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Review

# Vinegar (acetic acid) intake on glucose metabolism: A narrative review

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SUMMARY

Vinegar intake is considered a food item that improves blood glucose in humans. This review aimed to discuss studies that investigated the impact of vinegar intake on the glycemic profile in humans and the putative mechanistic cellular pathways in both human and animal models. A search of literature was performed on the Cochrane, MEDLINE and Web of Science databases for articles published between 1995 and 2018. There is considerable support for vinegar having a positive acute effect on blood glucose levels when combined with carbohydrate-rich meals. Conversely, there are few chronic interventions analyzing the impact of vinegar intake on blood glucose. Based on available evidence, we hypothesize three pathways by which vinegar may improve blood glucose: The inhibition of α-amylase action; increased glucose uptake; and mediation by transcription factors. When evaluating the current body of literature, daily vinegar intake in amounts of ~10–30 mL (~2–6 tablespoons) appear to improve the glycemic response to carbohydrate-rich meals; however, there is a paucity of studies investigating chronic effects of vinegar intake.



## 1. Introduction

For centuries, vinegar has been widely used as a dietary spice and natural remedy for various ailments in folk medicine. Moreover, it is considered a “super food” by laypersons, purported to improve weight loss, digestion and skin quality; so much so that there are even vinegar diets. The earliest report dates back 2300 years whereby Hippocrates (c. 420 BC) used vinegar for wound care [1].

Vinegar is a sour-tasting liquid obtained from the anaerobic conversion of sugars to ethanol by yeasts and aerobic oxidation of ethanol to acetic acid by bacteria. It may be classified in accordance with raw materials ‘grain vinegar’, such as those obtained from rice and wheat, or as ‘fruit’ vinegars, including juices from grape, apple and coconut [2].

Over the past few decades the prevalence of disorders related to glucose homeostasis such as Type 2 diabetes mellitus (T2DM), obesity and nonalcoholic fatty liver disease has dramatically increased throughout most of the world [3,4]. Despite many efforts, the current therapeutic options for the treatment of these disorders remain far from satisfactory, in part due to serious side effects following pharmacologic treatment [5]. Therefore, new compounds with potential preventive and therapeutic effects are continually being sought.

A plethora of benefits have been proposed for the intake of vinegar as a non-pharmacological alternative for subjects with diabetes [1,6,7]. In addition, acetic acid, one of the major components of vinegar, is a potential modulator of glucose metabolism in horses and rodents [8–11]. Hence, the aim of this narrative review is to provide an overview as to the impact of acute and chronic vinegar intake on the glycemic profile.

## 2. Method

A search of literature was performed on the Cochrane, MEDLINE and Web of Science databases for articles published between 1995 and 2018 using the following combinations of keywords: “acetic

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acid blood glucose", "apple cider vinegar", "apple cider vinegar health", "vinegar blood glucose", "vinegar blood insulin", "vinegar diabetes". Human interventions that performed glycemic analyses with vinegar ingestion were included. Moreover, animal studies were included to help elucidate potential mechanisms of action.

## 3. Mechanism of actions in animal studies

Nakao et al. [12] submitted rats to a protocol of exhaustive swimming and observed that immediate post-exercise provision of a combination of acetic acid plus glucose resulted in higher liver glycogen stores than either glucose or acetic acid alone within 2 h after exercise. This finding suggests that consumption of oral acetic acid with glucose can facilitate liver glycogen restoration during the early period of recovery. It should be noted that effects of acetic acid on glycogen repletion were only apparent when simultaneously consumed with glucose, a precursor of glycogen synthesis. Similarly, Fushimi et al. [8] pre-conditioned rats to 7 days of swimming exercise and then, after an overnight fast, submitted them to a 2-h swimming bout. Following the bout, the rodents were fed glucose with or without provision of acetic acid. Results indicated that acetic acid led to a greater preservation of soleus and gastrocnemius glycogen content, and this effect was dependent on the activation of glycogen synthase.

Research by Fushimi et al. [8–10] found that acetic acid decreases the synthesis of the enzymes xylulose-5-phosphate and fructose-2,6-biphosphatase in the liver, and also the ratio of fructose-1,6-bisphosphate to fructose-6-phosphate in skeletal muscle. It hence decreases the activity of phosphofructokinase-1 and hepatic malonyl-CoA (Fig. 1). Furthermore, since malonyl-CoA allosterically inhibits carnitine palmitoyl-transferase, its inhibition provides an increase in the action of carnitine palmitoyl-transferase and consequently in β-oxidation. This increase of hepatic β-oxidation is a possible mechanism that corroborates the results of Kondo et al. [13], who reported a decrease in visceral fat in patients submitted to vinegar intake.

Pan et al. [14] demonstrated that oral administration of acetic acid (10 mL/kg body weight once daily) in mice subjected to 8 weeks of treadmill exercise promoted a greater expression of AMP-activated protein kinase (AMPK), phosphorylated AMPK (pAMPK), peroxisome proliferator-activated receptor delta (PPARδ) mRNA, and peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α) levels in the soleus muscle. Moreover, acetic acid increased myosin heavy chain (MHC) oxidative type I and mixed oxidative-glycolytic type IIa expression, while increasing the IIb isoforms; results indicative of an enhanced endurance exercise capacity. Taken together these findings suggest that both acute and chronic acetic acid ingestion can optimize the restoration of muscle glycogen and increase fatty acid oxidation. The proposed mechanisms are illustrated in Fig. 2.

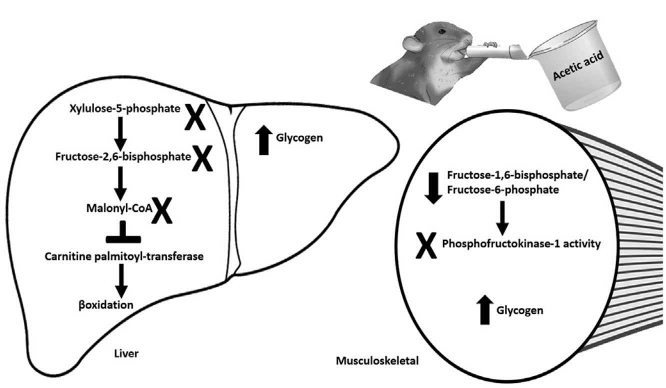


**Fig. 1.** Blood glucose improvement hypothesis through acetic acid action in the musculoskeletal system and liver. Rats fed acetic acid, which is a substance found in vinegars that improves glucose metabolism, exhibit lower glycolysis in the liver and musculoskeletal system, thus improving the glycogen restoration [8–10]. The known glycolysis inhibition by acetic acid in rats is represented by an X symbol.

## 4. Mechanism of actions in human studies

Mitrou et al. [15,16] showed that enhanced stimulation of glucose uptake caused by apple cider vinegar consumption may, at least partly, reduce the need for insulin secretion. To investigate these mechanistic actions, eleven insulin-resistant individuals were randomized to receive either 30 mL of apple cider vinegar or placebo before a test meal consisting of bread, cheese, ham, orange juice, butter and a cereal bar (equivalent to 75 g of carbohydrates). Compared with placebo, results showed that vinegar intake decreased insulinemia, while increasing blood flow and glucose uptake [15]. Several studies corroborate the findings of Mitrou et al., lending support to the hypothesis that the glycemic benefits of vinegar may be attributed to an improvement in glucose uptake [8–10]. Waller et al. (2009) provided horses with a hypertonic sodium acetate-acetic acid solution via nasogastric gavage followed by a typical hay-grain meal (acetate treatment) or a hay-grain meal alone (control treatment) after exhaustive exercise [11]. Acetate supplementation resulted in an enhanced rate of muscle glycogen resynthesis in skeletal muscle during the initial 4 h of the recovery period.

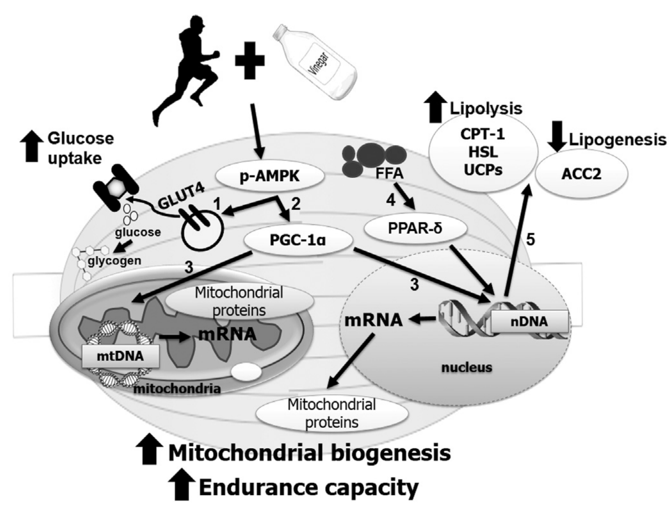


**Fig. 2.** Exercise training, coupled with vinegar intake, may improve glucose uptake and increase expression of genes involved in mitochondrial respiration and fatty acid oxidation [14]. Acetic acid across vinegar may promote fatty acid oxidation, sparing of muscle and liver glycogen utilization during exercise by AMPK stimulation, which optimizes muscle glycogen replacement and enhances glucose uptake after exercise. AMPK phosphorylation/activation results in GLUT4 translocation from intracellular storage depots to the plasma membrane (1) and activation of PGC-1α and its translocation to the mitochondria (2) and nucleus (3). In the mitochondria, PGC-1α activates additional transcription factors, which thereby increases the expression of key mitochondrial proteins involved with mitochondrial biogenesis, potentially culminating in improved endurance capacity. Among lipid pathways, elevated free fatty acids activate the nuclear transcription factor PPAR-δ (4), whereas increased expression of the CPT1, HSL and UCPs proteins, as well as inhibition of muscle ACC2, mediate reduction in the lipogenesis (5). AMPK, AMP-activated protein kinase; HSL, hormone-sensitive lipase; mtDNA, mitochondrial DNA; nDNA, nuclear DNA; pAMPK, phosphorylated AMPK; PGC-1α, peroxisome proliferator-activated receptor gamma coactivator 1-alpha; PPAR-δ Peroxisome proliferator-activated receptor delta; UCP, uncoupling protein.

## 5. Vinegar action during carbohydrate digestion

Given that an alkaline condition is required for optimal carbohydrate digestion [17], the acid properties of vinegar can result in hindered absorption when consumed with a carbohydrate-rich meal (Fig. 3). This is supported by in vitro data showing that a decrease in pH below 4.0 inactivates α-amylase [18]. However, a recent in vivo study found that α-amylase hydrolyzed up to 80% of bread starch in the first 30 min of gastric digestion [19]. Therefore, given that the pH of commercially marketed vinegars is about 2–3 [1,20], its consumption may inactivate the salivary α-amylase action and decrease its release until nutrients reach the small intestine, whose passage is responsible for 30–40% of complex carbohydrate digestion [17]. Furthermore, vinegar acid does not appear to damage the stomach lining, since its pH is less acidic than gastric juice and common acidic beverages (e.g. lemon Juice and Coca-Cola® Classic) (Table 1).

## 6. Acute impact of vinegar intake following carbohydrate-rich meals

Johnston et al. [24] sought to test the hypothesis that vinegar intake decreases the postprandial glycemic response only in meals composed of complex carbohydrates. Employing a crossover design, diabetics (n = 9) and non-diabetics (n = 29) received 10 g of apple cider vinegar added to the test meal of a bagel and orange juice or dextrose and orange juice. Compared to placebo (without vinegar), glycemia was 20% lower in the area under the curve 120 min after the meal, whilst the consumption of vinegar with dextrose did not show any glycemic improvement [24].

Since publication of the seminal study by Brighenti et al. (1995), in which vinegar in the form of salad dressing significantly altered the glycemic response to a mixed meal [25], a number of studies have endeavored to further investigate this topic in healthy subjects (Table 2) and in those with glucose disturbances (Table 3). As noted in these tables, most of the studies supporting a role for vinegar as a glucose-lowering nutraceutical are based on acute tests on its interaction with carbohydrate-rich meals. The usual studied dose is 20 g of vinegar per meal [25–30], which is equivalent to 1 g of acetic acid [26]. Converting to homemade measures, 20 g of vinegar corresponds to approximately 4 tablespoons [26].

**Table 1**
pH of common vinegar types and other substances Adapted from Reddy et al., 2016; Tawo et al., 2009; Zandim et al., 2004 [21–23].

| Common food items and substances | pH |
|---|---|
| Hydrochloric Acid (1 mol/L) | <1.0 |
| Gastric Juice | 1–3 |
| Lemon Juice | 2.3 |
| Coca-Cola® Classic | 2.4 |
| Rice Vinegar | 2.5 |
| White Wine | 2.5 |
| Apple Vinegar | 2.7 |
| Ethanol | 2.8 |
| Teas | 2.9–5.2 |
| Pineapple | 3.3 |
| Balsamic Vinegar | 3.4 |
| Orange | 3.6 |
| Tomato | 4.2 |
| Coffee | 5.1 |
| Urine | 6.0 |
| Distilled Water | 5.9 |
| Pure Water | 7.0 |
| Blood | 7.4 |
| Baking Soda Solution | 8.4 |
| Toothpaste | 9.9 |
| Milk of Magnesia | 10.5 |
| Sodium Hydroxide (1 mol/L) | 14.0 |

## 7. Impact of vinegar intake based on chronic interventions

Chronic interventions show that vinegar can improve glycemic and lipid profiles in those with type 2 diabetes (T2DM) and dyslipidemia [37,38]. Mahmoodi et al. divided 60 patients with T2DM into two groups: 15 mL intake of apple cider vinegar per day or control [37]. After one month, subjects who ingested vinegar decreased glycemia and glycated hemoglobin (HbA1c) from 175 mg/dL to 156 mg/dL and from 7.56% to 7.03%, respectively. In another study, hyperlipidemic subjects (14 men and 5 women subjects) who consumed 30 mL of apple cider vinegar twice daily for 8 weeks decreased serum concentrations of total cholesterol (−45 in men and −51 mg/dL in women), triglycerides (−105 in men and −109 mg/dL in women) and LDL (−39 in men and −20 mg/dL in women) from baseline, whereas HDL levels did not change [39]. Alternatively, a parallel, randomized, double-blind, placebo-controlled study of 97 participants found that daily consumption of

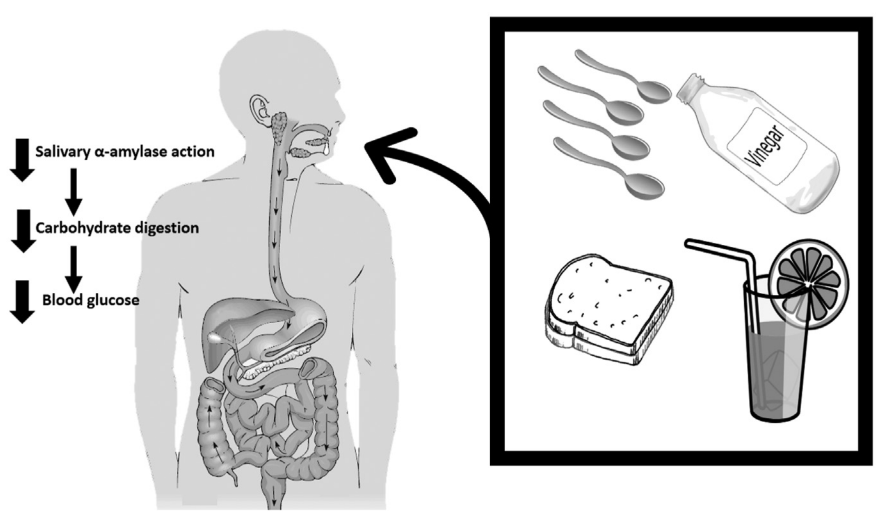


**Fig. 3.** Blood glucose improvement hypothesis through vinegar action in the α-amylase inhibition. When vinegar is ingested alongside carbohydrates-rich meals, a blood glucose improvement is believed to occur due to the α-amylase inhibition. Hence, there should be lower carbohydrate digestion until the nutrients reach the stomach, which results in lower blood glucose levels.

**Table 2**
Acute effects of vinegar intake on glycemic parameters of health subjects.

| Author and year | n | Study design | Intervention meal | Outcomes |
|---|---|---|---|---|
| Brighenti et al., 1995 [25] | 5 | Crossover, placebo-controlled | 100 g of chopped lettuce with olive oil, or olive oil plus 1 g of acetic acid in vinegar form or vinegar neutralized through sodium bicarbonate. After ingestion of the seasoned lettuce, 50 g of white bread was consumed | Blood glucose, analyzed before, and up to 95 min after meals, was 31% lower when they ingested lettuce salad with the dressing containing vinegar than the other tested meals |
| Liljeberg and Björck, 1998 [28] | 10 | Crossover, placebo-controlled | On the first day patients received 122 g of white bread, 8 g of olive oil and 23 g of cheese; on the second day they received the same meal with 20 g of vinegar | When individuals ingested the sandwich with vinegar, compared to that without vinegar, the blood glucose and postprandial insulinemia were reduced within 30–60 min |
| Johnston and Buller, 2005 [27] | 11 | Randomized, crossover, placebo-controlled | 20 g of apple cider vinegar added in test meals composed of bread and orange juice (glycemic load = 81). Additionally a lower glycemic load meal (glycemic load = 48) was analyzed, which contained 200 g of rice and 50 g of chicken breast, both cooked | Higher glycemic load meals ingested with vinegar resulted in postprandial glycemia 55% lower than meals without vinegar. There was no glycemia improvement when vinegar was ingested along with the lower glycemic load meal |
| Ostman et al., 2005 [31] | 12 | Randomized, crossover | 18, 23 and 28 g of vinegar with a white bread serving (50 g of carbohydrates) after overnight fasting | Postprandial glycemia response at 30 and 45 min, and the insulinemia at 15 and 30 min, were significantly reduced after ingesting 28 g of vinegar, in comparison with lower doses and the control meal (without vinegar) |
| Salbe et al., 2009 [29] | 5 | Randomized, crossover, placebo-controlled | Individuals randomly received placebo and 20 mL of apple vinegar followed by mashed potatoes (0.75 g of carbohydrate/kg body weight). Oral octreotide was given for insulin suppression along with the meals | Glycemia levels, measured every 20 min along 180 min of testing, were significantly higher after vinegar ingestion when compared with placebo |
| Ishak et al., 2018 [32] | 10 | Randomized, cross-over intervention | Intervention encompassed 4 trials: control, mixture only, exercise only, and exercise + mixture. The mixture consisted of 20 mL of garlic, ginger and lemon juices honey and apple cider vinegar based on a ratio of 1: 1: 1: 1: 1 | Postprandial glucose response calculated as area under curve for 120 min were 8%, 13% and 15% lower than control in mixture only, exercise alone and exercise + mixture, respectively |

30 mL of apple cider vinegar for two months did not improve lipid and HbA1c levels; however, the subjects were non-diabetics with normal lipid concentrations [38].

The longest study analyzing vinegar intake lasted twelve weeks [13]. Overweight Japanese patients were divided into one of three groups: 15 mL of apple cider vinegar (n = 51), 30 mL of apple cider vinegar (n = 54), or placebo (n = 50). In contrast to most of the acute studies and short-term studies, glycemic profile did not change (glycemia remained ~90 mg/dL, insulinemia ~10 μIU/mL and HbA1c ~5.3%). However, there was a reduction of serum triglycerides and visceral fat in the groups that ingested vinegar. Interestingly, participants who consumed 30 mL of apple cider vinegar showed a 41 mg/dL (157–116 mg/dL) reduction in serum triglycerides, but levels returned to baseline four weeks after of the end of intervention. Serum cholesterol levels also decreased in the group consuming a higher vinegar intake (220–207 mg/dL), while HDL and LDL levels did not change. Body weight decreased by two kilograms (from 73 to 71 kg) in the group ingesting 30 mL of vinegar per day, while the group that ingested 15 mL/day lost one kg (from 74 to 73 kg). Alternatively, the placebo group presented a slight body weight increase (200 g). Notwithstanding, this study had a number of controls that enhanced validity, including equating caloric intake between groups (~1800 calories/d), limiting alcohol intake, avoiding functional foods, and prohibiting vinegar consumption other than that provided in the study. Thus, given the greater fat loss reported in the vinegar groups compared to controls, vinegar can be considered more effective than many thermogenic supplements touted as fat burners [40,41].

Vinegar use shows promise for the treatment of polycystic ovary syndrome (PCOS). Wu et al. [42] demonstrated that consumption of a beverage containing 15 mL of apple cider vinegar for 90–110 d resulted in decreased markers of insulin resistance in six of the seven subjects and reduced the luteinizing hormone/follicle-stimulating hormone ratio in five of the subjects. Moreover, ovulatory menstruation was restored within 40 days in four of the subjects. While these findings are intriguing, the study was limited by a small sample size and lack of a control group.

## 8. Side-effects

Chronic intake of excessive amounts of vinegar can cause serious health problems. A large administration of apple cider vinegar regularly for 6 years was associated with high urinary excretion of potassium, sodium and bicarbonate and stimulated plasma renin activity in a 28-year-old patient admitted to the hospital because of muscle cramps and hypokalemia. The patient ingested ~250 mL of vinegar (i.e. 12.5 g of acetic acid) per day diluted in water and as salad dressing [43]. Moreover, acute vinegar intake was implicated as a causal factor of ulcerative injury to the oropharynx and oesophagus in a case report of a 39-year-old woman who drank one tablespoon of white vinegar to 'soften' crab shell stuck in her throat [44].

Unsubstantiated statements by the media may unduly influence the lay public to incorrectly administer vinegar therapeutically. For example, a 72-year-old Caucasian man with history of dyslipidemia, gastroesophageal reflux disease and mild obesity added 2 tablespoons daily of acetic acid (household vinegar) to his diet after reading an article in a health magazine that claimed vinegar helps to decrease food intake (by promoting satiety) and lowers cholesterol. Nine days later, the individual was admitted to the hospital with intractable singultus (hiccups), associated with anorexia and epigastric pain [45]. In another instance, a 14-year-old girl received chemical burns after following an Internet-based protocol for nevi removal using apple cider vinegar [46]. Vinegar also caused chemical burns to the face in an 8-year-old girl after her aunt applied a vinegar-containing solution in an effort to alleviate pediculosis capitis [47]. Topical incidents associated with vinegar have been reported in adults, as well. A home-made poultice

**Table 3**
Acute effects of vinegar intake on glycemic parameters of subjects with glucose disturbances.

| Author and year | Subjects | Study design | Intervention meal | Outcomes |
|---|---|---|---|---|
| Johnston et al., 2004 [26] | 8 individuals without diabetes, 11 with prediabetes and 10 with type 2 diabetes | Crossover, placebo- controlled | Patients were randomized to intake 20 g of apple cider vinegar along with 40 g of water or placebo drink, followed by a test meal consisting of white bread, butter and orange juice | After 30 and 60 min postprandial, the glycemic response was lower only in those subjects with prediabetes |
| White and Johnston, 2007 [30] | 11 type-2 diabetics non-insulin users | Randomized, crossover, placebo-controlled | Subjects were submitted to a standardized dietary plan for two days, which included adding 2 tablespoons of apple cider vinegar to the supper along with one slice of cheese (~30 g) | The fasting blood glucose level was significantly lower on the vinegar day, but biologically it was a very low value, in which glycemia decreased in only 5 mg/dL |
| Johnston et al., 2010 [24] | 9 diabetics and 29 non-diabetics subjects | Double-blind, randomized, crossover, placebo- controlled | 2 g, 10 g, or 20 g of apple cider or red raspberry vinegars were consumed 2 min or 5 h before the meal test, or "vinegar pill" (sodium acetate) administrated 2 min before the meal. Vinegar doses were added to the test meal of white bagel, 20 g butter and 200 g juice (3 trials) or dextrose solution (1 trial). Placebo drinks were prepared in an identical manner but minus the vinegar | Compared to the placebo test, the intake of 10 g of apple vinegar lower 20% the area under the curve 120 min for glycemia after the meal, whilst the consumption of vinegar with dextrose did not show any glycemic improvement |
| Mitrou et al., 2010 [33] | 10 patients with type 1 diabetes | Crossover, placebo-controlled | The subjects were randomly assigned to consume 30 mL vinegar + 20 mL water or placebo (50 mL water) 5 min before a meal composed of bread, cheese, turkey ham, orange juice, butter, and a cereal bar | Compared to the placebo test, the meal with vinegar lower by almost 20% the area under the curve 240 min for postprandial glycemia |
| Liatis et al., 2010 [34] | 16 type-2 diabetic individuals | Crossover, placebo-controlled | In the first group was given a high-glycemic index meal 50 g (mashed potatoes and 250 mL low-fat milk) on two different days, with and without the addition of 20 g wine vinegar. In the second group, patients were given an isocaloric meal with the same nutrient composition, but low-glycemic index (100 g whole grain bread, 55 g lettuce and 20 g low-fat cheese) | Incremental area under the curve of glucose for 120 min was lower after the addition of vinegar in the high-glycemic index meal, but not into low-glycemic index |
| Kuzeyli kahraman, 2011 [35] | 16 type-2 diabetic patients who had been treated with metformin only | Crossover, placebo-controlled | 275 g baked beans, 195 g rice, 106 g salad plus 50 g of grape vinegar on the first day, but not with vinegar on the second day | Postprandial blood glucose and insulin measurements were not different in the vinegar group when compared with the reference group |
| van Dijk et al., 2012 [36] | 12 type well-controlled 2 diabetic patients | Randomized, crossover | After an overnight fast, subjects ingested either 75 g glucose beverage with 25 g white vinegar or without vinegar | Vinegar co-ingestion did not attenuate the postprandial rise in plasma glucose or insulin |
| Panayota Mitrou et al., 2015 [15] | 11 insulin-resistant individuals | Randomized crossover study | 30 mL of apple vinegar or placebo before a test meal, which consisted of bread, cheese, ham, orange juice, butter and a cereal bar (equivalent to 75 g of carbohydrates) | Compared with placebo, the vinegar intake decreased the serum insulin and triglycerides, and increased the musculoskeletal glucose uptake performed through the arteriovenous difference method during 300 min |

containing 4.5% acetic acid applied to the dorsum of the left foot under occlusion with gauze in a 59-year-old woman resulted in a deeply ulcerated lesion [48].

## 9. Perspectives and clinical view

The majority of studies to date have used apple cider vinegar [13,15,16,24,27,29,30,37]. To the best of our knowledge, there are no studies that used garlic vinegar in a human intervention. Given evidence that garlic consumption improves lipid profiles and inhibits production of advanced glycation end products (AGEs) [49,50], future research should seek to determine if additional benefits are achieved through the consumption of garlic vinegar. Interestingly, cooking meat marinated in vinegar to 150 °C for 15 min per 1 h reduced the production of AGEs compared to cooking the meat without marinating [51].

In vitro data showed vinegar to be a good dietary source of antioxidants [52]. It should be noted however that the present review did not address this issue as apple cider is the more studied vinegar in human studies and its antioxidant effect is negligible. Despite claims that vinegar is a good antioxidant source, various fruits (e.g. orange, mango, cherry and banana) have an antioxidant activity between 8- and 40-fold higher than apple cider vinegar [53]. Thus, ingestion of fruits is a better alternative for attaining antioxidants than vinegar.

Regarding glucose disturbances, the majority of research covers the benefits of vinegar ingestion in subjects with T2DM, whereas only one study investigated its effects in subjects with T1DM. Further research is therefore warranted to better understand the relationship between vinegar intake and T1DM.

In addition to its use as a remedy for dysregulated glycemia, vinegar also shows promise in ameliorating non-alcoholic fatty liver disease, PCOS and weight loss. However, chronic interventions with more controlled diet are needed to draw better conclusions as to its efficacy.

Ultimately, since high intake of acidic foodstuffs such as vinegar can irritate mucous membranes, such as the mouth, it is important to monitor any symptoms that may occur. Caution is required in people with stomach disorders. Importantly, gastric problems are often encountered in patients with diabetes mellitus [54], and there is no support with respect to vinegar intake and stomach safety. The recommendation of vinegar consumption in clinical practice should be considered in line with individual preferences, e.g. taste tolerance.

## 10. Conclusion

Acute and short-term studies show that vinegar intake has a beneficial effect on the glycemic profile, with apple cider the most studied type of vinegar. Evidence suggests that chronic intake may improve glycemia as well, especially in T2DM individuals. However, while a considerable number of studies have acutely analyzed the effects of vinegar intake co-ingested with meals rich in carbohydrate, only a few interventions have included relevant follow-ups and diet control. Taken together, consumption of 10–30 mL (~2–6 tablespoons) of vinegar as a dressing or diluted in beverages appears to be adequate to acutely alter glycemic profile. In contrast, this dose can be infeasible if used habitually.

## Author's contributions

H.O.S. and W.M.A.M.M. conducted the literature search and drafted and revised the manuscript. G.A.R.S., JP and B.J.S. critically reviewed and revised the manuscript.

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None.

## Declaration of interest

The authors have no interests to declare.

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