cholesterol (TC), reduced fasting glucose, lower HbA1c levels, and supports weight loss, potentially improving insulin sensitivity. In most cases, no adverse effects or serious side effects were observed with doses of 15-30 ml per day. However, potential risks include delayed gastric emptying, exacerbation of gastroesophageal reflux disease (GERD), gastrointestinal disturbances, tooth erosion, although one study suggests that such supplementation may be associated with acute pancreatitis.

**Conclusions:** More research is needed on supplementation, particularly regarding its duration. Another risk is the search for health information online without critically evaluating the content. Weight loss through a proper diet and exercise appears to be key for improving insulin sensitivity, but supplementation may help achieve results in certain patient groups.

**Keywords:** Apple Cider Vinegar, Insulin Resistance, Type 2 Diabetes Mellitus, Public Health

## I INTRODUCTION AND PURPOSE

Insulin resistance is a common problem and may affect up to 46.5% of the world's population. The modern increase in obesity and lack of caloric balance leads to the accumulation of lipids, which contributes to the loss of insulin sensitivity [1][2]. There is an observable trend indicating increased attention and discussion regarding insulin resistance across online platforms. This heightened interest likely reflects growing awareness of its significant impact on public health [3]. Despite significant advancements in understanding insulin signaling pathways, many aspects of these mechanisms remain unclear. A comprehensive understanding of insulin’s actions is crucial for elucidating the development of metabolic syndrome and type 2 diabetes. This complexity stems from the intricate network of pathways involved, including insulin's effects on glucose uptake, lipid metabolism, and cellular signaling processes, all of which play a critical role in metabolic health [4][5]. In states of insulin resistance, a compensatory increase in insulin secretion can exacerbate metabolic dysregulation, leading to further disturbances in glucose and lipid homeostasis. During these states, insulin fails to suppress hepatic glucose production effectively, while simultaneously promoting lipid synthesis. This imbalance contributes to hyperglycemia and hypertriglyceridemia [6]. In this way, it contributes not only to type 2 diabetes but also to hypertension and coronary artery disease, and plays a fundamental role in the pathogenesis and clinical presentation of polycystic ovary syndrome (PCOS) [7][8].

Numerous studies have assessed the role of various supplementation strategies in improving parameters related to glucose metabolism and insulin sensitivity, including green tea, magnesium, vitamin D, and synbiotics. Recently, apple cider vinegar has also gained increasing popularity, although its associations with improvements in metabolic parameters,

lipid profiles, and glycemic levels have been studied for an extended period [4][9][10][11] [12][13]. Apple cider vinegar is a product obtained through a two-step fermentation process and contains acetic acid, usually at a concentration of 5-6%, polyphenols as well as a range of vitamins such as bioflavonoids, beta-carotene, vitamin E, vitamin B1, vitamin B2, vitamin B6, and vitamin C [14][15]. This literature review aims to highlight the potential benefits of apple cider vinegar supplementation, discuss its key effects on insulin and glucose metabolism, and also emphasize the potential risks associated with such supplementation.

## II STATE OF KNOWLEDGE

### 2.1 Mechanisms for improving insulin sensitivity

One of the proposed mechanisms through which apple cider vinegar improves insulin sensitivity is by delaying gastric emptying [16][17]. This effect has been shown to reduce appetite and may also lead to more stable blood glucose levels after carbohydrate-rich meals, thereby reducing postprandial insulinemia and, as a result, inhibiting the development of insulin resistance. Low-glycemic-index diets work in a similar manner, which is why they are promoted for preventing and reducing insulin resistance [18][19]. It has been shown that in healthy individuals with normal body weight, apple cider vinegar reduces postprandial blood glucose levels. This effect is accompanied by a lower insulin release in response to a starchy meal [20]. Similar results were observed in a group of individuals with type 2 diabetes, where the use of apple cider vinegar was associated with significant reductions in postprandial blood glucose, insulin levels, and triglyceridemia compared to the control group. Furthermore, one proposed mechanism of action for apple cider vinegar was identified: it was found to enhance glucose uptake by skeletal muscles when compared to the placebo group [21]. Another study also demonstrated that, compared to the placebo group, individuals with or without insulin resistance who consumed apple cider vinegar exhibited lower insulin levels 60 minutes after a meal. Additionally, insulin sensitivity improved in both individuals with type 2 diabetes and those with insulin resistance, although this effect was more pronounced in the group with insulin resistance [22]. One of the proposed mechanisms for achieving more stable postprandial glycemia is also the inhibition of disaccharide absorption through the suppression of intestinal disaccharidases such as intestinal maltase, sucrase and lactase . [23]

[24]. Additionally, apple cider vinegar may inhibit the activity of lipase in the small intestine, thereby reducing the absorption and digestion of fats, which can lead to an improvement in lipid metabolism [24].

In addition to mechanisms affecting the digestion and absorption of sugars, apple cider vinegar also exerts effects on skeletal muscles and the liver. As demonstrated in animal studies, it transiently inhibits glycolysis, enhances glycogenesis without excessive glycogen synthesis, and promotes glucose uptake for glycogen synthesis. This process is considered a key mechanism in preventing insulin resistance. [25][26]. Another significant action of apple cider vinegar appears to be the reduction of gene expression involved in gluconeogenesis and lipogenesis. This effect is mediated through the activation of AMP-activated protein kinase (AMPK) in the liver [27] .

A distinct mechanism of action for apple cider vinegar is its role in reducing oxidative stress in individuals with dyslipidemia and type 2 diabetes. In a study comparing individuals who consumed apple cider vinegar to a control group, lower levels of malondialdehyde (MDA) were observed. MDA is a potential marker of oxidative stress, which plays a significant role in the development of insulin resistance. The authors suggest that interventions aimed at reducing oxidative stress and oxidative damage are beneficial for improving insulin sensitivity in individuals with insulin resistance and type 2 diabetes [28][29][30].

## 2.2 The advantages of apple cider vinegar supplementation.

### Benefits Achieved in insulin and glucose metabolism

It should be noted that although new studies on the effects of apple cider vinegar on glucose and insulin parameters are still being published, research on this impact dates back to 1988 [4]. However, in modern times, it is possible to conduct increasingly precise studies. For example, a randomized, double-blind, placebo-controlled study published in June 2024, conducted on young adults with overweight and obesity, revealed that after just four weeks of apple cider vinegar supplementation, a reduction in fasting glucose levels was observed. The best results, however, were achieved with 12 weeks of supplementation [31]. A beneficial effect on

reducing fasting glycemia was also observed in the group of patients with type 2 diabetes also in studies where supplementation was compared with a control group [28][32]. A 2023 meta-analysis involving 1,320 adults confirmed that consuming apple cider vinegar may have a beneficial effect on fasting glucose levels, both with supplementation lasting less than 12 weeks and with at least 12 weeks of supplementation [33]. Research also shows that apple cider vinegar has a beneficial effect on reducing postprandial insulin and glucose levels in healthy individuals, as well as in those with insulin resistance and type 2 diabetes [21] [22].

One of the most intriguing aspects appears to be how supplementation can affect HbA1c levels, which reflect average blood glucose over the past 90 days and are used to assess individual glycemic control [34]. Studies in this area have also been conducted, demonstrating that supplementation is associated with a reduction in HbA1c levels in healthy patients and patients with overweight and obesity, as well as those with type 2 diabetes, as confirmed by a meta-analysis encompassing 25 clinical trials. [32][33][35]. At the same time, the same meta-analysis does not reveal any significant impact of apple cider vinegar supplementation on the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), a method used to measure insulin resistance, or on serum insulin levels. [33]. The most noticeable and well-documented changes in parameters following apple cider vinegar supplementation over various periods remain fasting glucose levels and HbA1c, as confirmed by the latest studies, which were not included in the mentioned meta-analysis. [31][32].

**Benefits Achieved in Anthropometric measurements**

Apple cider vinegar may also have a positive impact on weight loss and other anthropometric parameters. A randomized, double-blind, placebo-controlled trial demonstrated that in young adults without diabetes but with excess body weight, supplementation resulted in a reduction in body weight and BMI after 4 weeks. By week 8, there was also a decrease in body fat ratio and the waist-to-hip ratio. The best results, however, were achieved after 12 weeks of supplementation [31]. This is also confirmed by a study where, in overweight/obese individuals, a consistent reduction in BMI was observed over a 60-day supplementation period when taken before meals [35]. Patients with type 2 diabetes, dyslipidemia, or prediabetes also experience benefits in terms of body weight, waist and hip circumference, and BMI [32][36]. Interestingly, a randomized controlled trial involving individuals with

elevated body weight found that, when comparing a group that implemented lifestyle interventions such as exercise and dietary changes with another group that combined these interventions with effervescent tablets containing apple cider vinegar, the addition of apple cider vinegar supplementation was associated with fewer occurrences of issues like abnormal food intake and various digestive problems, including appetite changes, constipation, cravings, and gas, compared to the group without this intervention. However, significant benefits such as substantial reductions in body weight, BMI, waist and hip circumference, and waist-to-hip ratio were observed in both groups after 60 days, suggesting that apple cider vinegar may support achieving the desired effects of exercise and diet when incorporated into a lifestyle intervention [37]. It is undeniable that preventing and treating overweight and obesity are crucial for enhancing insulin sensitivity [38][39].

**Benefits Achieved in Lipid Profile Parameters**

Studies show that consuming apple cider vinegar can have positive effects on lipid metabolism after just 5 weeks of supplementation in individuals with type 2 diabetes, dyslipidemia, or prediabetic conditions. In patients without such health conditions, similar effects have been observed in studies after 8 weeks of supplementation [31][36]. For example, a randomized, double-blind, placebo-controlled trial demonstrated that in young individuals without chronic diseases or medication use but with overweight and obesity, supplementation was associated with a significant reduction in total cholesterol and triglycerides after 8 and 12 weeks of supplementation compared to baseline measurements at week 0 [31]. Studies in patients with type 2 diabetes are also very important. In these patients, a reduction in LDL cholesterol was observed, along with decreases in total cholesterol and triglycerides. However, no effect on HDL cholesterol levels was noted. [21][32][36]. On the other hand, a meta-analysis revealed that consuming apple cider vinegar leads to a reduction in total cholesterol (TC), but a significant decrease in triglycerides (TG) was observed when supplementation lasted more than 12 weeks. Effects such as reductions in TC and TG were also observed in subgroup analyses of patients with diabetes [33].

## 2.3 PCOS

PCOS is a condition affecting 6-20% of women of reproductive age, with approximately 75% of them potentially experiencing insulin resistance, with higher rates observed in women with increased body mass [40][41]. Apple cider vinegar supplementation may also offer benefits in this group by reducing HOMA-IR, leading to improved insulin sensitivity. However, there have been relatively few studies to date regarding apple cider vinegar supplementation in these women [42].

## 2.4 Physical exercise

Regular physical activity offers substantial benefits for glycemic and insulin regulation. Scientific evidence indicates that combining aerobic exercise with resistance training provides the most effective outcomes in this area. This combination leads to significant improvements in weight reduction, waist circumference, diastolic blood pressure (DBP), triglyceride (TG) levels, total cholesterol (TC), as well as glucose and insulin levels in the bloodstream [43]. Structured exercise programs also provide benefits by increasing insulin sensitivity in individuals with type 2 diabetes [44]. A study combining two factors known to reduce insulin resistance—physical exercise and apple cider vinegar—was conducted. The research involved 60 obese women over an 8-week intervention period. Resistance training, apple cider vinegar consumption, and a combination of both had a significant impact on parameters such as reducing resistin, insulin, fasting glucose, and insulin resistance in obese women ($p \leq 0.05$). It should be noted that resistin is an adipokine potentially linking obesity with diabetes, while also activating the endothelium and thereby contributing to the development of cardiovascular diseases in metabolic syndrome. [45] [46]. However, the best results were achieved in participants who combined resistance training with apple cider vinegar supplementation. [47]. The study emphasizes the superiority of combined therapeutic strategies, including physical exercise, and highlights that the best results are achieved by combining physical activity with supplementation.

## 2.5 Risks and side effects

Despite the fact that apple cider vinegar is often associated with improved insulin sensitivity and glucose parameters, it is important to be mindful of the risks tied to its growing popularity,

especially as information spreads on online platforms. The primary concern should be consulting a healthcare professional to ensure there are no contraindications to such supplementation. Moreover, it is crucial not to overlook the importance of other key factors in managing diseases like insulin resistance, such as medications and lifestyle changes. Apple cider vinegar has the important effect of slowing gastric emptying, which, while reducing blood glucose and insulin levels after meals, may have adverse consequences for certain patient groups. For instance, individuals with diabetic gastroparesis or insulin-dependent diabetes may experience worsened glycemic control, as delayed stomach emptying can lead to unpredictable blood sugar fluctuations, complicating the management of insulin therapy [17]. Delayed gastric emptying may also exacerbate symptoms of gastroesophageal reflux, such as burping, which can have a negative impact on this group of patients [48]. Furthermore, urine acidification and changes in bowel movements have also been observed, which appear to be explained by the inhibition of disaccharide digestion in the intestine [49]. There have been reports of a case where a supplement containing apple vinegar might have triggered acute pancreatitis, although there is limited data linking pancreatitis to apple cider vinegar [50]. One study suggests that vinegar, as an appetite-reducing agent, should not be recommended, as its effect is primarily due to reduced appetite, poor tolerance, and nausea resulting from its consumption [20]. Additionally, this supplementation may be associated with tooth erosion, especially when consuming larger amounts of apple cider vinegar than those used in studies, which typically range from 15-30 ml [21][22][28][42][51][52]. The benefits and risks should therefore be assessed individually for each patient, but potential risks should be recognized. Therefore, knowledge about certain limitations related to such supplementation should be disseminated. Despite the described concerns, studies suggest that the risk of side effects from consumption in recommended amounts and in the suggested manner appears to be minimal [21][48].

## III CONCLUSIONS

There are many benefits associated with apple cider vinegar supplementation, with the most proven in studies being the reduction of fasting glucose, lowering of HbA1c, reduction of triglyceridemia and total cholesterol, as well as facilitating weight loss. This indicates that apple cider vinegar may support improved lipid profile parameters, as well as better insulin

and glucose metabolism parameters, especially in patients with type 2 diabetes and insulin resistance.

The average daily dose in studies was 15-30g, although one study suggested that the optimal dose might be 15 ml per day due to a greater effect of apple cider vinegar in lowering TG and TC levels at doses ≤15ml/day. The daily dose is also crucial in terms of potential complications related to excessive intake, such as tooth erosion, which has been observed with the consumption of a glass per day [21][22][28][42][51][52]. An important issue remains the fact that the impact of such supplementation on children has not been thoroughly studied, which is why the authors emphasize that this review applies to the adult population. Despite the rare occurrence of complications in existing studies, a cautious approach should be advocated due to certain side effects triggered by apple cider vinegar supplementation in individuals who are more vulnerable. There is also a lack of research on how long this supplementation can be used safely. Therefore, adverse effects should be well-known, and one should be cautious about information spread on the internet, avoiding following it without consulting a specialist or verifying the source [48]. Given this, the ongoing trend of searching for therapeutic solutions online, frequently without a full understanding of the potential consequences of a particular intervention, is troubling [3]. Introducing such supplementation to reduce insulin resistance and type 2 diabetes should not replace interventions like diet and physical activity for weight loss, as excess body weight plays a major role in the development of insulin resistance and metabolic disorders which are associated with an increased risk of developing cardiovascular diseases [53].

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