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Original article

A Preliminary Study on the Effects of Lemon Juice and Vitamin C on Postprandial Glucose in Overweight Nondiabetic Adults

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Abstract
Postprandial hyperglycemia, together with obesity and elevated body mass index, represents a significant risk factor for the development of type 2 diabetes mellitus. Acidic foods and antioxidants have been suggested to modulate postprandial glycemic responses. This preliminary study aimed to investigate the effects of lemon juice and vitamin C supplementation on postprandial blood glucose concentrations in overweight adults. A randomized crossover trial was conducted in which participants co-ingested a standardized bread meal with water, lemon juice, or vitamin C at two doses (500 mg and 1000 mg). Capillary blood glucose concentrations were measured over a 180-min postprandial period. Co-ingestion of lemon juice and both doses of vitamin C significantly attenuated postprandial glycemic responses compared with water. Peak glucose concentrations were markedly lower following lemon juice and vitamin C supplementation, accompanied by a more gradual post-peak decline. These effects were further reflected by significant reductions in the incremental area under the curve ($iAUC_{0-180}$) following lemon juice and the higher vitamin C dose, with a borderline reduction observed at the lower dose, indicating a dose-dependent effect. Overall, these findings support a potential role for lemon juice and vitamin C in postprandial glycemic modulation and highlight the need for confirmation in larger, longer-term studies assessing dose–response relationships and their potential to delay progression to type 2 diabetes mellitus.
Keywords. Glycemic Index, Lemon Juice, Vitamin C, Overweight.

Introduction

Type 2 diabetes mellitus (T2DM) is the most prevalent metabolic disease worldwide, characterized by its increasing prevalence and incidence, chronicity, and association with severe long-term vascular and neuropathic complications [1,2]. Approximately 589 million adults aged 20–79 years were living with diabetes worldwide in 2024, a number projected to rise substantially in the coming decades [3].
During the prediabetes stage, individuals may present with impaired fasting glucose (IFG) and/or impaired glucose tolerance (IGT), characterized by blood glucose concentrations that are elevated above normal but do not meet the diagnostic criteria for T2DM [4]. Importantly, a substantial proportion of individuals with prediabetes progress to T2DM over time, with reported annual conversion rates of 5–10% and cumulative progression estimates of approximately 25–50% over several years of follow-up [4]. Lifestyle factors, such as diets high in saturated fats and refined carbohydrates and reduced physical activity, promote metabolic dysregulation and insulin resistance, increasing the risk of impaired glucose tolerance and T2DM [2]. Furthermore, excess adiposity and obesity are significant contributors to these conditions, with populations exhibiting higher body mass index (BMI) progressively associated with greater disease risk [5].
To improve postprandial glycemic control, a range of dietary strategies has been examined, including the consumption of low–glycemic index foods and modifications in meal composition, such as the co-ingestion of carbohydrates with proteins, dietary fiber, or acidic components [6]. In addition, accumulating evidence suggests that specific dietary interventions and food-derived additives—such as vinegar [7], acidic fruit juices including lemon juice [8,9], and selected micronutrients and antioxidant-rich compounds [10,11]—may further attenuate postprandial glycemic responses.
Moreover, free radical–mediated oxidative stress plays a critical role in the pathogenesis of diabetes mellitus and its associated complications [12,13]. Consequently, antioxidant-rich dietary components and antioxidant supplementation have been proposed as potential modulators of glucose metabolism. Building on this understanding, the present study aimed to evaluate the effects of concomitant consumption of vitamin C supplementation or lemon juice with a starch-rich food (bread) on postprandial plasma glucose concentrations in a sample of overweight, nondiabetic adults.

Materials And Methods

Subject Criteria

Participants were eligible for inclusion if they were apparently healthy adults aged 18–60 years, including men and non-pregnant women, with a body mass index (BMI) of 25.0–29.9 kg/m². Exclusion criteria included known allergy or intolerance to any components of the test meals, excessive alcohol consumption, engagement in intense physical exercise, current smoking or smoking cessation within the previous three months, a history of eating disorders, diagnosed diabetes mellitus, or other medical conditions known to affect nutrient absorption or gastrointestinal function. Participants were also excluded if they were using anticoagulant therapy or taking medications known to influence appetite or glucose metabolism.

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Informed Consent
All volunteers provided written informed consent after receiving oral information about the study's aims and protocol. Participants were not informed of the specific objective of the study; however, they were told that the research aimed to improve understanding of the digestion of starch-rich meals when consumed in combination with commonly consumed beverages or vitamin supplements.

Test Meals
Each test meal consisted of 5–6 slices (100 g) of crustless wheat toast bread (Tartine white bread, Malta) and either 250 mL of spring water (Dajla, Libya), lemon juice, or vitamin C supplementation (Purafit, Germany) administered at doses of 500 mg or 1000 mg. Vitamin C effervescent tablets were dissolved in 250 mL of water prior to consumption. Lemon juice was prepared by mixing 125 mL of freshly squeezed lemon juice with 125 mL of spring water in a 1:1 ratio, providing approximately 50–65 mg of vitamin C [14].

Study Design
The participants were randomized into two groups; all participants underwent all intervention conditions in a randomized crossover design with a one-week washout period, during which they received the test meals for breakfast concomitantly with either water, lemon juice, or vitamin C (1000 mg) in the first experiment, or vitamin C (500 mg) in the second experiment. All participants were instructed to complete the checklist and conduct two baseline blood glucose measurements between 09:00 and 09:15. The breakfast (test meal) was consumed consistently over a duration of 12 to 15 minutes, between 09:15 and 09:30. Following the initiation of breakfast, blood glucose levels were measured at 15, 30, 45, 60, 90, 120, 150, and 180 minutes. Each participant was instructed to consume water or one of the other fluids concomitantly while ingesting 100 g of the bread (trial meal) after removal of the crusts.

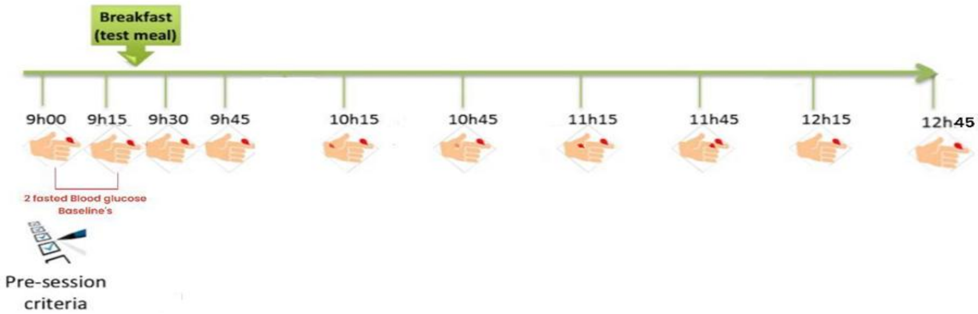

Figure 1. Overview of the study design

Measurements
Each participant self-monitored capillary blood glucose using the finger-prick method with a monitoring kit provided by the research team before data collection. Participants received instructions on correct device use to ensure accurate and consistent measurements. The kit consisted of single-use Accu-Chek Softclix lancets, an Accu-Chek Active glucose meter, and corresponding test strips (Roche Diabetes Care France, Meylan, France). Capillary blood glucose measurements obtained with the Accu-Chek Active glucose meter correspond to plasma glucose concentrations. Participants performed two repeated measurements at baseline and single measurements at all subsequent time points. Meal consumption times, blood glucose concentrations, and measurement times were recorded using a standardized form provided by the research team, and blood glucose values and timestamps were verified using data stored in the glucose meter memory.

Statistical Analysis
Postprandial blood glucose concentrations were expressed as changes from baseline (0 min). The incremental area under the curve ($iAUC_{0-180}$) was calculated using the trapezoidal method and used as an index of postprandial glycemic response. Statistical analyses were performed using SPSS software (IBM, Chicago, IL, USA). Owing to the crossover design, differences between interventions (water, lemon juice, vitamin C 500 mg, and vitamin C 1000 mg) were analyzed using paired t-tests. A p-value < 0.05 was considered statistically significant.

Results
Demographic Characteristics of participants
Six volunteers (overweight participants; 4 males and 2 females) were recruited for the study. The mean age was 29y and the average weight and BMI were 82.83±2.1kg and 28±0.6, respectively, while the mean fast blood glucose levels were 90.1±1.3mg/dL, and the average HbA1C was 4.9167±0.08 kg/m^2.

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Table 1. Demographic Characteristics of Individuals (gender, age, weight, FBG, HbA1C, and BMI)

Variables	**Total participants**
number	6
Gender Male (%) Female (%)	- 4 (66.6%) 2 (33.3%)
Age/year (±SEM)	29±1.6
Weight/kg (±SEM)	82.83±2.1
BMI (kg/m^2)	28±0.6
FBG (mg/dl) (±SEM)	90.1±1.3
HbA1C (%)	5.0±0.08

Postprandial Blood Glucose Responses

Changes in postprandial blood glucose levels and incremental area under the curve (iAUC$_{0-180}$) among participants (water, lemon juice, and vitamin C 1000 mg)

Postprandial blood glucose levels for the water, lemon juice, and vitamin C (1000 mg) trials are shown in (Figure 2). Blood glucose peaked and reached maximum levels at 60 min in all conditions. At 60-min the glucose level was higher in the water group (166 ± 15 mg/dL) than in the lemon juice (129 ± 10 mg/dL; p = 0.04) and vitamin C groups (122 ± 11 mg/dL; p = 0.008), indicating attenuation of the postprandial peak by both interventions. After 60 min, glucose levels declined more gradually in the lemon juice and vitamin C trials compared with the sharper decrease observed in the water trial. In line with the observed postprandial blood glucose profiles, the incremental area under the curve (iAUC$_{0-180}$) was lower following lemon juice and vitamin C 1000MG compared with water, reaching statistical significance for both lemon juice and vitamin C 1000mg (P =0.012, P=0.048), respectively.

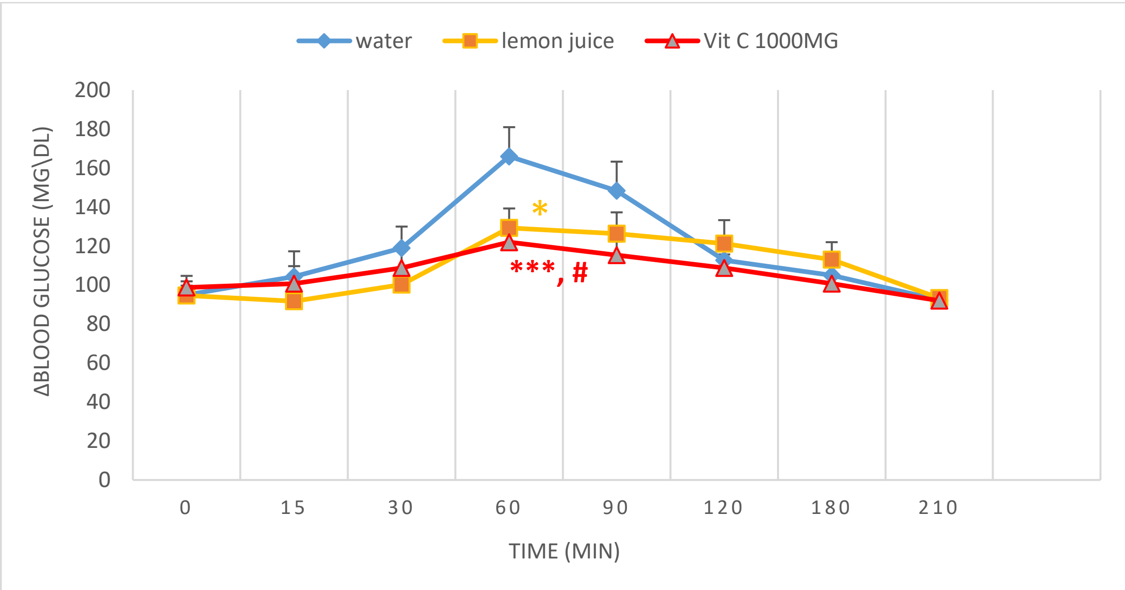

Figure 2. Changes in the postprandial blood glucose levels among participants (after water, lemon juice, and vitamin C 1000 mg). Values are expressed as mean + S.E.M, ***p<0.001 ** and *p<0.05 in comparison to water intake, and #p<0.05 in comparison to Limon juice.

Changes in postprandial blood glucose levels and incremental area under the curve (iAUC$_{0-120}$) among participants (water, lemon juice, and vitamin C 500mg)

Postprandial blood glucose responses under the water, lemon juice, and vitamin C (500 mg) conditions within the same participants are presented in (Figure 3). In all crossover conditions, blood glucose levels peaked at 60 min following the standard bread meal intake. At 60 min, postprandial glucose concentrations were significantly higher during the water condition (152.33 ± 13.34 mg/dL) compared with both the lemon juice (118.33 ± 10.03 mg/dL; p = 0.016) and vitamin C (500 mg) conditions (114.33 ± 6.98 mg/dL; p = 0.03), These within-subject comparisons indicate that both lemon juice and vitamin C supplementation attenuated the postprandial glucose peak relative to water. Consistent with these findings, the incremental area under the curve (iAUC$_{0-180}$) for vitamin C (500 mg) was lower than that of the water condition, reaching borderline statistical significance (p = 0.05).

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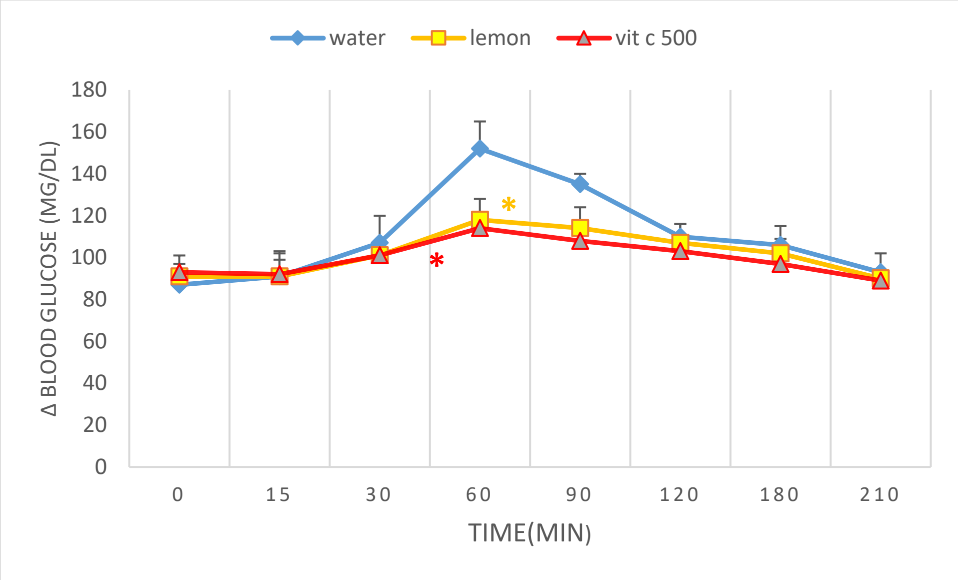

Figure 3. Changes in the postprandial blood glucose levels among overweight participants (after water, lemon juice, and vitamin C 500 mg). Values are expressed as mean + S.E.M, *p <0.05 in comparison to water intake

Discussion

This preliminary study demonstrates that co-ingestion of lemon juice or vitamin C (500 mg and 1000 mg) with a standardized bread meal significantly attenuates postprandial glycemic responses compared with water in overweight adults. Although blood glucose concentrations peaked at 60 minutes under all conditions, peak values were markedly lower following lemon juice and vitamin C supplementation. This attenuation was accompanied by a more gradual post-peak decline, indicating modulation of postprandial glucose dynamics. In line with these profiles, $iAUC_{0-180}$ values were significantly reduced following lemon juice and the higher vitamin C dose, with a borderline reduction observed at the lower dose, supporting a dose-dependent effect. These findings are consistent with previous clinical studies and meta-analysis reporting reductions in postprandial glycemic responses following consumption of acidic foods and beverages, including vinegar [15,16], pickled foods [17], and pomegranate juice [18]. The low pH of these foods is widely considered a key determinant of their glycemic-lowering effects [8,19]. One proposed mechanism involves inhibition of salivary α-amylase activity during gastric digestion, leading to delayed starch hydrolysis [20]. In addition, acidic foods may slow gastric emptying, further attenuating postprandial glucose responses [21]. Collectively, these mechanisms support the hypothesis that the low pH of lemon juice contributes to its glycemic-modulating effects. Although the present study was conducted in overweight, non-diabetic adults, our findings run parallel to previous studies performed in patients with type 2 diabetes mellitus. Those studies have consistently shown that vitamin C can act as an adjunct to improve glycemic control, with reported reductions in fasting and postprandial glucose levels and HbA1c, particularly when administered alongside standard antidiabetic therapy. [22] The effects on FBG were found to be significant with a single intake of vitamin C versus placebo in a previous meta-analysis of randomized controlled trials [23]. Another systematic review and meta-analysis involving 1447 patients with type T2DM showed a significant reduction in serum HbA1c, fasting insulin, and fasting blood glucose levels after a high dose of vitamin C supplementation (≥1000 mg/day) for extended periods (≥12 weeks) which suggest to enhance glycemic control in T2DM patients [24]. However, the literature remains controversial in this context, Ashor et al.'s meta-analysis of 22 RCTs (on 937 adults) found no glycaemic benefit of vitamin C in the general population, but significant reductions in glucose and HbA1c emerged among participants with type 2 diabetes. [25]. This suggests that outcomes may depend on factors such as dose, duration, and patient characteristics. In conclusion, this preliminary trial indicates that co-ingestion of lemon juice or vitamin C significantly attenuates postprandial glycemic responses in overweight, non-diabetic adults. Given that elevated postprandial hyperglycemia represents an early metabolic abnormality associated with increased risk of progression to T2DM, interventions that reduce postprandial glycemic responses may have important clinical relevance in delaying disease onset. Nevertheless, larger-scale studies with longer intervention durations and broader dose ranges are required to more comprehensively evaluate their potential in modulating postprandial glycemia and reducing diabetes risk.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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