Metabolism Open 20 (2023) 100260

Contents lists available at ScienceDirect

Metabolism Open

journal homepage: www.sciencedirect.com/journal/metabolism-open

The effects of mango consumption on vascular health and immune function

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ARTICLE INFO

Keywords:
Mango
VCAM-1
Antioxidant enzymes
Vascular health
Immune function

ABSTRACT

Objectives: Heart disease, caused by atherosclerosis, is the leading cause of death. Maintaining vascular integrity is crucial to reducing atherosclerosis risk. Mangos are rich in fiber, vitamins, minerals, and phytochemicals that may offer cardioprotective and immune-boosting benefits. However, their effects on the vasculature and immune system in adults with overweight and obesity remain unclear. The objective of this study was to investigate the effects of mango consumption on vascular health and immune function in adults with overweight and obesity.
Methods: In a 12-week, crossover study, 27 overweight and obese participants consumed either 100 kcals of mangos daily or isocaloric low-fat cookies daily. Fasting blood samples were collected at baseline, week 4, and week 12 and analyzed for vascular cell adhesion molecule-1 (VCAM-1), intercellular adhesion molecule-1 (ICAM-1), P-selectin, E-selectin, sCD4, sCD8, sCD3E, and sCD45, tumor necrosis factor-alpha (TNF-α), catalase (CAT), glutathione peroxidase (GPx), and superoxide dismutase (SOD).
Results: Mango consumption significantly decreased VCAM-1 between baseline and week 4 ($P = 0.046$) and week 12 ($P = 0.004$). CAT increased between baseline and week 12 ($P = 0.035$) with mango consumption. GPx increased at week 12 compared to baseline and week 4 ($P < 0.05$). At week 12, SOD was higher after mango consumption compared to low-fat cookie consumption ($P = 0.046$). There were no significant differences in ICAM-1, P-selectin, E-selectin, sCD4, sCD8, sCD3E, sCD45 or TNF-α concentrations ($P > 0.05$ for all non-significant results).
Conclusions: This study suggests that 100 kcals of mangos may benefit the integrity of the vasculature by reducing VCAM-1 and increasing SOD, CAT, and GPx levels. Mangos can be an alternative snack for improving atherosclerosis and oxidative stress risk factors.

1. Introduction

More than 70 % of adults in the United States (US) have either overweight or obesity [1]. Having overweight or obesity is associated with several diseases such as cancer, diabetes, and cardiovascular disease (CVD) [2]. CVD, specifically heart disease resulting from atherosclerosis, is the leading cause of death in the US [3].

Obesity is a major cause of oxidative stress which stimulates inflammation through pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF-α), interleukins (IL)-1, IL-1β, and IL-3, with the former two cytokines being pro-atherogenic [2,4]. Overweight and obesity are also associated with increased C-reactive protein (CRP) levels which acts as a mediator of atherosclerosis [5]. It has been previously shown that CRP can induce cell adhesion molecule expression of intercellular adhesion molecule-1 (ICAM-1), vascular cell adhesion molecule-1 (VCAM-1), E-selectin, and P-selectin [6,7]. These adhesion molecules function in the leukocyte adhesion cascade that is part of the inflammatory response [8,9], and may serve as markers of endothelial damage and/or atherosclerosis [10].

Recommending individuals with overweight and obesity to incorporate more fruits and vegetables in their diet can be an effective strategy toward improving overall health, particularly for CVD [11,12]. High intakes of fruit and vegetables can be protective against inflammation and endothelial dysfunction [13,14]. Mangos (*Mangifera indica* L.) are a popular stone fruit commonly eaten throughout the world. It is rich in antioxidants, such as ascorbic acid and carotenoids, and polyphenols, such as flavonoids and mangiferin [15,16]. In fact, mangiferin provides many health properties such as acting as an antioxidant, antidiabetic, anticancer, and immunomodulatory [17–20]. Previous research has shown that mango consumption can increase antioxidant capacity in healthy volunteers [21]. More recently, consuming mangos increased antioxidant capacity in volunteers with overweight and obesity while also decreasing CRP concentrations [22]. This may suggest that mango consumption can improve vascular health by decreasing the

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https://doi.org/10.1016/j.metop.2023.100260
Received 26 August 2023; Received in revised form 6 October 2023; Accepted 9 October 2023
Available online 13 October 2023

expression of adhesion molecules. However, little is known about the effects of mango consumption on vascular health and its immune boosting capacity or function in adults with overweight and obesity.

The purpose of this study was to investigate the effects of daily mango consumption for 12 weeks on the serum concentration levels of cell adhesion molecules, immune and inflammation markers, and antioxidant enzymes in participants with overweight and obesity. We hypothesized that mango consumption for 12 weeks will improve vascular health, and immune and inflammation markers while also improving antioxidant enzymes.

2. Materials and methods

2.1. Study design

This intervention was a crossover study that had two 12-week interventions with a 4-week washout period between interventions. Details on the study design have already been previously described by Rosas et al. [22]. Briefly, participants were randomized into either the mango intervention group or the low-fat cookie group. Participants were required to make three study visits at baseline, week 4, and week 12. Participants came to the laboratory in a fasted state (≥10 h) where blood samples were obtained. Blood samples were centrifuged, and serum was stored at −80 °C for later analyses. Twenty-four hours prior to each laboratory visit, participants were instructed to refrain from caffeine and alcohol consumption, and exercise. During the intervention, participants consumed a pre-portioned amount of 100 kcals of either fresh mangos or low-fat cookies daily. During the washout period and low-fat cookie intervention, participants were instructed to refrain from eating mangos. All participants were instructed to maintain their usual diet and physical activity level for the duration of the study. The study protocol was approved by San Diego State University's Institutional Review Board Committee and all participants provided informed written consent prior to enrollment. This trial was registered at ClinicalTrials.gov (NCT03957928).

2.2. Participants

Twenty-seven participants (16 males, 11 females; mean age 26.0 ± 8.1 years; mean BMI 31.8 ± 4.1 kg/m^2) were recruited locally by posted flyers. At baseline, the mango group had a mean body weight of 94.2 ± 14.7 kg and BMI of 31.6 ± 4.1 kg/m^2, and the low-fat cookie group had a mean body weight of 94.8 ± 14.5 kg and BMI of 31.9 ± 4.1 kg/m^2 (Table 1). Relatively healthy (i.e., without diagnosed conditions and not on medications) volunteers that were between the ages of 18–55 years with a BMI ≥26 kg/m^2 were included in the study. Individuals that had a mango or gluten allergy, conditions resulting in metabolic disorders or chronic inflammation, took prescription dietary supplements, were pregnant or lactating, had irregular menstrual cycles, or were smokers were excluded from participation.

Table 1
Participant demographic information.

Characteristic	Participants (n = 27)
Age (y)	26.0 ± 8.1
Sex	
Male	16
Female	11
Height (cm)	172.4 ± 8.4
Weight (kg)	94.5 ± 14.6
Body fat (%)	40.15 ± 9.1
BMI (kg/m^2)	31.8 ± 4.1
BMI classification	
Overweight	13
Obesity	14

Data are expressed as means ± SDs except for sex and BMI classification, which are expressed as the number of participants. Body fat was measured via DXA (dual-energy X-ray absorptiometry). BMI classifications: Overweight (25–29.9 kg/m^2). Obesity (≥30 kg/m^2). BMI, body mass index.

2.3. Biomarkers

2.3.1. Cell adhesion molecules

Serum concentrations of VCAM-1, ICAM-1, E-selectin, and P-selectin were measured using enzyme-linked immunosorbent assay (ELISA) kits (R&D Systems, Inc., Minneapolis MN; catalog #DVC00, #DCD540, #DSLE00, and #DPSE00, respectively). The microplates were precoated with a monoclonal antibody specific for human VCAM-1, wild type human ICAM-1, E-selectin, and P-selectin, respectively. Both VCAM-1 and ICAM-1 were conjugated to horseradish peroxidase (HRP) and incubated with a substrate solution of Color Reagent A (stabilized hydrogen peroxide) and Color Reagent B (stabilized chromogen) followed by a stop solution. The optical density was read using a microplate reader set at a wavelength of 450 nm.

2.3.2. Immune and inflammation markers

Soluble CD4 and CD8 in serum samples were measured using a solid-phase sandwich ELISA kit (Invitrogen, Thermo Fisher Scientific, Waltham, MA, catalog #EH90RB and MyBioSource, San Diego, CA, catalog #MBS722786, respectively). Soluble CD3 epsilon (sCD3E) chain and CD45 were measured using a competitive ELISA kit (MyBioSource, catalog #MBS7244372 and #MBS7233139, respectively). Samples were incubated with biotin conjugate followed by streptavidin-HRP. After incubation, the absorbance was read with a microplate reader set at a wavelength of 450 nm.

TNF-α was measured using a solid-phase sandwich ELISA kit (Thermo Fisher Scientific, catalog #50-180-59). Samples were incubated with a biotin conjugate solution followed by the addition of streptavidin-HRP. After incubation, the absorbance was read at a wavelength of 450 nm.

2.3.3. Antioxidant enzymes

Catalase (CAT) was measured using an assay kit (Cayman Chemical, Ann Arbor, MI, catalog #707002). The catalase enzyme activity was measured using a reaction of catalase and hydrogen peroxide, with the addition of potassium hydroxide to terminate the reaction. The absorbance was read at a wavelength of 540 nm.

Glutathione peroxidase (GPx) was measured using an assay kit (Cayman Chemical, catalog #703102). GPx activity was measured indirectly by a coupled reaction with glutathione reductase from the reduction of hydroperoxide by GPx. The absorbance was read at a wavelength of 340 nm.

Serum SOD activity was measured using a SOD assay kit (Cayman Chemical, catalog #706002). The SOD assay procedure utilizes tetrazolium salt for detection of superoxide radicals generated by xanthine oxidase and hypoxanthine. The procedure began by adding diluted Radical Detector (tetrazolium salt solution) and the sample to each well. Xanthine oxidase was then added to the wells, mixed, then incubated for 30 min at room temperature. After incubation, the absorbance was read at a wavelength of 450 nm.

2.4. Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (Version 27; IBM Corp., Armonk, NY). A two-way repeated measure analysis of variance (ANOVA) was used to examine the effects of mango and low-fat cookie consumption on all biomarkers (VCAM-1, ICAM-1, E-selectin, P-selectin, sCD4, sCD8, sCD3E, sCD45, CAT, GPx, and SOD) over time. Paired t-tests were also performed to examine the baseline differences between week 4 and week 12, and between groups for all biomarkers. If the paired *t*-test indicated a significant difference at baseline between groups, then baseline values were used as covariates

for subsequent analyses. However, there were no significant baseline differences. Intra-assay coefficients of variations (CV) for biochemical measures were calculated by dividing the standard deviation (SD) of a set of measurements by the set mean and multiplying by 100. A post hoc power analysis was performed using G*Power (Version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). This study had a statistical power of 0.80. Data are expressed as means ± SDs. A p-value ≤0.05 is considered statistically significant.

3. Results

3.1. Cell adhesion molecules

Mango consumption significantly decreased VCAM-1 concentrations between baseline and week 4 (P = 0.046) and week 12 (P = 0.004) (Table 2). Low-fat cookie consumption did not result in any significant difference between baseline and weeks 4 and 12. When comparing mango to low-fat cookie consumption, there was a non-significant decreasing trend for mango consumption at week 12 (P = 0.065).

Mango and low-fat cookie consumption did not result in any significant differences for ICAM-1 between baseline and weeks 4 or 12; nor were there any significant differences when comparing mango to low-fat cookie consumption in ICAM-1 concentrations. Mango and low-fat cookie consumption also did not result in any significant differences for E-selectin or P-selectin between baseline and weeks 4 or 12. Neither E-selectin nor P-selectin resulted in any significant differences when comparing mango to low-fat cookie consumption (Table 2).

3.2. Immune and inflammation markers

Mango and low-fat cookie consumption did not result in any significant differences for sCD4, sCD8, sCD3E, or sCD45 between baseline and weeks 4 or 12; nor were there any significant differences when comparing mango to low-fat cookie consumption for the aforementioned immune markers (Table 3). There were no significant differences for TNF-α levels between baseline and weeks 4 and 12 or between interventions (Fig. 1A).

Table 2
Effects of mango and low-fat cookie consumption on vascular related inflammatory markers at baseline, week 4, and week 12.

	Mangos (n = 27)			Low-fat cookies (n = 27)		
Measurements	Baseline	Week 4	Week 12	Baseline	Week 4	Week 12
VCAM-1 (ng/mL)	484.3 ± 105.4[a]	470.7 ± 98.1[b]	464.5 ± 91.9[b]	477.4 ± 106.4[ab]	474.5 ± 112.2[ab]	481.9 ± 109.0[ab]
ICAM-1 (ng/mL)	35.63 ± 7.95	36.41 ± 9.34	35.26 ± 8.49	35.05 ± 8.56	35.3 ± 8.24	34.78 ± 7.09
E-Selectin (ng/mL)	18.22 ± 9.91	16.84 ± 10.48	18.77 ± 10.81	18.58 ± 10.43	17.91 ± 8.33	19.28 ± 13.04
P-Selectin (ng/mL)	95.72 ± 33.39	97.26 ± 31.27	94.56 ± 34.89	102.23 ± 33.81	103.51 ± 33.39	97.64 ± 37.34

Data are expressed as means ± SDs. Superscript letters (a and b) denote statistical significance (P ≤ 0.05). Data within rows with superscripts of differing letters indicate significant differences between variables; and data with superscripts of the same letters indicate no significant (P > 0.05) differences between variables. Statistical significance for mango consumption for VCAM-1 between baseline and week 4 (P = 0.046) and week 12 (P = 0.004), and a non-significant trend between mango and low-fat cookie consumption at week 12 (P = 0.065). Intra-assay coefficients of variation were as follows: VCAM-1, 3.48; ICAM-1, 4.30; P selectin, 4.02; E selectin, 4.36. VCAM-1, vascular cell adhesion molecule-1, ICAM-1, intercellular adhesion molecule-1.

Table 3
Effects of mango and low-fat cookie consumption on immune function biomarkers at baseline, week 4, and week 12.

	Mangos (n = 27)			Low-fat cookies (n = 27)		
Measurements	Baseline	Week 4	Week 12	Baseline	Week 4	Week 12
sCD4 (ng/mL)	42.8 ± 60.0	43.0 ± 60.3	42.1 ± 60.3	42.4 ± 60.5	41.8 ± 58.6	42.2 ± 59.9
sCD8 (ng/mL)	0.78 ± 0.23	0.75 ± 0.21	0.80 ± 0.30	0.81 ± 0.22	0.79 ± 0.21	0.82 ± 0.29
sCD3E (ng/mL)	3.01 ± 2.35	3.19 ± 2.27	3.23 ± 2.23	2.96 ± 2.10	2.94 ± 1.86	3.11 ± 2.07
sCD45 (ng/mL)	51.5 ± 9.88	50.4 ± 6.50	52.5 ± 6.41	52.0 ± 7.23	52.2 ± 8.37	52.4 ± 7.69

Data are expressed as means ± SDs. Data within rows with different superscript letters indicate statistical significance (p ≤ 0.05). Data without superscript letters indicated non-significance. Intra-assay coefficients of variation were as follows: CD4, 8.29; CD8, 4.25; CD3E, 4.35; CD45, 4.40. sCD4, sCD8, and sCD45, soluble CD4, CD8, and CD45, respectively; sCD3E, soluble CD3 epsilon.

3.3. Antioxidant enzymes

Mango consumption resulted in a non-significant increasing trend for SOD between baseline and week 12 (P = 0.068) (Fig. 1B). When comparing mango to low-fat cookie consumption, mango consumption resulted in a significant increase in SOD at week 12 (P = 0.046). For CAT, mango consumption resulted in a significant increase at week 12 compared to baseline (P = 0.035) whereas CAT did not significantly change from baseline to weeks 4 or 12 with low-fat cookie consumption (Fig. 1C). Mango consumption also resulted in a significant increase in GPx activity at week 12 compared to baseline and week 4 (P < 0.05) (Fig. 1D). Low-fat cookie consumption did not significantly change GPx activity from baseline to weeks 4 or 12.

4. Discussion

This study investigated the effects that daily mango consumption for 12 weeks had on vascular health and immune function by measuring serum concentrations levels of cell adhesion molecules, immune and inflammatory markers, and antioxidant enzyme markers. Based on the results of this study, mango consumption decreased VCAM-1 concentrations and increased SOD concentrations while also improving CAT and GPx. However, the results also showed that mango consumption had no effect on immune or inflammation markers. These results suggest that daily mango consumption may offer potential health benefits toward vascular health.

In the present study, VCAM-1 concentrations were significantly lowered with mango consumption, and there was a non-significant decreasing trend with mango consumption compared to low-fat cookie consumption at week 12. VCAM-1 is a cell adhesion molecule responsible for strengthening the adhesion and arresting the leukocytes to the endothelium prior transmigration into the subendothelial space at sites of inflammation [8,9]. This indicates that mango consumption may decrease inflammation activity within the endothelium of the arterial walls. It is possible that the antioxidant properties of mangiferin in mangos may be reducing endothelial dysfunction and maintaining homeostasis by reducing endoplasmic reticulum stress induced TXNIP/NLRP3 inflammasome activation, or by the positive regulation of AMPK activity [23]. Mangos have been shown to decrease CRP concentrations, which may be decreasing VCAM-1 expression [22,24]. Previous research have shown that mango consumption can improve markers of dyslipidemia, which may decrease the amount of circulating low-density lipoprotein (LDL) particles that pass through the endothelium [21,22,25].

Although there is a lack of research on the effects of mango consumption on vascular health, we can make inferences based on other

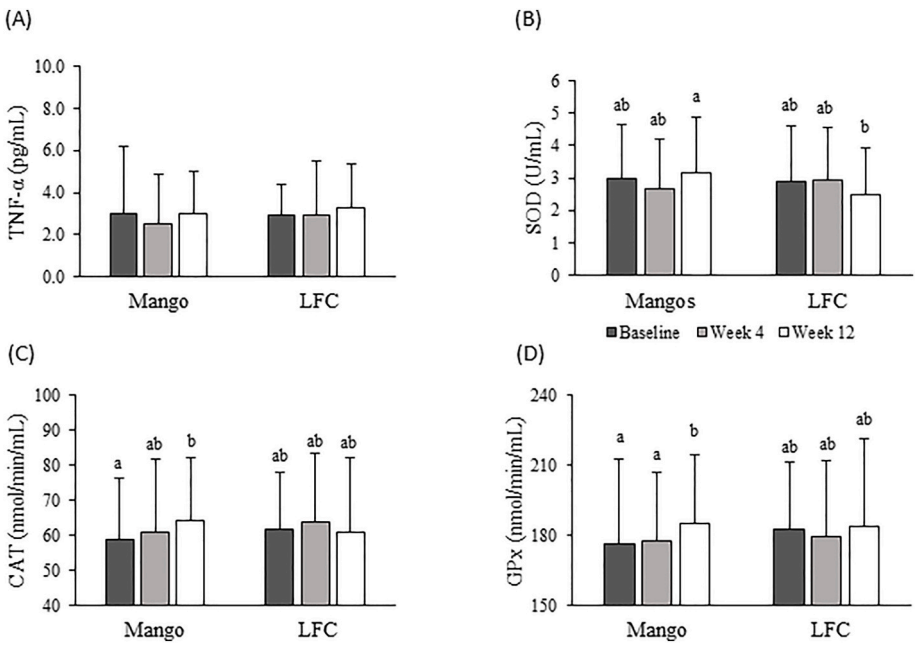

Fig. 1. Effects of mango and low-fat cookie consumption on serum levels of (A) Tumor necrosis factor-alpha (TNF-α); (B) superoxide dismutase (SOD); (C) catalase (CAT); (D) glutathione peroxidase (GPx) at baseline, week 4, and week 12. Data are expressed as means ± SDs. Superscript letters (a and b) denote statistical significance ($P \leq 0.05$). Bars with superscripts of differing letters indicate significant differences between variables; and bars with superscripts of the same letters indicate no significant ($P > 0.05$) differences between variables. Mango consumption compared to low-fat cookie consumption resulted in statistical significance at week 12 for SOD ($P = 0.046$) and a non-significant trend between baseline and week 12 for mango consumption ($P = 0.068$). CAT resulted in statistical significance at week 12 compared to baseline for mango consumption ($P = 0.035$). GPx resulted in statistical significance at week 12 compared to baseline and week 4 for mango consumption ($P < 0.05$). Intra-assay coefficients of variation were as follows: TNF-α, 9.39; CAT, 5.24; GPx, 9.30; SOD, 8.69. LFC, low-fat cookie.

fruits or vegetables. Similar to the results of this study, a recent randomized control trial evaluating the effects of consuming a single avocado daily for 12 weeks compared to a control diet found that VCAM-1 significantly decreased from baseline to week 12 [26]. Likewise, pomegranate juice and vitamin C-rich apple juice decreased VCAM-1 levels post intervention [27,28]. However, pomegranate and apple juice have shown mixed results because other studies have not found significant differences in VCAM-1 concentrations [29–31].

Much like VCAM-1, ICAM-1 is also a cell adhesion molecule responsible for strengthening the adhesion of leukocytes to the endothelium [8,9]. However, ICAM-1 is less prevalent in atherosclerotic cases compared to VCAM-1 [32,33]. The present study did not find any significant differences on ICAM-1 with mango consumption. Similar to the results of the present study, other fruits, such as avocado, cloudy apple juice, and pomegranate juice consumption did not make changes in ICAM-1 concentrations [26,29,30]. However, daily consumption of two fresh apples decreased ICAM-1 concentrations [31] as well as apple juice [28,34].

Prior to VCAM-1 and ICAM-1 acting on the leukocytes adhered to the endothelium, the initial leukocyte recruitment into the vascular tissue begins with selectins capturing leukocytes and rolling them along the epithelium [8,9]. While P-selectins are expressed under inflammatory and non-inflammatory conditions, E-selectins are increased under inflammatory conditions as they need to be synthesized by activated endothelial cells [8,9]. The results of this study did not find any significant differences in either E− or P-selectin concentrations after mango consumption. Koutsos et al. found that daily consumption of two fresh apples did not significantly affect E− or P-selectin [31]. E-selectin concentration was also unaffected by apple juice [28], and pomegranate juice [29]. Likewise, P-selectin concentration was unaffected by beetroot juice [35].

Both sCD4 and sCD8 are released from the activation of T cells which are a part of cell-mediated immunity [36]. While the literature on the effects that mango consumption has on immunity is sparse, one study showed that mangiferin may provide immunoprotective effects by protecting cellular immune responses in rats induced with immunotoxicity [20]. Similarly, an immunomodulatory effect was seen with an in vivo study that showed mangiferin enhanced the concentration of immunoglobins and higher numbers of lymphocytes and neutrophils in mice induced with benzo(*a*)pyrene, which suggest an immunoprotective role [37]. However, the present study did not find similar results as mango consumption did not result in significant effects on immune markers. These differing results might be due to different subject models (animal versus human), or differing biomarkers measured (IgM and IgG versus sCD4, sCD8, sCD45, and sCD3E) and specimens used (whole blood versus serum). These methodological differences may explain why the present study did not result in significant changes in immune markers.

TNF-α is a cytokine that is a regulator of inflammatory responses produced during acute inflammation or during innate immune response [38]. TNF-α is elevated in individuals with overweight and obesity [39]. However, the present study did not find a similar outcome with TNF-α. Freeze-dried mango found no effect on TNF-α in obese individuals after 12 weeks of mango consumption [40], which are consistent with our results. In contrast, animal models have shown that mangiferin can prevent the increase of pro-inflammatory mediators, such as cortical samples of TNF-α and plasma IL-1B in stress-induced rats [41], and reduced plasma levels of TNF-α in rats with gastrointestinal inflammation [42]. The lack of significant changes in TNF-α in the present study may be due to non-elevated baseline levels. Since our population were relatively healthy individuals with no signs of comorbidity, TNF-α was not elevated at baseline. Thus, there may have been little ability to decrease it further.

CAT and GPx are antioxidant enzymes that decompose hydrogen peroxide to water and oxygen [43,44]. Although there were no significant differences observed in immune and inflammation markers with mango consumption, serum levels of antioxidant enzymes CAT and GPx increased after 12 weeks of mango consumption. These results are analogous to previous research where mango consumption increase

antioxidant capacity in adults with overweight and obesity [22] and adults of normal weight [21]. In another study that assessed antioxidant status, mice were administered benzo(*a*)pyrene to induce lung carcinogenesis and found that levels of glutathione, SOD, CAT, GPx, glutathione reductase, vitamin E and vitamin C were decreased. After co-administration of mangiferin, a protective effect against these events was seen when activities of these antioxidant enzymes improved [45]. Both these human and animal studies suggest that mango, or mangiferin enhances antioxidant status and neutralizes reactive species and therefore oxidative stress is reduced [46].

SOD is a potent antioxidant with several proposed benefits to human health [47], and acts as a first line of defense against free radicals and reactive species in cells [48]. In the present study, there was a significant increase in SOD concentrations for mango consumption compared to low-fat cookie consumption. In a study investigating the effects mango pulp had on thioacetamide induced hepatotoxicity in rats, the investigators found that the hepatoxicity induced oxidative stress was decreased with mango pulp, which resulted in increases in SOD concentrations as well [49]. In another study investigating the effects of mangiferin on cerebral ischemia-reperfusion injury in Wistar male rats, it was found that mangiferin increased SOD activity in brain tissue after cerebral ischemic injury [50]. Nuclear factor erythroid 2-related factor 2 (Nrf2) is a gene that is involved with the transcription of major antioxidant genes, such as SOD [51]. Endothelial cells pretreated with mangiferin upregulated the expression of both Nrf2 and SOD-1 after being exposed to a hyperglycemic environment [51].

Previous research has shown that overexpression of SOD can reduce the oxidation of LDL by endothelial cells [52,53]. Mangiferin has been shown to decrease oxidized LDL particles in animal models [54]. During the pathogenesis of atherosclerosis, oxidized LDL particles that are retained within the subendothelial space trigger an inflammatory response that has downstream effects that include the upregulation of adhesion molecules, such as VCAM-1 [4]. Therefore, a possible mechanism to explain the present study's findings may be that the increased SOD after mango consumption might be reducing LDL oxidation, thereby reducing VCAM-1 expression.

Another possible mechanism may be that the increased SOD concentration might be reducing the TNF-α-induced expression of VCAM-1. Lin et al. [55] showed that SOD overexpression in human aortic endothelial cells transfected with adenovirus carrying the human SOD gene blocks the TNF-α –induced VCAM-1 expression, which is being mediated by the inhibition of the JNK phosphorylation pathway. While TNF-α in the present study did not result in significant changes, it is still possible that SOD was blocking VCAM-1 expression through this mechanism. This may explain the possible connection between VCAM-1 and SOD as it relates to vascular health. While human clinical trials that report on both SOD and VCAM-1 concentrations are lacking, a recent study that serum SOD increased and VCAM-1 concentrations decreased in patients with Hashimoto's thyroiditis after 8 weeks of consuming powdered black cumin seeds daily [56].

Although mangiferin is the most studied bioactive compound in mangos, there are other bioactive constituents in fresh mango, such as catechins, anthocyanins, gallic acid, and benzoic acid that may result in the increase in antioxidant enzyme activities [16]. Mango is also a good source of carotenoids, ascorbic acid, and dietary fiber that may contribute to the improved antioxidant enzyme activities [57,58].

5. Limitations and future directions

While being one of the first studies to investigate the effects of mango consumption on vascular health and immunity in individuals with overweight and obesity, there are some limitations. This study had a moderate sample size which may limit the ability to extrapolate the results of this study to the general population. The design of this study only included participants with overweight and obesity. Therefore, we do not know if these results are reproducible in individuals with a healthy BMI. And while the participants of this study had overweight and obesity, they did not have cardiometabolic diseases that would result in elevated VCAM-1, ICAM-1, E-selectin, and P-selectin at baseline, nor were they immunocompromised or had inflammation. Also, this study used serum to obtain soluble forms of the biomarkers measured. It may be beneficial to look for these markers in whole blood as well. Future studies with larger sample sizes should investigate the effects of mango consumption on vascular health in individuals with a healthy BMI, and in participants with diagnosed cardiometabolic diseases, such as atherosclerosis, type 2 diabetes, or hypertension; likewise, mango consumption should be investigated further in a similar population as well as individuals with chronic inflammation or the immunocompromised.

6. Conclusion

In conclusion, the results of this study suggest that 100 kcals of daily mango consumption for 12 weeks may improve vascular integrity by decreasing VCAM-1 and increasing SOD, CAT and GPx concentrations. This suggests that mango consumption might be a healthier snack alternative compared to the low-fat control snack for vascular health and oxidative stress. Further studies are granted to fully elucidate the benefit of mangos toward the vascular endothelium and immunity.

Funding

This study was supported by the National Mango Board [#603024]. The funding source did not have any involvement in the conduct of the research including study design, data collection, analysis and interpretation, and preparation of the article.

Data availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Robert J. Castro: Conceptualization, Data curation, Visualization, Writing – original draft. **Kazandra Pedroza:** Data curation, Visualization, Writing – original draft. **Mee Young Hong:** Conceptualization, Data curation, Funding acquisition, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare there are no competing interests.

Acknowledgements

The authors would like to thank all the study participants for their contributions. The authors would also like to thank Celeste O'Mealy, Sherry Pinneo, and Martin Rosas Jr. for their help with sample collection.

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