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Apple cider vinegar for weight management in Lebanese adolescents and young adults with overweight and obesity: a randomised, double-blind, placebo-controlled study

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ABSTRACT

Background and aims Obesity and overweight have become significant health concerns worldwide, leading to an increased interest in finding natural remedies for weight reduction. One such remedy that has gained popularity is apple cider vinegar (ACV).

Objective To investigate the effects of ACV consumption on weight, blood glucose, triglyceride and cholesterol levels in a sample of the Lebanese population.

Materials and methods 120 overweight and obese individuals were recruited. Participants were randomly assigned to either an intervention group receiving 5, 10 or 15 mL of ACV or a control group receiving a placebo (group 4) over a 12-week period. Measurements of anthropometric parameters, fasting blood glucose, triglyceride and cholesterol levels were taken at weeks 0, 4, 8 and 12.

Results Our findings showed that daily consumption of the three doses of ACV for a duration of between 4 and 12 weeks is associated with significant reductions in anthropometric variables (weight, body mass index, waist/hip circumferences and body fat ratio), blood glucose, triglyceride and cholesterol levels. No significant risk factors were observed during the 12 weeks of ACV intake.

Conclusion Consumption of ACV in people with overweight and obesity led to an improvement in the anthropometric and metabolic parameters. ACV could be a promising antiobesity supplement that does not produce any side effects.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Recently, there has been increasing interest in alternative remedies to support weight management, and one such remedy that has gained popularity is apple cider vinegar (ACV).

⇒ A few small-scale studies conducted on humans have shown promising results, with ACV consumption leading to weight loss, reduced body fat and decreased waist circumference.

WHAT THIS STUDY ADDS

⇒ No study has been conducted to investigate the potential antiobesity effect of ACV in the Lebanese population. By conducting research in this demographic, the study provides region-specific data and offers a more comprehensive understanding of the impact of ACV on weight loss and metabolic health.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results might contribute to evidence-based recommendations for the use of ACV as a dietary intervention in the management of obesity.

⇒ The study could stimulate further research in the field, prompting scientists to explore the underlying mechanisms and conduct similar studies in other populations.

INTRODUCTION

Obesity is a growing global health concern characterised by excessive body fat accumulation, often resulting from a combination of genetic, environmental and lifestyle factors.[1] It is associated with an increased risk of numerous chronic illnesses such as type 2 diabetes, cardiovascular diseases, several common cancers and osteoarthritis.[1–3]

According to the WHO, more than 1.9 billion adults were overweight worldwide in 2016, of whom more than 650 million were obese.[4] Worldwide obesity has nearly tripled since 1975.[4] The World Obesity Federation's 2023 Atlas predicts that by 2035 more than half of the world's population will be overweight or obese.[5]

According to the 2022 Global Nutrition Report, Lebanon has made limited progress towards meeting its diet-related non-communicable diseases target. A total of 39.9% of adult (aged ≥18 years) women and 30.5% of adult men are living with obesity. Lebanon's obesity prevalence is higher than the regional average of 10.3% for women and 7.5% for men.[6] In Lebanon, obesity was considered as the most important health problem by 27.6% and ranked fifth after cancer, cardiovascular, smoking and HIV/AIDS.[7]

In recent years, there has been increasing interest in alternative remedies to support weight management, and one such remedy that has gained popularity is apple cider vinegar (ACV), which is a type of vinegar made by fermenting apple juice. ACV contains vitamins, minerals, amino acids and polyphenols such as flavonoids, which are believed to contribute to its potential health benefits.[8 9]

It has been used for centuries as a traditional remedy for various ailments and has recently gained attention for its potential role in weight management.

In hypercaloric-fed rats, the daily consumption of ACV showed a lower rise in blood sugar and lipid profile.[10] In addition, ACV seems to decrease oxidative stress and reduces the risk of obesity in male rats with high-fat consumption.[11]

A few small-scale studies conducted on humans have shown promising results, with ACV consumption leading to weight loss, reduced body fat and decreased waist circumference.[12 13] In fact, It has been suggested that ACV by slowing down gastric emptying, might promote satiety and reduce appetite.[14–16] Furthermore, ACV intake seems to ameliorate the glycaemic and lipid profile in healthy adults[17] and might have a positive impact on insulin sensitivity, potentially reducing the risk of type 2 diabetes.[8 10 18]

Unfortunately, the sample sizes and durations of these studies were limited, necessitating larger and longer-term studies for more robust conclusions.

This work aims to study the efficacy and safety of ACV in reducing weight and ameliorating the lipid and glycaemic profiles in a sample of overweight and obese adolescents and young adults of the Lebanese population. To the best of our knowledge, no study has been conducted to investigate the potential antiobesity effect of ACV in the Lebanese population.

Materials and methods

Participants

A total of 120 overweight and obese adolescents and young adults (46 men and 74 women) were enrolled in the study and assigned to either placebo group or experimental groups (receiving increasing doses of ACV).

The subjects were evaluated for eligibility according to the following inclusion criteria: age between 12 and 25 years, BMIs between 27 and 34 kg/m^2, no chronic diseases, no intake of medications, no intake of ACV over the past 8 weeks prior to the beginning of the study. The subjects who met the inclusion criteria were selected by convenient sampling technique. Those who experienced heartburn due to vinegar were excluded.

Demographic, clinical data and eating habits were collected from all participants by self-administered questionnaire.

STUDY DESIGN

This study was a double-blind, randomised clinical trial conducted for 12 weeks.

Subjects were divided randomly into four groups: three treatment groups and a placebo group. A simple randomisation method was employed using the randomisation allocation software. Groups 1, 2 and 3 consumed 5, 10 and 15 mL, respectively, of ACV (containing 5% of acetic acid) diluted in 250 mL of water daily, in the morning on an empty stomach, for 12 weeks. The control group received a placebo consisting of water with similar taste and appearance. In order to mimic the taste of vinegar, the placebo group's beverage (250 mL of water) contained lactic acid (250 mg/100 mL). Identical-looking ACV and placebo bottles were used and participants were instructed to consume their assigned solution without knowing its identity. The subject's group assignment was withheld from the researchers performing the experiment.

Subjects consumed their normal diets throughout the study. The contents of daily meals and snacks were recorded in a diet diary. The physical activity of the subjects was also recorded. Daily individual phone messages were sent to all participants to remind them to take the ACV or the placebo. A mailing group was also created. Confidentiality was maintained throughout the procedure.

At weeks 0, 4, 8 and 12, anthropometric measurements were taken for all participants, and the level of glucose, triglycerides and total cholesterol was assessed by collecting 5 mL of fasting blood from each subject.

Anthropometric measurements

Body weight was measured in kg, to the nearest 0.01 kg, by standardised and calibrated digital scale. Height was measured in cm, to the nearest 0.1 cm, by a stadiometer. Anthropometric measurements were taken for all participants, by a team of trained field researchers, after 10–12 hours fast and while wearing only undergarments.

Body mass indices (BMIs) were calculated using the following equation:

$$\mathrm{BMI}\ (\mathrm{kg/m^2}) = \frac{\mathrm{Body\ Weight\ (kg)}}{(\mathrm{Height\ (m)})^2} \tag{1}$$

The waist circumference measurement was taken between the lowest rib margin and the iliac crest while the subject was in a standing position (to the nearest 0.1 cm). Hip circumference was measured at the widest point of the hip (to the nearest 0.1 cm).

The body fat ratio (BFR) was measured by the bioelectrical impedance analysis method (OMRON Fat Loss Monitor, Model No HBF-306C; Japan). Anthropometric variables are shown in table 1.

Blood biochemical analysis

Serum glucose was measured by the glucose oxidase method.[19] Triglyceride levels were determined using a serum triglyceride determination kit (TR0100, Sigma-Aldrich). Cholesterol levels were determined using a

Table 1 Baseline demographic, anthropometric and biochemical variables of the three apple cider vinegar groups (group 1, 2 and 3) and the placebo group (group 4)

Variable	Group 1 (n=30)	Group 2 (n=30)	Group 3 (n=30)	Group 4 (placebo) (n=30)
Gender (%)				
Male	40.0 (n=12)	33.3 (n=10)	36.6 (n=11)	43.3 (n=13)
Female	60.0 (n=18)	66.7 (n=20)	63.4 (n=19)	56.7 (n=17)
Age (years)	17.2±5.2	18.1±5.5	17.6±5.1	17.8±5.7
Weight (kg)	79.0±27.1	79.3±28.5	77.2±27.2	79.1±28.6
Height (cm)	157.4±20.1	158.6±22.2	157.1±20.8	156.9±21.4
BMI (kg/m^2)	30.6±3.1	30.2±2.8	30.0±3.0	30.7±3.2
Waist (cm)	85.9±3.8	84.7±4.4	85.3±4.8	84.2±4.3
Hip (cm)	106.4±3.5	105.8±3.4	105.1±3.9	106.6±3.7
BFR (%)	29.8±6.7	28.1±5.5	30.4±6.3	29.1±5.8
FBS (mg/dL)	120.1±10.9	118.9±13.1	119.9±7.2	113.6±12.5
TG (mg/dL)	170.1±17.9	167.2±13.2	165.9±13.8	168.1±18.2
TC (mg/dL)	176.0±13.1	173.6±16.3	176.9±11.1	178.5±11.5

All values are mean±SD unless stated otherwise
Group 1: daily intake of 5 mL of ACV; group 2: daily intake of 10 mL of ACV; group 3: daily intake of 15 mL of ACV.
ACV, apple cider vinegar; BFR, body fat ratio; BMI, body mass index; FBS, fasting blood sugar; TC, total cholesterol; TG, triglycerides.

cholesterol quantitation kit (MAK043, Sigma-Aldrich). Biochemical variables are shown in table 1.

Statistical methods and data analysis

Data are presented as mean±SD. Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) software (version 23.0). Significant differences between groups were determined by using an independent t-test. Statistical significance was set at $p<0.05$.

ETHICAL APPROVAL

The study protocol was reviewed and approved by the research ethics committee (REC) of the Higher Centre for Research (HCR) at The Holy Spirit University of Kaslik (USEK), Lebanon. The number/ID of the approval is HCR/EC 2023–005. The participants were informed of the study objectives and signed a written informed consent before enrolment. The study was conducted in accordance to the International Conference and Harmonisation E6 Guideline for Good Clinical Practice and the Ethical principles of the Declaration of Helsinki.

RESULTS

Sociodemographic, nutritional and other baseline characteristics of the participants

A total of 120 individuals (46 men and 74 women) with BMIs between 27 and 34 kg/m^2, were enrolled in the study. The mean age of the subjects was 17.8±5.7 years and 17.6±5.4 years in the placebo and experimental groups respectively.

The majority of participants, approximately 98.3%, were non-vegetarian and 89% of them reported having a high eating frequency, with more than four meals per day. Eighty-seven per cent had no family history of obesity and 98% had no history of childhood obesity. The majority reported not having a regular exercise routine and experiencing negative emotions or anxiety. All participants were non-smokers and non-drinkers. A small percentage (6.7%) were following a therapeutic diet.

Effects of ACV intake on anthropometric variables

The addition of 5 mL, 10 mL or 15 mL of ACV to the diet resulted in significant decreases in body weight and BMI at weeks 4, 8 and 12 of ACV intake, when compared with baseline (week 0) ($p<0.05$). The decrease in body weight and BMI seemed to be dose-dependent, with the group receiving 15 mL of ACV showing the most important reduction (table 2).

The impact of ACV on body weight and BMI seems to be time-dependent as well. Reductions were more pronounced as the study progressed, with the most significant changes occurring at week 12.

The circumferences of the waist and hip, along with the Body Fat Ratio (BFR), decreased significantly in the three treatment groups at weeks 8 and 12 compared with week 0 ($p<0.05$). No significant effect was observed at week 4, compared with baseline ($p>0.05$). The effect of ACV on these parameters seems to be time-dependent with the most prominent effect observed at week 12 compared with week 4 and 8. However it does not seem to be dose dependent, as the three doses of ACV showed a similar level of efficacy in reducing the circumferences of the waist/hip circumferences and the BFR at week 8 and 12, compared with baseline (table 2).

Table 2 Anthropometric variables of the participants at weeks 0, 4, 8 and 12

Variable	Week 0	Week 4	Week 8	Week 12
Weight (kg)				
Group 1	79.0±27.1	78.1±26.5*‡	77.3±26.0*‡	73.9±23.7*‡
Group 2	79.3±28.5	78.1±27.4*†	77.2±27.4*†	71.9±26.1*†
Group 3	77.2±27.2	74.0±26.6*†‡	72.6±26.4*†‡	70.2±25.0*†‡
Group 4 (placebo)	79.1±28.6	79.3±28.4†‡	78.4±28.7†‡	78.8±28.6†‡
BMI (kg/m^2)				
Group 1	30.6±3.1	30.3±2.9*‡	30.0±2.8*‡	28.8±2.2*‡
Group 2	30.2±2.8	29.8±2.5*†	29.4±2.6*†	27.3±2.7*†
Group 3	30.0±3.0	28.7±3.1*†‡	28.1±3.2*†‡	27.2±2.9*†‡
Group 4 (placebo)	30.7±3.2	30.8±3.1†‡	30.4±3.3†‡	30.6±3.2†‡
Waist (cm)				
Group 1	85.9±3.8	84.8±3.9	83.9±3.7*	83.0±3.9*
Group 2	84.7±4.4	83.2±4.5	82.4±4.6*	82.0±3.8*
Group 3	85.3±4.8	83.4±4.7	82.7±4.5*	81.9±5.0*
Group 4 (placebo)	84.2±4.3	84.2±4.4	84.5±4.5	84.4±4.6
Hip (cm)				
Group 1	106.4±3.5	105.7±3.6	105.1±3.4*	104.6±3.6*
Group 2	105.8±3.4	104.9±3.3	104.4±3.2*	103.8±3.5*
Group 3	105.1±3.9	104.0±3.8	103.5±4.0*	102.9±3.8*
Group 4 (placebo)	106.6±3.7	106.5±3.9	106.4±3.9	106.7±3.5
BFR (%)				
Group 1	29.8±6.7	29.6±6.6	29.1±6.8*	28.5±6.6*
Group 2	28.1±5.5	27.6±5.4	27.1±5.6*	26.6±5.4*
Group 3	30.4±6.3	29.7±6.4	29.2±6.5*	28.5±6.3*
Group 4 (placebo)	29.1±5.8	29.2±5.9	29.3±6.0	29.4±5.6

Group 1: daily intake of 5 mL of ACV; group 2: daily intake of 10 mL of ACV; group 3: daily intake of 15 mL of ACV.
All values are mean±SD.
*p<0.05; compared with baseline (week 0).
†p<0.05; compared with group 1 within a specific week.
‡p<0.05; compared with group 2 within a specific week.
ACV, apple cider vinegar; BFR, body fat ratio; BMI, body mass index.

The placebo group did not experience any significant changes in the anthropometric variables throughout the study (p>0.05). This highlights that the observed improvements in body weight, BMI, waist and hip circumferences and Body Fat Ratio were likely attributed to the consumption of ACV.

Effects of ACV on blood biochemical parameters

The consumption of ACV also led to a time and dose dependent decrease in serum glucose, serum triglyceride and serum cholesterol levels. (table 3).

Serum glucose levels decreased significantly by three doses of ACV at week 4, 8 and 12 compared with week 0 (p<0.05) (table 3). Triglycerides and total cholesterol levels decreased significantly at weeks 8 and 12, compared with week 0 (p<0.05). A dose of 15 mL of ACV for a duration of 12 weeks seems to be the most effective dose in reducing these three blood biochemical parameters.

There were no changes in glucose, triglyceride and cholesterol levels in the placebo groups at weeks 4, 8 and 12 compared with week 0 (table 3).

These data suggest that continued intake of 15 mL of ACV for more than 8 weeks is effective in reducing blood fasting sugar, triglyceride and total cholesterol levels in overweight/obese people.

Adverse reactions of ACV

No apparent adverse or harmful effects were reported by the participants during the 12 weeks of ACV intake.

DISCUSSION

During the past two decades of the last century, childhood and adolescent obesity have dramatically increased healthcare costs.[20 21] Diet and exercise are the basic elements of weight loss. Many complementary therapies

Table 3 Biochemical variables of the participants at weeks 0, 4, 8 and 12

Variable	Week 0	Week 4	Week 8	Week 12
FBS (mg/dl)				
Group 1	120.1±10.9	118.6±10.6*‡	116.8±10.7*‡	114.6±9.8*‡
Group 2	118.9±13.1	117.5±12.9*†	115.4±12.6*#*†	110.1±12.2*#*†
Group 3	119.9±12.2	116.6±12.6*†‡	115.1±12.1*†‡	108.0±11.1*†‡
Group 4	118.6±12.5	118.7±12.6†	118.5±12.8†‡	117.2±12.9†‡
TG (mg/dL)				
Group 1	170.1±17.9	168.2±18.2	166.0±17.8*‡	163.1±17.6*‡
Group 2	167.2±13.2	165.2±13.6	163.0±13.2*†	154.7±12.6*†
Group 3	165.9±13.8	163.7±13.7	161.8±13.6*†‡	151.8±12.0*†‡
Group 4	166.1±18.2	166.3±18.0	166.5±18.3†‡	166.7±18.1†‡
TC (mg/dL)				
Group 1	176.0±13.1	174.2±13.5	171.9±13.1*‡	170.0±13.9*‡
Group 2	175.6±12.9	173.8±13.2	171.3±12.9*†	164.2±12.8*†
Group 3	176.9±11.1	174.7±11.7	172.5±11.1*†‡	162.2±11.3*†‡
Group 4	178.5±11.5	178.8±11.2	177.8±11.9†‡	178.6±11.7†‡

Group 1: daily intake of 5 mL of ACV; group 2: daily intake of 10 mL of ACV; group 3: daily intake of 15 mL of ACV.
All values are mean±SD.
*p<0.05; compared with baseline (week 0).
†p<0.05; Compared with group 1 within a specific week.
‡p<0.05; Compared with group 2 within a specific week.
ACV, apple cider vinegar; FBS, fasting blood sugar; TC, total cholesterol; TG, triglycerides.

have been promoted to treat obesity, but few are truly beneficial.

The present study is the first to investigate the anti-obesity effectiveness of ACV, the fermented juice from crushed apples, in the Lebanese population.

A total of 120 overweight and obese adolescents and young adults (46 men and 74 women) with BMIs between 27 and 34 kg/m^2, were enrolled. Participants were randomised to receive either a daily dose of ACV (5, 10 or 15 mL) or a placebo for a duration of 12 weeks.

Some previous studies have suggested that taking ACV before or with meals might help to reduce postprandial blood sugar levels,[22 23] but in our study, participants took ACV in the morning on an empty stomach. The choice of ACV intake timing was motivated by the aim to study the impact of apple cider vinegar without the confounding variables introduced by simultaneous food intake. In addition, taking ACV before meals could better reduce appetite and increase satiety.

Our findings reveal that the consumption of ACV in people with overweight and obesity led to an improvement in the anthropometric and metabolic parameters.

It is important to note that the diet diary and physical activity did not differ among the three treatment groups and the placebo throughout the whole study, suggesting that the decrease in anthropometric and biochemical parameters was caused by ACV intake.

Studies conducted on animal models often attribute these effects to various mechanisms, including increased energy expenditure, improved insulin sensitivity, appetite and satiety regulation.

While vinegar is composed of various ingredients, its primary component is acetic acid (AcOH). It has been shown that after 15 min of oral ingestion of 100 mL vinegar containing 0.75 g acetic acid, the serum acetate levels increases from 120 µmol/L at baseline to 350 µmol/L[24]; this fast increase in circulatory acetate is due to its fast absorption in the upper digestive tract.[24 25]

Biological action of acetate may be mediated by binding to the G-protein coupled receptors (GPRs), including GPR43 and GPR41.[25] These receptors are expressed in various insulin-sensitive tissues, such as adipose tissue,[26] skeletal muscle, liver,[27] and pancreatic beta cells,[28] but also in the small intestine and colon.[29 30]

Yamashita and colleagues have revealed that oral administration of AcOH to type 2 diabetic Otsuka Long-Evans Tokushima Fatty rats, improves glucose tolerance and reduces lipid accumulation in the adipose tissue and liver. This improvement in obesity-linked type 2 diabetes is due to the capacity of AcOH to inhibit the activity of carbohydrate-responsive, element-binding protein, a transcription factor involved in regulating the expression of lipogenic genes such as fatty acid synthase and acetyl-CoA carboxylase.[26 31] Sakakibara and colleagues, have reported that AcOH, besides inhibiting lipogenesis, reduces the expression of genes involved in gluconeogenesis, such as glucose-6-phosphatase.[32] The effect of AcOH on lipogenesis and gluconeogenesis is in part mediated by the activation of 5'-AMP-activated protein kinase in the liver.[32] This enzyme seems to be an important pharmacological target for the treatment of metabolic disorders such as obesity, type 2 diabetes and hyperlipidaemia.[32 33]

5'-AMP-activated protein kinase is also known to stimulate fatty acid oxidation, thereby increasing energy expenditure.[32 33] These data suggest that the effect of ACV on weight and fat loss may be partly due to the ability of AcOH to inhibit lipogenesis and gluconeogenesis and activate fat oxidation.

Animal studies suggest that besides reducing energy expenditure, acetate may also reduce energy intake, by regulating appetite and satiety. In mice, an intraperitoneal injection of acetate significantly reduced food intake by activating vagal afferent neurons.[32–34] It is important to note that animal studies done on the effect of acetate on vagal activation are contradictory. This might be due to the site of administration of acetate and the use of different animal models.

In addition, in vitro and in vivo animal model studies suggest that acetate increases the secretion of gut-derived satiety hormones by enter endocrine cells (located in the gut) such as GLP-1 and PYY hormones.[25 32–35]

Human studies related to the effect of vinegar on body weight are limited.

In accordance with our study, a randomised clinical trial conducted by Khezri and his colleagues has shown that daily consumption of 30 mL of ACV for 12 weeks significantly reduced body weight, BMI, hip circumference, Visceral Adiposity Index and appetite score in obese subjects subjected to a restricted calorie diet, compared with the control group (restricted calorie diet without ACV). Furthermore, Khezri and his colleagues showed that plasma triglyceride and total cholesterol levels significantly decreased, and high density lipoprotein cholesterol concentration significantly increased, in the ACV group in comparison with the control group.[13 32–34]

Similarly, Kondo and his colleagues showed that daily consumption of 15 or 30 mL of ACV for 12 weeks reduced body weight, BMI and serum triglyceride in a sample of the Japanese population.[12 13 32–34]

In contrast, Park *et al* reported that daily consumption of 200 mL of pomegranate vinegar for 8 weeks significantly reduced total fat mass in overweight or obese subjects compared with the control group without significantly affecting body weight and BMI.[36] This contradictory result could be explained by the difference in the percentage of acetate and other potentially bioactive compounds (such as flavonoids and other phenolic compounds) in different vinegar types.

In Lebanon, the percentage of the population with a BMI of 30 kg/m^2 or more is approximately 32%. The results of the present study showed that in obese Lebanese subjects who had BMIs ranging from 27 and 34 kg/m^2, daily oral intake of ACV for 12 weeks reduced the body weight by 6–8 kg and BMIs by 2.7–3.0 points.

It would be interesting to investigate in future studies the effect of neutralised acetic acid on anthropometric and metabolic parameters, knowing that acidic substances, including acetic acid, could contribute to enamel erosion over time. In addition to promoting oral health, neutralising the acidity of ACV could improve its taste, making it more palatable. Furthermore, studying the effects of ACV on weight loss in young Lebanese individuals provides valuable insights, but further research is needed for a comprehensive understanding of how the effect of ACV might vary across different age groups, particularly in older populations and menopausal women.

CONCLUSION

The findings of this study indicate that ACV consumption for 12 weeks led to significant reduction in anthropometric variables and improvements in blood glucose, triglyceride and cholesterol levels in overweight/obese adolescents/adults. These results suggest that ACV might have potential benefits in improving metabolic parameters related to obesity and metabolic disorders in obese individuals. The results may contribute to evidence-based recommendations for the use of ACV as a dietary intervention in the management of obesity. The study duration of 12 weeks limits the ability to observe long-term effects. Additionally, a larger sample size would enhance the generalisability of the results.

Contributors RA-K: conceptualisation, methodology, data curation, supervision, guarantor, project administration, visualisation, writing–original draft. EE-H: conceptualisation, methodology, data curation, visualisation, writing–review and editing. JA: investigation, validation, writing–review and editing.

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Competing interests No, there are no competing interests.

Patient consent for publication Consent obtained from parent(s)/guardian(s)

Ethics approval This study involves human participants and was approved by the research ethics committee of the Higher Center for Research (HCR) at The Holy Spirit University of Kaslik (USEK), Lebanon. The number/ID of the approval is HCR/EC 2023-005. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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REFERENCES

1 Jehan S, Zizi F, Pandi-Perumal SR, *et al*. Energy imbalance: obesity, associated comorbidities, prevention, management and public health implications. *Adv Obes Weight Manag Control* 2020;10:146–61.

2 Fruh SM. Obesity: risk factors, complications, and strategies for sustainable long-term weight management. *J Am Assoc Nurse Pract* 2017;29:S3–14.

3 Poirier P, Giles TD, Bray GA, *et al*. Obesity and cardiovascular disease: pathophysiology, evaluation, and effect of weight loss. *Circulation* 2006;113:898–918.
4 World Health Organization. Obesity and overweight. 2021. Available: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight
5 Reuters. More than half of the world will be overweight or obese by 2035 - report. 2023. Available: https://www.reuters.com/business/healthcare-pharmaceuticals/more-than-half-world-will-be-overweight-or-obese-by-2035-report-2023-03-02/
6 Global Nutrition Report. Country nutrition projects, Available: https://globalnutritionreport.org/resources/nutrition-profiles/asia/western-asia/lebanon/
7 Mallat S, Geagea AG, Jurjus RA, *et al*. Obesity in Lebanon: a national problem. *WJCD* 2016;06:166–74.
8 Chiu H-F, Chiang M, Liao H-J, *et al*. The ergogenic activity of cider vinegar: a randomized cross-over, double-blind, clinical trial. *Sports Med Health Sci* 2020;2:38–43.
9 Yagnik D, Serafin V, J Shah A. Antimicrobial activity of apple cider vinegar against Escherichia coli, Staphylococcus aureus and Candida albicans; downregulating cytokine and microbial protein expression. *Sci Rep* 2018;8:1732.
10 Ousaaid D, Laaroussi H, Bakour M, *et al*. Beneficial effects of apple vinegar on hyperglycemia and hyperlipidemia in hypercaloric-fed rats. *J Diabetes Res* 2020;2020:9284987.
11 Halima BH, Sonia G, Sarra K, *et al*. Apple cider vinegar attenuates oxidative stress and reduces the risk of obesity in high-fat-fed male Wistar rats. *J Med Food* 2018;21:70–80.
12 Kondo T, Kishi M, Fushimi T, *et al*. Vinegar intake reduces body weight, body fat mass, and serum triglyceride levels in obese Japanese subjects. *Biosci Biotechnol Biochem* 2009;73:1837–43.
13 Khezri SS, Saidpour A, Hosseinzadeh N, *et al*. Beneficial effects of apple cider vinegar on weight management, visceral adiposity index and lipid profile in overweight or obese subjects receiving restricted calorie diet: a randomized clinical trial. *Journal of Functional Foods* 2018;43:95–102.
14 Darzi J, Frost GS, Montaser R, *et al*. Influence of the tolerability of vinegar as an oral source of short-chain fatty acids on appetite control and food intake. *Int J Obes (Lond)* 2014;38:675–81.
15 Hlebowicz J, Darwiche G, Björgell O, *et al*. Effect of apple cider vinegar on delayed gastric emptying in patients with type 1 diabetes mellitus: a pilot study. *BMC Gastroenterol* 2007;7:46.
16 Santos HO, de Moraes WMAM, da Silva GAR, *et al*. Vinegar (acetic acid) intake on glucose metabolism: a narrative review. *Clin Nutr ESPEN* 2019;32:1–7.
17 Hadi A, Pourmasoumi M, Najafgholizadeh A, *et al*. The effect of apple cider vinegar on lipid profiles and glycemic parameters: a systematic review and meta-analysis of randomized clinical trials. *BMC Complement Med Ther* 2021;21:179.
18 Morgan J, Mosawy S. The potential of apple cider vinegar in the management of type 2 diabetes. *Int J Diabetes Res* 2016;5:129–34.
19 Walker HK, Hall WD, Hurst JW, eds. *Clinical Methods: The History, Physical, and Laboratory Examinations.*3rd ed. Boston: Butterworths, 1990.
20 Wang G, Dietz WH. Economic burden of obesity in youths aged 6 to 17 years: 1979-1999. *Pediatrics* 2002;109:E81–1.
21 Sanyaolu A, Okorie C, Qi X, *et al*. Childhood and adolescent obesity in the United States: a public health concern. *Glob Pediatr Health* 2019;6:2333794X19891305.
22 Nosrati HR, Mousavi SE, Sajjadi P, *et al*. Effect of apple cider vinegar on postprandial blood glucose in type 2 diabetic patients treated with hypoglycemic agents. *Journal of Babol University of Medical Sciences* 2013;15:7–11.
23 Johnston CS, Quagliano S, White S. White S.vinegar ingestion at mealtime reduced fasting glucose concentrations in healthy adults at risk for type 2 diabetes. *Journal of Functional Foods* 2013;5:2007–11.
24 Sugiyama S, Fushimi T, Kishi M, *et al*. Bioavailability of acetate from two vinegar supplements: capsule and drink. *J Nutr Sci Vitaminol* 2010;56:266–9.
25 Hernández MAG, Canfora EE, Jocken JWE, *et al*. The short-chain fatty acid acetate in body weight control and insulin sensitivity. *Nutrients* 2019;11:1943.
26 Le Poul E, Loison C, Struyf S, *et al*. Functional characterization of human receptors for short chain fatty acids and their role in polymorphonuclear cell activation. *J Biol Chem* 2003;278:25481–9.
27 Brown AJ, Goldsworthy SM, Barnes AA, *et al*. The orphan G protein-coupled receptors Gpr41 and Gpr43 are activated by propionate and other short chain carboxylic acids. *J Biol Chem* 2003;278:11312–9.
28 Priyadarshini M, Villa SR, Fuller M, *et al*. An acetate-specific GPCR, FFAR2, regulates insulin secretion. *Mol Endocrinol* 2015;29:1055–66.
29 Karaki S-I, Tazoe H, Hayashi H, *et al*. Expression of the short-chain fatty acid receptor, Gpr43, in the human colon. *J Mol Histol* 2008;39:135–42.
30 Tazoe H, Otomo Y, Karaki S-I, *et al*. Expression of short-chain fatty acid receptor Gpr41 in the human colon. *Biomed Res* 2009;30:149–56.
31 Yamashita H, Fujisawa K, Ito E, *et al*. Improvement of obesity and glucose tolerance by acetate in type 2 diabetic Otsuka Long-Evans Tokushima Fatty (OLETF) rats. *Biosci Biotechnol Biochem* 2007;71:1236–43.
32 Sakakibara S, Yamauchi T, Oshima Y, *et al*. Acetic acid activates hepatic AMPK and reduces hyperglycemia in diabetic KK-A(Y) mice. *Biochem Biophys Res Commun* 2006;344:597–604.
33 Schimmack G, Defronzo RA, Musi N. AMP-activated protein kinase: role in metabolism and therapeutic implications. *Diabetes Obes Metab* 2006;8:591–602.
34 Goswami C, Iwasaki Y, Yada T. Short-chain fatty acids suppress food intake by activating vagal afferent neurons. *J Nutr Biochem* 2018;57:130–5.
35 Ahima RS, Antwi DA. Brain regulation of appetite and satiety. *Endocrinol Metab Clin North Am* 2008;37:811–23.
36 Park JE, Kim JY, Kim J, *et al*. Pomegranate vinegar beverage reduces visceral fat accumulation in association with AMPK activation in overweight women: a double-blind, randomized, and placebo-controlled trial. *Journal of Functional Foods* 2014;8:274–81.