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Acceptability of *Moringa oleifera* leaf powder among healthy adults in the United States

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ABSTRACT

Objective: To assess the acceptability of moringa leaf powder, a nutrient-dense plant that has been mostly tested in pre-clinical studies.
Methods: We conducted an acceptability study of different doses of moringa leaf powder in California in 2023. Participants were randomly assigned to one of the three groups (one tsp. ≈ 2.4 g [low dose], two tsp. ≈ 4.8 g [medium dose], or three tsp. ≈ 7.2 g [high dose]) and instructed to consume the moringa powder with foods or beverages for seven days. Participants were interviewed and had their skin carotenoid levels measured at baseline and endline and completed daily surveys on consumption and side effects. The study outcomes were consumption (number of days it was consumed), liking (sum of organoleptic characteristics ratings) and side effects (number of symptoms reported).
Results: Fifty-two participants were enrolled; 96 % completed the study. The number of days that moringa was consumed (Median = 7, Interquartile range:7,7), changes in skin carotenoid levels, and total liking scores did not differ by dose group ($p = 0.56$, $p = 0.79$, and $p = 0.27$, respectively). The number of overall and gastrointestinal (GI) symptoms differed by dose group. Participants in the high dose group self-reported more overall ($p = 0.001$) and GI symptoms ($p = 0.002$) than those in the low dose group.
Conclusions: Compliance in consuming moringa was high for all groups, suggesting that all three doses tested may be acceptable in future moringa supplementation trials. GI symptoms may occur more frequently when the moringa doses are higher than 7 g/day, but they tend to be mild and transient.

1. Introduction

Moringa (*Moringa oleifera,* Moringaceae) is a drought-resistant, nutrient-dense tree with high concentrations of anti-inflammatory plant chemicals in its edible leaves and seeds. Moringa leaf powder is rich in essential amino acids (Freiberger et al., 1998), total protein, and fiber (Leone et al., 2018), as well as vitamins and minerals, such as iron (Leone et al., 2018), calcium, and provitamin A carotenoids (Saini et al., 2014; Olson and Fahey, 2011). Besides its nutritional use, moringa has several therapeutic and prophylactic uses (Olson and Fahey, 2011; Fahey, 2005; Gopalakrishnan et al., 2016). Its medicinal properties have been linked to the presence of antioxidant compounds, including polyphenols and glucosinolates (Tumer et al., 2015).

In animal studies, supplementation with moringa has shown positive effects on several health conditions associated with chronic inflammation, including markers for diabetes, obesity, and metabolic syndrome. Specifically, moringa leaf powder has demonstrated the potential to reduce glucose, total cholesterol, triglycerides, and low-density lipoprotein cholesterol in rabbits (Yasoob et al., 2022). As an isothiocyanate-rich seed extract, it has shown promise in delaying the onset of type 2 diabetes in rats (Waterman et al., 2020), suggesting that moringa could support the management of diabetes.

The effects of moringa consumption on humans remain unclear, although results from a few studies with human subjects are encouraging, especially those from postprandial studies. Adding 20 g moringa leaf powder to a traditional meal on two different days, decreased postprandial glucose in Saharawi refugees with type 2 diabetes, compared to controls, but had no effects on healthy subjects (Leone et al., 2018). In a randomized control trial (RCT) conducted in Spain, moringa consumed as six daily capsules of dry leaf powder (2.4 g/day)

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for 12 weeks significantly decreased fasting blood glucose and glycated hemoglobin (HbA1c) among pre-diabetic subjects (Gómez-Martínez et al., 2022). A higher dose of moringa leaf powder (4 g capsules twice a day) for a four-week supplementation period resulted in no significant differences in fasting plasma glucose or HbA1c and a tendency to reduce blood pressure among treatment-naïve diabetic patients in an RCT in Thailand (Taweerutchana et al., 2017).

Regarding dosage and side effects, a few studies with adults have tested moringa leaf powder given as tablet(s) with daily doses between 4.6 g - 8 g for 40 to 120 days but did not specifically report adverse or side effects (Kumari, 2010; Kushwaha et al., 2014). In the RCT conducted in Spain, GI symptoms were reported as the reason for dropping out from the intervention group ($n = 2$) but were deemed unrelated to the treatment by the investigators (Gómez-Martínez et al., 2022). There were no reports of hypoglycemia in either group in the RCT in Thailand, but four of 16 patients (25 %) in the treatment group reported transient diarrhea that spontaneously resolved within a few days (Taweerutchana et al., 2017).

Moringa leaf powder has also been tested mixed with other foods (Leone et al., 2018; Mogaka et al., 2022), offering a less medicalized, food-based approach. However, due to the somewhat bitter taste of moringa leaves, determining a dose high enough to guarantee the best clinical outcomes while maintaining the acceptability of the supplement is an important consideration. For instance, although Leone and colleagues reported significant positive effects of consuming 20 g of moringa leaf powder on blood glucose levels, the color and taste of the meal that had moringa powder was rated significantly lower than those of meals without it (Leone et al., 2018). Such a high dose, although potentially efficacious, may not be consistently consumed in longer intervention trials. We assessed the acceptability of three different doses of moringa leaf powder among healthy individuals, to build evidence for the design of future moringa clinical studies.

2. Methods

2.1. Study design and setting

The study design was a pre/posttest with three groups, in which participants were randomly assigned to consume one of three doses of moringa leaf powder to test the acceptability of each dose. The study setting was a large urban public university in California and the target population were healthy adults working at the university.

2.2. Study participants

Participant recruitment was conducted through outreach to staff organizations and advertisements, using physical or digital fliers. The study sample included adults (18–65 years old), who were employed and able to communicate in English. The following exclusion criteria were implemented: individuals who were pregnant or lactating, already consumed moringa regularly, had been told that they have diabetes or hypothyroidism, were taking any medication (except occasional use of over-the-counter pain medication and contraceptives), or followed a medically prescribed diet. The target sample size was 60 subjects (~20 per group), which was selected based on availability of resources.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the University of California, Berkeley Institutional Review Board (CPHS # 2022–10-15,659). Written informed consent was obtained from all subjects.

2.3. Intervention

Participants were randomly assigned to one of the three moringa leaf powder daily doses: one tsp. (~2.4 g - low dose), two tsp. (~4.8 g - medium dose), or three tsp. (~7.2 g - high dose). The moringa leaf powder used in this study was certified organic (organic moringa leaf powder was the sole ingredient), approved for marketing and commercially available in the US, and distributed by Kuli Kuli Inc., but it was provided with an unmarked label. Total doses of seven tsp. (~17 g), 14 tsp. (~34 g), or 21 tsp. (~51 g) of moringa powder were provided to participants to take home at the beginning of the study after the enrollment and baseline interview was completed (day 1). Participants were instructed to add the moringa leaf powder to foods and/or beverages each day for seven days. A written handout with dose-specific instructions and two simple recipes and a measuring teaspoon (for standardization purposes) were provided. Daily text messages were sent to participants during morning hours to remind them to consume the moringa powder per their allocated dose.

2.4. Data collection

Study data collection procedures were conducted as follows. The baseline visit coincided in time with study enrollment, and included the following:

1) Participants were interviewed and asked questions about their contact information, sociodemographic characteristics (age, gender, race/ethnicity), moringa consumption (ever and past week), and presence of any digestive problems in the previous 24 h (e.g. diarrhea, bloating, or any other digestive symptoms).

2) Participants had their skin carotenoid level (a biomarker related to fruit and vegetable consumption) measured using the Veggie Meter® (Ermakov et al., 2018). This measurement involved scanning a finger using a quick, non-invasive optical method that required the participant to gently press their non-dominant ring finger against a lens surface, with the help of a spring-loaded cover. The Veggie Meter® employs reflection spectroscopy to quantify carotenoids in the skin and provides skin carotenoid scores on a 0–800 scale. Calibration and steps taken to minimize lens interference followed manufacturer instructions and previous recommendations (Radtke et al., 2021). Three measurements were collected, five seconds apart, and the equipment calculated an average score. Given the high carotenoid content in moringa leaf powder (Fidyasari et al., 2024), changes in skin carotenoid scores were used to complement reported moringa consumption.

3) A research assistant distributed moringa powder packets according to the dose group information. Moringa leaf powder distribution occurred at the baseline visit only.

Between the baseline and endline (days 2–7), monitoring of consumption was done by sending daily text messages to participants with a link to a brief online survey to record moringa leaf powder consumption and any possible side effects in the previous 24 h. Texts were sent at the same time every day during morning hours. A research assistant reviewed responses daily and followed a protocol for immediate reporting of specific side effects to the lead investigator.

The endline visit was similar to the baseline one with regards to the interview and skin carotenoid measurements. However, participants were asked more questions about their consumption of moringa (amount consumed, reasons for not consuming their dose, when and how they consumed it). Participants rated its organoleptic characteristics using a five-point Likert scale with text answer options ranging from *"Dislike it a lot"* to *"Like it a lot"* and corresponding emoji faces. They were also asked what they liked most about the moringa powder, what they did not like, and whether they would be willing to continue consuming it. At the end of the endline visit, participants received a $30 gift card for their participation. Study activities occurred during November 2022–May 2023.

2.5. Study outcomes

We operationalized acceptability based on consumption, liking, and side effects. Consistently, the main outcomes of this acceptability study are:

1) *Moringa Consumption*, defined as the total numbers of days the moringa powder was consumed and measured by self-report using the daily monitoring and endline survey;
2) *Moringa Liking*, defined as the total liking score and quantified as the sum of scores from the ratings of three organoleptic characteristics (taste, texture, and appearance) of the moringa powder that were asked in the endline survey; and
3) *Moringa Side Effects*, defined as the total number of symptoms experienced and measured by self-report over the seven-day period using the daily monitoring and endline survey (including some that were perceived as neutral or positive by participants).

Other outcomes were the *reported dose consumed*, which was quantified as a proportion, i.e. (estimated total dose consumed/assigned total dose) x 100, and then dichotomized as consuming the full assigned dose vs. less; *change in skin carotenoids*, defined as the difference in skin carotenoid score from baseline to endline, based on the Veggie Meter® measurements; and *willingness to continue consuming moringa*, quantified as the proportion of participants who indicated they would be willing to continue consuming the moringa powder in the endline survey. To better understand moringa consumption, we also asked participants about the time of the day when they usually consumed the moringa powder and how they consumed it (i.e., with hot/cold foods or drinks).

We also reported *gastrointestinal (GI) symptoms*, defined as the total number of self-reported GI symptoms over the seven-day study period. Because of moringa's fiber content, and/or the presence of other substances with laxative properties (Jiang et al., 2020), GI symptoms might be more likely related to its intake, so it was considered relevant to report them separately. Finally, because symptoms may have been present even before participants consumed the moringa powder, we also quantified *changes in the number of symptoms in the previous 24 h* between the baseline and endline interviews to take into account any symptoms reported at baseline.

2.6. Data analysis

Participants with missing outcome data were excluded from analysis. Group assignment for analysis was based on the dose participants received and were instructed to consume.

Distributions of baseline and outcome variables were described overall and by dose group as median (Interquartile range), for continuous variables, or frequencies and percentages, for categorical variables. Statistical tests for evaluating by-group differences in continuous outcomes were selected based on whether the within-group distributions were approximately normal (based on visual inspection and normal probability plots) and whether they had approximately equal variances (i.e., if the ratio of the largest to the smallest group variance was ≤ 1.5) (Morgan, 2017). Under these criteria, Kruskal-Wallis tests were performed to test for differences in total acceptability scores and sub-scale scores, total number of symptoms and digestive symptoms reported during the study, and change in the total number of symptoms and digestive symptoms reported at endline vs baseline. Welch's ANOVA was used to test for between-group differences in skin carotenoid change scores, given approximate normality but unequal variances (Morgan, 2017). For categorical outcomes, Chi-square or Fisher's exact tests were used to test for significant by-group differences. As a sensitivity analysis, the change in skin carotenoid by group was modeled accounting for baseline skin carotenoid level using multivariate linear regression. A p-value <0.05 was considered statistically significant. Analyses were conducted using SAS software version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

A total of 52 participants were enrolled in the study, representing 66 % of those who were eligible; 50 participants completed the study indicating a 96 % retention rate (Supplemental Figure). The distribution of participants' gender differed by dose group ($p = 0.002$). No other significant differences between dose groups were detected (Table 1).

Self-report of the total number of days that moringa was consumed did not differ by group ($p = 0.56$). Eighty-eight percent of participants consumed moringa during the full supplementation period (i.e., seven days); no significant differences by dose group were detected in this proportion ($p = 0.65$). The overall proportion who consumed the full dose (i.e., assigned number of teaspoons) was 82 %, with no significant differences observed by dose group ($p = 0.76$), as presented in Table 2. Analysis of the change in skin carotenoid values between the baseline and endline indicated small median change scores (<10 points in all groups) and no significant differences by dose group ($p = 0.79$). Modeling skin carotenoid at the endline while accounting for scores at baseline also resulted in non-significant differences between groups ($p = 0.85$).

Median total liking scores did not differ by dose group ($p = 0.27$), nor did median sub-scales scores for taste ($p = 0.62$), texture ($p = 0.21$) or visual appearance ($p = 0.48$), as shown in Table 3. Most participants (82 %) reported that they would be willing to continue consuming the moringa leaf powder, with no significant differences by dose group ($p = 0.34$). Although most participants reported to have consumed the moringa powder in the morning (56 %), those in the high dose group reported consumption at night more frequently ($p = 0.048$). The most common way to consume the moringa powder was mixed with cold drinks (46 %), with no significant differences by dose group (Supplemental Table).

As shown in Table 4, the number of symptoms self-reported during the study differed by dose group ($p = 0.003$), which seemed to be driven by differences in self-report of GI symptoms ($p = 0.002$). Pairwise comparisons indicated that participants in the highest dose (three tsp./

Table 1
Distribution of characteristics of study participants (healthy adults in California) at baseline[1].

	Overall ($n = 52$)	1 tsp./day (n = 20)	2 tsp./day ($n = 17$)	3 tsp./day ($n = 15$)	P[2]
Age, years[3]	44.5 (30, 56)	42 (31, 54)	39.0 (32, 48)	52 (27, 58)	0.8
Gender					<0.01
Man	15 (28.8)	9 (45.0)	0 (0.0)	6 (40.0)	
Woman	37 (71.2)	11 (55.0)	17 (100.0)	9 (60.0)	
Race/ethnicity					0.4
Latino/a/x or Hispanic	19 (36.5)	7 (35.0)	5 (29.4)	7 (46.7)	
Asian, NHOPI	15 (28.8)	7 (35.0)	3 (17.6)	5 (33.3)	
NH White	9 (17.3)	4 (20.0)	4 (23.5)	1 (6.7)	
NH Black	3 (5.8)	0 (0.0)	3 (17.6)	0 (0.0)	
AIAN	1 (1.9)	0 (0.0)	0 (0.0)	1 (6.7)	
NH Mixed or Other	5 (9.6)	2 (10.0)	2 (11.8)	1 (6.7)	
Reported GI symptoms in the past 24h[4]	5 (9.6)	1 (5.0)	1 (5.9)	3 (20.0)	0.4
Reported Non-GI symptoms in the past 24h[5]	2 (3.9)[6]	1 (5.0)	0 (0.0)[6]	1 (6.7)	0.7
Skin carotenoid score[3]	338 (283, 406)	327 (293, 384)	351 (301, 425)	313 (275, 360)	0.3

AIAN, American Indian or Alaska Native; GI, gastrointestinal; NH, Non-Hispanic; NHOPI, Native Hawaiian, or Pacific Islander.
[1] Data are presented as frequency (%), unless otherwise noted.
[2] Kruskal-Wallis tests for continuous variables or Fisher's exact tests for categorical variables were used.
[3] Data are presented as median (Q1, Q3).
[4] Diarrhea ($n = 1$), bloating ($n = 3$), stomachache (n = 1), and other digestive problems (n = 3) were reported.
[5] Non-GI symptoms reported at baseline: congested, tight chest (n = 1), and regular allergies (n = 1).
[6] Excludes one observation with missing data.

Table 2
Distribution of consumption of moringa leaf powder by participants (healthy adults in California) during the intervention, by dose group[1].

	One tsp./day (n = 19)	Two tsp./day (n = 17)	Three tsp./day (n = 14)	P[2]
No. of days consumed moringa[3]	7.0 (7.0, 7.0)	7.0 (7.0, 7.0)	7.0 (7.0, 7.0)	0.6
Moringa consumption duration				0.6
7 days	17 (89.5)	14 (82.4)	13 (92.9)	
< 7 days	2 (10.5)	3 (17.6)	1 (7.1)	
Moringa dose consumed				0.8
Full assigned dose	16 (84.2)	13 (76.5)	12 (85.7)	
Less than the assigned dose	3 (15.8)	4 (23.5)	2 (14.3)	
Change in skin carotenoid scores[3]	5.0 (−16.0, 26.0)	7.0 (−21.0, 24.0)	1.5 (−11.0, 23.0)	0.8

[1] Data are presented as frequency (%) unless otherwise specified.
[2] *P*-values for statistical differences by group, derived from Chi-square tests for categorical variables, Kruskal-Wallis test for days consumed moringa, and Welch's ANOVA for skin carotenoid scores.
[3] Change in scores between baseline and endline. Data are presented as median (interquartile range).

Table 3
Distribution of liking of moringa leaf powder reported by participants (healthy adults in California) at the endline, by dose group[1].

	One tsp./day (n = 19)	Two tsp./day (n = 17)	Three tsp./day (n = 14)[2]	P[3]
Total liking score	10.0 (8.0, 13.0)	9.0 (7.0, 12.0)	8.5 (6.0, 10.5)	0.3
Liking sub-scores				
Taste	3.0 (3.0, 5.0)	3.0 (2.0, 4.0)	3.0 (2.0, 4.0)	0.6
Texture	4.0 (3.0, 4.0)	3.0 (3.0, 4.0)	3.0 (2.0, 3.0)	0.2
Visual appearance	3.0 (2.0, 4.0)	3.0 (2.0, 3.0)	3.0 (2.0, 3.0)	0.5
Willing to continue consuming Moringa[4,5]	17 (89.5)	12 (70.6)	12 (85.7)	0.3

[1] Data are presented as median (interquartile range), unless otherwise noted.
[2] Sample sizes in this group vary by analysis due to missing data for taste (n = 1), texture (n = 1), and total liking scores (n = 2).
[3] *P*-values for statistical differences by group are derived from Kruskal-Wallis tests for continuous variables or Fisher's exact tests for the categorical variable.
[4] Data are presented as frequency (%).
[5] Versus *No* or *Not sure*.

day) group self-reported more overall symptoms (p = 0.001) and GI symptoms (p = 0.002) than those in the low dose (one tsp./day) group (median = 2 vs. median = 0, respectively). A tendency to report more overall symptoms and GI symptoms in the highest vs the medium dose (two tsp./day) group was also observed (p = 0.084 and p = 0.065, respectively). These results were based on all daily data available, including data from participants who were lost to follow up (n = 2). Among those who completed the trial (n = 50), the median change in the number of self-reported symptoms in the previous 24 h between the baseline and endline was zero and did not differ significantly by dose group, both for overall (p = 0.22) and GI symptoms (p = 0.15).

4. Discussion

We tested three daily doses of moringa leaf powder: low (one tsp./day ≈ 2.4 g/day), medium (two tsp./day ≈ 4.8 g/day) and high dose (three tsp./day ≈ 7.2 g/day) consumed for one week by healthy adults and found no differences in relative consumption and liking of the moringa powder by dose group. Self-reported symptoms, including GI ones, were more frequent among participants in the highest dose group compared to those in the lowest dose group. Nevertheless, at the end of the trial most participants indicated they would be willing to continue consuming it, with no significant differences by dose group.

Table 4
Distribution of side effects self-reported by participants (healthy adults in California) throughout the intervention, by dose group[1].

	One tsp./day (n = 20)	Two tsp./day (n = 17)	Three tsp./day (n = 15)	P[2]
No. of symptoms self-reported during intervention[3]	0.0 (0.0, 1.0)[a]	0.0 (0.0, 1.0)[a,b]	2.0 (1.0, 2.0)[b]	<0.01
No. of GI symptoms self-reported during intervention[3]	0.0 (0.0, 1.0)[a]	0.0 (0.0, 1.0)[a,b]	2.0 (1.0, 2.0)[b]	<0.01
	(n = 19)	(n = 17)	(n = 14)	
Change in the no. of symptoms experienced in the previous 24 h[4]	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 1.0)	0.2
Change in the no. of GI symptoms experienced in the previous 24 h[4]	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 1.0)	0.1

Different superscript letters indicate pairwise significant differences between dose groups (p < 0.05).
[1] Data are presented as median (interquartile range).
[2] P-values for statistical differences by group, derived from Kruskal-Wallis tests.
[3] Based on all daily data available, including data from n = 2 participants who were lost to follow up.
[4] Change between baseline and endline.

This trial showed that compliance with moringa consumption instructions was high, as most participants consumed the full assigned dose of moringa leaf powder and did so during the full supplementation period (seven days). Compliance levels in this study compared well with those reported from RCTs conducted in Thailand and Spain (≥ 80 % compliance in both) where moringa powder was given at higher (4-g-capsule twice a day) and similar (2.4 g/day) doses but encapsulated (Gómez-Martínez et al., 2022; Taweerutchana et al., 2017). This suggests that providing moringa powder with foods that make its taste more perceptible does not necessarily affect compliance, when doses are between 2.4 and 7.2 g.

In this study, responses varied across participants in terms of how much they liked the moringa powder's taste, texture, or visual appearance, but no trends were identified based on the dose received. This variation may be due to personal preferences and/or the different ways study participants incorporated the moringa powder into their foods (e.g., trying it out with different foods to mask taste). Consistent with the low liking scores indicated by some participants in this study, lower ratings of the color and taste of a test meal with 20 g of moringa compared with a meal with no powder added were reported by Leone and collaborators (Leone et al., 2018). Despite this, most participants in this study indicated they were willing to continue consuming moringa powder if they were offered that opportunity, and this did not differ by dose group.

Although participants received and reportedly consumed different daily doses of a plant that is high in carotenoids, we did not observe notable increases in skin carotenoid scores after the study and were unable to detect differences by dose group on changes in skin carotenoid values between the baseline and endline (or at endline while controlling for baseline values). One potential explanation for these results may be related to consumption of other fruit and vegetable sources of carotenoids, which we did not measure and assumed randomization would balance out. It is also possible that the Veggie Meter® measurements were not sensitive to changes in moringa consumption at the specified doses, or that the one-week study period was not long enough to detect changes. A randomized dietary intervention study among diverse racial/ethnic groups in the United States previously demonstrated that Veggie Meter® scores were responsive to increases in daily carotenoid intake over a period of six weeks (Jilcott Pitts et al., 2023). Notably, the authors

of that study found that plasma carotenoids increased in response to the intervention more quickly (evident at the three-week timepoint) than did skin carotenoids (levels increased throughout six-week intervention), likely due to the absorption, distribution, and excretion characteristics of ingested carotenoids as they relate to these tissues. Thus, it is possible a longer intervention would be needed to detect potential changes in skin carotenoid levels in response to moringa consumption.

Reports of side effects from moringa consumption in intervention studies are scarce, even when much higher daily doses (15–30 g/day) were provided to immunocompromised patients (Tshingani et al., 2017; Gambo et al., 2021). In the RCT in Thailand, four of 16 patients (25 %) in the moringa group (8 g/day) reported diarrhea symptoms that self-resolved in a few days (Taweerutchana et al., 2017). GI symptoms associated with moringa leaf consumption may be due to its relatively high fiber content, which was previously quantified as 32.8 ± 0.2 g/100 g of dry weight (Leone et al., 2018). Dietary fiber, made up of non-digestible carbohydrates and lignin, promotes digestion by increasing fecal mass and stimulating peristalsis, but highly fermentable types, such as oligosaccharides, can rapidly increase gas production through microbial fermentation in the large intestine, causing GI discomfort, bloating, and flatulence (El-Salhy et al., 2017). Thus, increases in dietary fiber intake can result in minor (even acute) GI symptoms, but such symptoms usually dissipate after a short adaptation period (Jiang et al., 2020). Moringa also contains the fatty alcohol 1-octacosanol, which has been shown to have laxative effects in mice (Jiang et al., 2020). Given limited research on the latter, along with differing reports regarding the fiber composition of moringa (Leone et al., 2018; Fidyasari et al., 2024), further research on the biochemical composition of moringa leaf powder and its biological effects in humans is warranted to fully explain the reported GI symptoms. Nevertheless, our data suggest that GI symptoms may occur more frequently when the moringa dose is higher than 7 g/day. We found that the median number of GI symptoms reported in the high moringa dose group, although small, was significantly higher than that in the low dose group. It is important to remark that in some cases participants perceived some of these GI symptoms (e.g. more frequent bowel movements) as neutral or even positive.

This study has several limitations. First, we relied on self-reported behaviors of consumption and side effects. People generally over-report socially desirable (or expected) behavior, such as daily consumption that matches the intake instructions received. Our attempts to address this limitation included: a) standardized interviewer training emphasizing avoidance of verbal or body language responses to participants' answers, and b) measurement of skin carotenoid levels, a biomarker for consumption of fruits and vegetables (Ermakov et al., 2018), using a noninvasive equipment that correlates well with plasma or serum carotenoids (Jilcott Pitts et al., 2022). Another limitation was the lack of dietary data, which may have differed by group, potentially affecting consumption and side effects. A third limitation relates to the study's small sample size, which consequently limited statistical power and may have affected our ability to detect significant differences in some outcomes. Lastly, the sample is conformed mostly by individuals who identified as female, limiting the generalizability of the study findings. On the other hand, an important strength of this study was the use of randomization to allocate participants to each dose group. Randomization often results in group balance with regard to known and unknown confounders (Zabor et al., 2020) and in that way reduces extraneous differences (Lichtenstein et al., 2021). Furthermore, the study findings add to the limited body of evidence on the acceptability of moringa, which can inform the design of future clinical studies on its health benefits.

In conclusion, the study results suggest favorable acceptability levels of moringa leaf powder doses between 2.4 and 7.2 g/day among individuals with no particular motivation to consume it. However, the use of a high daily dose of moringa powder (~7.2 g/day) would need to be considered carefully (e.g. balance between benefits and risks) because of potential GI side effects. Starting moringa supplementation at a lower dose and increasing it slowly over time may decrease the risk of GI side effects, if they are due to its fiber content (Borkoles et al., 2022). Given the promising results that moringa leaf powder supplementation has shown in a few studies to improve biomarkers related to diabetes (Leone et al., 2018; Gómez-Martínez et al., 2022) and blood pressure (Taweerutchana et al., 2017), more research evaluating how moringa consumption might improve health outcomes is warranted.

CRediT authorship contribution statement

Susana L. Matias: Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Caitlin D. French:** Writing – review & editing, Project administration, Investigation, Data curation. **Jessica Saavedra:** Writing – review & editing, Investigation. **Akshara Shankar:** Writing – review & editing, Investigation. **Aidan S. Rymland:** Writing – review & editing, Investigation. **Ivan Rodriguez Beltran:** Writing – review & editing, Investigation. **Jose O. Collado:** Writing – review & editing, Investigation. **Carrie Waterman:** Writing – review & editing, Resources, Funding acquisition.

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Declaration of competing interest

Carrie Waterman is a co-inventor on the United States patent application No. 14683730 titled: Extracts from Plants of the Moringaceae Family and Methods of Making. The remaining authors have no conflict of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2025.103048.

Data availability

The authors do not have permission to share data.

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