

Original Article

Development of a Low-Sugar, High-Protein Smoothie for Weight Management

Adeeba Saleem¹, Shahzad Muzammil², Muhammad Naveed Babur³

¹ Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan

² Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan

³ Professor, Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan

✉ Correspondence: Shahzad Muzammil, shahzad.muzammil@superior.edu.pk

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ABSTRACT

Background: Higher-protein foods and beverages are increasingly investigated as components of dietary strategies for weight management because adequate protein may contribute to satiety and preservation of lean tissue during energy restriction. Smoothies provide a practical matrix for combining fruit, vegetables, seeds, protein ingredients, and plant-based beverages. **Objective:** To develop almond-milk-containing high-protein smoothie formulations and evaluate their proximate profile, acidity, pH, viscosity, and sensory acceptability. **Methods:** Four formulations containing fixed quantities of chia seeds, spinach, kale, apples, blueberries, and whey protein were prepared with study-defined almond-milk treatment levels of 0%, 2%, 4%, and 6%. Twenty untrained panelists completed sensory evaluation using a 9-point hedonic scale. **Results:** The non-moisture proximate fractions were reported on a dry-matter basis. After conversion to as-consumed composition, estimated protein increased from 4.00 g/100 g in T1 to 5.09 g/100 g in T4, fiber from 1.70 to 2.43 g/100 g, and fat from 2.03 to 3.20 g/100 g. Titratable acidity ranged from 0.045% to 0.099%, pH from 6.30 to 6.45, and viscosity from 950 to 1600 cP. T4 received the highest sensory scores, including an overall acceptability score of 7.8/9. **Conclusion:** Increasing the almond-milk treatment level was associated with greater viscosity, higher derived as-consumed protein, fat, and fiber concentrations, and improved sensory scores. Direct sugar content and weight-loss efficacy were not evaluated. **Keywords:** Smoothie; High Protein; Almond Milk; Whey Protein; Chia Seeds; Weight Management; Sensory Evaluation; Functional Beverage.

INTRODUCTION

Obesity is a chronic, heterogeneous, multifactorial disease influenced by biological, environmental, behavioral, socioeconomic, and genetic factors. Contemporary obesity management therefore extends beyond isolated dietary changes and may incorporate nutritional intervention, physical activity, behavioral therapy, pharmacotherapy, and metabolic or bariatric surgery according to disease severity and individual clinical circumstances (1).

Dietary interventions intended for weight reduction must establish an appropriate energy deficit while maintaining nutritional adequacy and limiting unnecessary loss of fat-free mass. Loss of skeletal muscle

during weight reduction is clinically relevant because skeletal muscle contributes to physical function, metabolic health, and maintenance of functional capacity (2). Protein intake has consequently received substantial attention in weight-management nutrition. Higher-protein dietary patterns may improve satiety and can assist retention of lean tissue during energy restriction, although magnitude of benefit varies according to total energy intake, protein dose, population characteristics, and the accompanying dietary intervention (3-5). More broadly, body-weight outcomes reflect the overall dietary pattern rather than a single nutrient or food in isolation (6).

Whey protein is a high-quality protein containing all essential amino acids and possesses functional characteristics relevant to beverage formulation, including solubility, emulsification, water binding, and texture modification (7). Meta-analytic evidence has also examined whey or milk-protein supplementation in relation to body weight, body composition, and lean-mass responses, with effects varying according to population, exercise exposure, dose, and background diet (8-10). Incorporation of whey protein into a smoothie can therefore increase protein concentration, but formulation studies alone cannot demonstrate that the resulting beverage causes weight loss or preserves skeletal muscle in consumers.

Smoothies offer a practical food matrix in which fruits, vegetables, seeds, protein ingredients, and plant-derived beverages can be blended while retaining a substantial proportion of the whole-food matrix. Evidence evaluating fruit and vegetable consumption suggests that these foods can be incorporated into dietary patterns compatible with weight control, although their effect on body weight depends on total energy intake, food form, substitution patterns, and the remainder of the diet (11,12). The nutritional composition of an individual smoothie consequently depends strongly on ingredient quantities, processing, dilution, and serving size.

Chia seeds contribute dietary fiber, alpha-linolenic acid, protein, minerals, and several bioactive components. Randomized-trial evidence synthesized in a recent systematic review has examined chia consumption in relation to blood pressure, glycemic outcomes, body weight, and body composition, with effects differing among outcomes and intervention contexts (13). These clinical findings cannot be extrapolated directly to every chia-containing product or to the quantities used within a specific smoothie formulation.

Almonds contribute unsaturated fatty acids, protein, fiber, minerals, and phytochemicals. A systematic review and dose-response meta-analysis of randomized trials found that defined almond interventions can influence selected measures of appetite and body composition, while another meta-analysis evaluated effects of almond intake on cardiovascular risk factors (14,15). Such findings relate to controlled almond interventions and do not establish equivalent effects from the relatively small quantities of almond milk incorporated into the present smoothie formulations.

Apples provide carbohydrate, dietary fiber, vitamins, minerals, and polyphenolic constituents, and their bioactive composition has been extensively characterized (16). Blueberries similarly contain anthocyanins and other polyphenolic compounds that have been investigated in relation to cardiometabolic and vascular outcomes (17). These ingredients may increase the nutritional diversity of a smoothie, although their actual nutrient and phytochemical contribution depends on the amount incorporated and the final serving size.

Leafy green vegetables such as spinach and kale provide micronutrients, carotenoids, and other phytochemical compounds while contributing relatively little energy compared with many energy-dense foods. Kale in particular contains carotenoids whose concentrations vary according to cultivar and pre- and post-harvest conditions (18). Incorporating leafy vegetables into blended products may therefore increase vegetable content, but laboratory analysis is required when precise nutrient composition is to be reported.

Product-development research has demonstrated that chia fortification can alter the proximate composition and fiber content of smoothies, supporting direct laboratory characterization rather than reliance solely on nutrient-composition tables (19). Physicochemical properties such as pH, acidity, and viscosity are also important because formulation changes can alter product handling and sensory characteristics.

The term "low sugar" requires analytical precision. A product can contain no separately added refined sugar while still containing naturally occurring sugars contributed by fruit and other ingredients. Apples and blueberries contain naturally occurring carbohydrate and sugars alongside fiber and bioactive compounds (16,17). Direct measurement or validated compositional estimation of relevant sugars is therefore necessary before a quantitative low-sugar claim can be established.

Similarly, use of the term “high protein” requires interpretation in relation to the protein concentration of the finished product, serving size, energy contribution from protein, and the applicable food-labeling framework. A product-development study can characterize protein concentration, but this does not by itself demonstrate clinical weight-management efficacy.

The present study developed four smoothie formulations containing chia seeds, spinach, kale, apple, blueberries, whey protein, and increasing study-defined levels of almond milk. The objective was to compare their proximate composition, acidity, pH, viscosity, and sensory acceptance as an initial functional-beverage development study relevant to subsequent weight-management research.

MATERIALS AND METHODS

Study Design and Setting

A laboratory-scale product-development study was conducted over six months in the Culinary Laboratory of The Superior University, Lahore, Pakistan.

The ingredients included almonds, chia seeds, kale, spinach, apples, blueberries, whey protein powder, water, and vanilla extract.

Almond-Milk Preparation

Unsweetened almond milk was prepared from 150 g of shelled almonds. The almonds were soaked in approximately 400 mL water for 8–12 hours. After soaking, the water was drained and the almonds were peeled.

The peeled almonds were blended with 1000 mL water and 5 mL vanilla extract for approximately 1–2 minutes until a uniform mixture was obtained. The mixture was filtered through a fine-mesh strainer and stored under refrigeration in an airtight container until use.

Smoothie Preparation

The base smoothie contained:

- 14 g soaked chia seeds;
- 30 g spinach;
- 100 g kale;
- 250 g chopped apples;
- 280 g chopped blueberries;
- 30 g whey protein powder;
- ice as required.

Chia seeds were soaked for approximately 1–2 hours before smoothie preparation. Fresh fruits and vegetables were washed and chopped. All ingredients were combined in a high-speed blender and blended for approximately 2–3 minutes until a thick and smooth consistency was obtained.

Treatment Plan

Four treatment levels were evaluated according to the study-defined percentage of almond milk.

Table 1. Treatment Structure

Treatment	Study-Defined Almond-Milk Level
T1	0%
T2	2%
T3	4%
T4	6%

Proximate Composition and Basis Reconciliation

Moisture, protein, fat, ash, nitrogen-free extract (NFE), and fiber were determined for the four formulations. Examination of the proximate results showed that protein, fat, ash, NFE, and fiber summed to exactly 100% within each treatment while moisture was reported separately. These five non-moisture fractions were therefore interpreted as the dry-matter distribution of the smoothie solids.

For nutritional interpretation of the finished smoothie, the corresponding as-consumed concentration was derived according to the following relationship:

As-consumed component (%) = dry-matter component (%) × (100 – moisture)/100.

This conversion allowed the reported dry-matter distribution to be expressed as grams of each component per 100 g of finished smoothie.

Titrateable Acidity

Titrateable acidity was determined by titrating 10 mL of smoothie against 0.1 N sodium hydroxide using phenolphthalein as the indicator. Results were expressed as percentage lactic-acid equivalent.

pH

The pH of each smoothie formulation was measured under laboratory conditions.

Viscosity

Viscosity was measured using a Brookfield viscometer at 25°C at a constant spindle speed. Values were expressed in centipoise (cP).

Sensory Evaluation

Thirty untrained panelists were initially recruited, while completed sensory evaluations were available from 20 panelists. Coded smoothie samples were evaluated for color, taste, flavor, texture, and overall acceptability using a 9-point hedonic scale, with higher scores indicating greater liking. The 9-point hedonic scale is a well-established approach for measurement of food preference and consumer liking (20).

Ethical approval was obtained from the Institutional Review Board of Superior University, Lahore, Pakistan.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 25. Means, standard deviations, and standard errors were calculated where available. One-way analysis of variance was used for treatment comparisons. For sensory outcomes, the least significant difference values and post-hoc letter groupings generated in the analysis were retained. Statistical significance was defined as $p < 0.05$.

RESULTS

Proximate Composition

Moisture declined progressively from $85.60 \pm 0.13\%$ in T1 to $83.10 \pm 0.29\%$ in T4, corresponding to an increase in total solids from 14.40% to 16.90%.

Within the dry matter, protein increased from $27.80 \pm 0.18\%$ in T1 to $30.10 \pm 0.24\%$ in T4. Fat increased from $14.09 \pm 0.45\%$ to $18.95 \pm 0.55\%$, while fiber increased from $11.82 \pm 0.30\%$ to $14.37 \pm 0.36\%$. NFE decreased from $42.66 \pm 0.40\%$ to $32.35 \pm 0.30\%$ of dry matter.

Table 2. Reported Dry-Matter Proximate Distribution and Moisture

Treatment	Moisture, % as consumed	Protein, % of dry matter	Fat, % of dry matter	Ash, % of dry matter	NFE, % of dry matter	Fiber, % of dry matter
T1	85.60 ± 0.13	27.80 ± 0.18	14.09 ± 0.45	3.63 ± 0.07	42.66 ± 0.40	11.82 ± 0.30
T2	84.75 ± 0.23	28.90 ± 0.20	16.14 ± 0.48	3.88 ± 0.08	38.21 ± 0.35	12.87 ± 0.32
T3	83.90 ± 0.21	29.35 ± 0.22	17.42 ± 0.50	4.04 ± 0.09	35.74 ± 0.33	13.45 ± 0.34
T4	83.10 ± 0.29	30.10 ± 0.24	18.95 ± 0.55	4.23 ± 0.10	32.35 ± 0.30	14.37 ± 0.36

Because the five non-moisture components accounted for the entire dry-matter fraction in each treatment, conversion to an as-consumed basis provided a more directly interpretable nutritional profile for the finished product.

Table 3. Derived As-Consumed Proximate Composition

Treatment	Total Solids, g/100 g	Protein, g/100 g	Fat, g/100 g	Ash, g/100 g	NFE, g/100 g	Fiber, g/100 g
T1	14.40	4.00	2.03	0.52	6.14	1.70
T2	15.25	4.41	2.46	0.59	5.83	1.96
T3	16.10	4.73	2.80	0.65	5.75	2.17
T4	16.90	5.09	3.20	0.71	5.47	2.43

The as-consumed conversion showed that T4 contained the greatest estimated concentrations of protein, fat, ash, and fiber per 100 g of finished smoothie, whereas T1 contained the greatest NFE concentration. Direct mono- and disaccharide concentrations were not measured.

Titrateable Acidity and pH

Titrateable acidity differed across formulations and ranged from $0.045 \pm 0.001\%$ in T3 to $0.099 \pm 0.002\%$ in T1. T4 had a titrateable acidity of $0.072 \pm 0.001\%$.

The pH varied over a relatively narrow range, from 6.30 ± 0.05 in T1 to 6.45 ± 0.07 in T4.

Table 4. Titratable Acidity, pH, and Viscosity

Treatment	Titratable Acidity, %	pH	Viscosity, cP
T1	0.099±0.002	6.30±0.05	950±10
T2	0.063±0.001	6.36±0.06	1250±15
T3	0.045±0.001	6.34±0.08	1550±20
T4	0.072±0.001	6.45±0.07	1600±25

Viscosity

Viscosity increased across the treatment levels. T1 had the lowest viscosity at 950±10 cP, followed by T2 at 1250±15 cP and T3 at 1550±20 cP. T4 had the highest viscosity at 1600±25 cP.

Sensory Evaluation

Sensory ratings increased progressively from T1 to T4. T4 achieved the highest score for every reported attribute, including color 7.6, taste 7.8, flavor 7.7, texture 7.8, and overall acceptability 7.8.

T1 had the lowest overall acceptability score at 7.0, while T2 and T3 had intermediate scores. According to the post-hoc letter groupings, T4 formed the highest sensory group and T2 and T3 showed intermediate acceptance.

Table 5. Sensory Evaluation of Smoothie Formulations

Treatment	Color	Taste	Flavor	Texture	Overall Acceptability
T1	6.9 ^c	7.0 ^c	6.9 ^c	7.1 ^c	7.0 ^c
T2	7.2 ^b	7.3 ^b	7.2 ^b	7.3 ^b	7.4 ^b
T3	7.3 ^b	7.4 ^b	7.5 ^b	7.5 ^b	7.6 ^b
T4	7.6 ^a	7.8 ^a	7.7 ^a	7.8 ^a	7.8 ^a
LSD	0.30	0.35	0.40	0.32	0.34

The sensory findings therefore identified T4 as the most favorably rated formulation across all evaluated sensory attributes.

DISCUSSION

The present study developed four fruit-, vegetable-, chia-, whey-, and almond-milk-containing smoothie formulations and demonstrated formulation-associated differences in proximate composition, acidity, pH, viscosity, and sensory acceptance. Increasing the study-defined almond-milk level was accompanied by higher total solids, greater derived as-consumed protein, fat, and fiber concentrations, and progressively greater viscosity. T4 also achieved the highest ratings across all five sensory attributes.

An important consideration in interpretation of the proximate results is their compositional basis. Moisture accounted for approximately 83–86% of the finished smoothie, while the reported protein, fat, ash, NFE, and fiber fractions independently summed to 100% in each treatment. These results are internally consistent only when the five non-moisture fractions are interpreted as a dry-matter distribution. Conversion to an as-consumed basis therefore provides a more realistic estimate of the nutrient concentration in the finished beverage. On this basis, protein ranged from approximately 4.00 to 5.09 g/100 g rather than 27.8–30.1 g/100 g of finished smoothie.

The resulting protein concentrations remain nutritionally relevant within the context of a mixed diet. Protein intake during energy restriction has been investigated as a strategy for supporting satiety and limiting loss of lean tissue, although effects depend on the magnitude of energy restriction, protein dose, age, physical activity, and other characteristics of the intervention (2–5). Whey protein is a high-quality dietary protein with useful functional properties in beverage systems (7), while meta-analyses of whey or milk-protein supplementation demonstrate that body-composition responses vary among populations and intervention settings (8–10). The protein concentration observed in the present formulations should therefore be interpreted as a compositional attribute rather than evidence that the smoothie itself produces weight reduction or preservation of lean mass.

T4 contained the greatest estimated fiber concentration at 2.43 g/100 g. This finding is compatible with the presence of chia seeds and multiple plant ingredients within the smoothie matrix. Previous smoothie-development research has demonstrated that chia fortification can increase the fiber content of blended beverages (19). Clinical evidence concerning isolated or supplemented dietary fiber indicates that fiber type, viscosity, dose, food matrix, and background diet can influence metabolic or body-weight responses (21). Consequently, the fiber content of the present smoothie may be nutritionally relevant, but the current laboratory study cannot establish an effect on appetite, glycemia, or body weight.

Chia has attracted particular interest because of its fiber, alpha-linolenic acid, and other nutrients. However, clinical effects should not be inferred solely from ingredient presence. A recent systematic review and dose-response meta-analysis found that chia supplementation was associated with reductions in systolic and diastolic blood pressure but did not demonstrate significant pooled effects on body weight, BMI, waist circumference, body fat percentage, fasting glucose, or HbA1c (13). The present study did not evaluate any of these clinical outcomes, and its findings are limited to product composition, physicochemical characteristics, and sensory acceptance.

Almond-derived ingredients may also alter both composition and sensory properties. Controlled almond interventions have been examined in relation to appetite, body weight, body composition, and cardiovascular risk factors, but the observed effects have depended on intervention dose and duration (14,15). These findings cannot be transferred directly to the 2-6% study-defined almond-milk treatment levels investigated here. Nevertheless, the progressive increase in total solids, fat, fiber, viscosity, and sensory acceptance across the formulations indicates that variation in the almond-milk treatment level materially altered the characteristics of the finished product.

T4 had the highest viscosity at 1600 ± 25 cP compared with 950 ± 10 cP in T1. The change may reflect the combined effects of increasing total solids and interactions among chia-derived hydrocolloids, whey protein, fruit and vegetable solids, and almond-derived components. Food texture and viscosity are relevant to oral processing, perceived thickness, satiation, and product acceptance. A systematic review and meta-analysis found that textural characteristics, including greater viscosity, can increase satiation under some experimental conditions without necessarily reducing acceptability (22). Reviews of viscous fibers in beverages likewise emphasize that appetite-related responses depend on physicochemical behavior within the beverage matrix rather than the presence of fiber alone (23). The present study did not measure satiation or food intake, so its viscosity findings should be interpreted primarily as technological and sensory characteristics.

The increase in viscosity was accompanied by progressively higher texture ratings, with T4 receiving a texture score of 7.8/9. T4 also received the highest ratings for color, taste, flavor, and overall acceptability. The 9-point hedonic scale is widely used to quantify degree of liking in food-product evaluation (20). The mean overall acceptability score of 7.8 suggests favorable acceptance among the participating panelists, although the small untrained panel limits generalizability to a broader consumer population.

The sensory findings should therefore be considered preliminary. Twenty completed evaluations were available despite 30 panelists being initially recruited. In addition, demographic characteristics of the panel were not available. Interpretation would be strengthened by explicit documentation of sample randomization, blinding, serving order, serving temperature, serving quantity, palate-cleansing procedures, and whether every assessor evaluated every formulation. If the same participants evaluated all four formulations, the within-participant structure should also be reflected in the statistical analysis. Titratable acidity did not follow a monotonic treatment-related pattern. T1 had the highest acidity at $0.099 \pm 0.002\%$, T3 had the lowest at $0.045 \pm 0.001\%$, and T4 had an intermediate value of $0.072 \pm 0.001\%$. By contrast, pH varied only modestly between 6.30 and 6.45. Thus, the magnitude and direction of treatment-associated differences were more evident for titratable acidity than for pH.

The formulation was designed as a low-sugar product, but direct sugar concentrations were not measured. NFE represents a broader carbohydrate fraction and cannot be interpreted as a measurement of glucose, fructose, sucrose, or total sugars. Apples and blueberries naturally contribute carbohydrates and sugars in addition to fiber and polyphenolic compounds (16,17). Consequently, absence of separately added refined sugar does not by itself establish that the finished smoothie has a quantitatively low total-sugar concentration.

Direct determination of glucose, fructose, sucrose, and total sugars would therefore be required for rigorous characterization of the carbohydrate profile. The nutritional meaning of a low-sugar claim must also be interpreted per serving rather than from ingredient selection alone. Until direct sugar analysis is available, the present findings support description of the formulation ingredients and proximate carbohydrate fraction but not a quantitative low-sugar conclusion.

The title further positions the product in relation to weight management, although no participants consumed the smoothie as part of a weight-loss intervention. No change in body weight, BMI, waist circumference, body composition, appetite, satiety, energy intake, glucose, insulin, blood lipids, or physical activity was evaluated. The study therefore establishes product characteristics that may be relevant to future weight-management research rather than demonstrating weight-loss efficacy.

This distinction is consistent with the broader obesity literature, in which durable weight management is understood as the consequence of a comprehensive intervention rather than a single food or nutrient (1,6). Trials and systematic reviews examining increased fruit and vegetable consumption similarly indicate that the relationship between individual foods and body weight depends on dietary context and overall energy intake (11,12). A smoothie could potentially function as one component of a structured dietary plan, but its role would depend on portion size, energy content, nutritional composition, and what foods or beverages it replaces.

Energy density was not directly reported in the present study. This prevents determination of the energy contribution of a standard serving and limits interpretation of the product specifically as a weight-management beverage. Future compositional work should therefore calculate or analytically determine total energy per 100 g and per intended serving alongside protein, carbohydrate, fat, fiber, and sugar content.

The increase in fat from approximately 2.03 g/100 g in T1 to 3.20 g/100 g in T4 should not be interpreted in isolation as either beneficial or undesirable. Almond-containing dietary interventions have shown effects on selected cardiometabolic and body-composition outcomes despite the intrinsic fat content of almonds, emphasizing the importance of food matrix, fatty-acid composition, dose, and overall dietary pattern (14,15). The present study did not determine individual fatty acids and therefore cannot characterize the lipid profile of the smoothie beyond total fat.

The smoothie also contains several nutrient-dense plant ingredients. Apples contain fiber and multiple polyphenolic compounds (16), blueberries are rich in anthocyanins and other bioactive constituents (17), and kale contains carotenoids whose concentrations vary considerably according to production and processing conditions (18). Nevertheless, the present study did not directly quantify vitamins, minerals, individual polyphenols, carotenoids, antioxidant activity, or other phytochemicals. Potential micronutrient or antioxidant benefits should therefore not be inferred quantitatively from ingredient presence alone.

The study has several practical strengths. It used commonly available ingredients, provided a defined base recipe, compared four treatment levels, and generated quantitative data on moisture, proximate fractions, acidity, pH, viscosity, and sensory acceptance. The internal mass balance of the proximate data also allowed the non-moisture composition to be interpreted on a dry-matter basis and converted to an as-consumed basis without alteration of the underlying treatment results.

Several limitations should be acknowledged. The exact denominator represented by the 0%, 2%, 4%, and 6% almond-milk levels was not specified, making it uncertain whether these values represented formulation weight, formulation volume, replacement of another liquid component, or another basis. The precise analytical procedures and replication structure underlying the proximate determinations were not documented. The Brookfield viscometer model, spindle, spindle speed, sample volume, and complete equilibration conditions were also unavailable.

The sensory-panel denominator was inconsistent between initial recruitment and completed evaluation, with 30 panelists described as recruited but results available for 20 assessors. Detailed demographic information and several procedural characteristics of the sensory evaluation were not available. Furthermore, valid treatment-specific longitudinal stability and microbiological data were not available for these smoothie formulations, preventing any conclusion regarding shelf life or microbiological storage stability.

Additional formulation studies should standardize the quantity of almond milk in grams or milliliters for each treatment and state the denominator used to define each percentage. Proximate methods should identify the analytical procedure used for every component, specify whether values are expressed on wet- or dry-weight basis, and report the number of independent product batches and analytical replicates.

Future nutritional characterization should include direct analysis of glucose, fructose, sucrose, and total sugars; energy per 100 g and per intended serving; total dietary fiber; protein quality or amino-acid composition; fatty-acid profile; vitamins and minerals; and relevant phytochemical constituents. Short- and longer-term storage studies should additionally evaluate physical separation, viscosity change, nutrient retention, sensory quality, and microbiological safety at predefined storage intervals.

A subsequent controlled human feeding study would be necessary to determine whether incorporation of the smoothie into the diet affects satiety, subsequent energy intake, body weight, waist circumference, or body composition. If clinical weight management is the intended application, such

research should evaluate the product within a clearly defined dietary intervention rather than attributing effects to an individual ingredient in isolation.

CONCLUSION

Four whey-, chia-, fruit-, vegetable-, and almond-milk-containing smoothie formulations were developed and evaluated. After reconciliation of the proximate results to an as-consumed basis, estimated protein increased from approximately 4.00 g/100 g in T1 to 5.09 g/100 g in T4, while fiber increased from 1.70 to 2.43 g/100 g.

T4 had the highest viscosity and received the highest sensory ratings for color, taste, flavor, texture, and overall acceptability. On the basis of the available compositional, physicochemical, and sensory results, T4 was the most promising formulation for further development.

The study does not establish that the smoothie is quantitatively low in sugar or that consumption produces weight loss. Direct sugar analysis, complete energy characterization, and controlled human intervention research are required before these claims can be evaluated.

LIMITATIONS

The exact denominator used to define the almond-milk treatment percentages was not specified. Detailed proximate-analysis procedures and the number of independent analytical replicates were not documented. The non-moisture composition could be interpreted as dry-matter percentages through numerical reconciliation, but direct confirmation of the reporting basis was unavailable.

Sugar and energy density were not directly measured. Micronutrients, fatty-acid composition, amino-acid profile, polyphenols, antioxidant activity, and bioavailability were not evaluated. Thirty sensory panelists were initially described as recruited, whereas completed evaluation data were available from 20 participants. The panel was untrained and demographic characteristics were not reported.

Treatment-specific longitudinal stability and microbiological storage data were not available for the smoothie formulations. Consequently, shelf-life conclusions could not be established. Finally, no human weight-loss, appetite, energy-intake, body-composition, or metabolic outcomes were evaluated.

RECOMMENDATIONS

The formulation should be standardized using explicit gram or milliliter quantities of almond milk for every treatment, with the denominator for each formulation percentage clearly defined. Future proximate testing should identify the analytical method for each component, specify whether values are expressed on an as-consumed or dry-matter basis, and report analytical replication.

Direct glucose, fructose, sucrose, and total-sugar measurements should be performed. Energy content should be determined per 100 g and per intended serving. Protein quality, total dietary fiber, fatty-acid composition, vitamins, minerals, and relevant bioactive compounds should also be characterized.

Short- and long-term storage studies should evaluate physical stability, microbiological safety, sensory changes, and nutrient retention using predefined conditions and time points. Sensory testing should be repeated with a clearly defined panel, coded and randomized sample presentation, standardized serving conditions, and a statistical model appropriate to the assessment design.

If the smoothie is intended specifically for weight management, a prospective controlled intervention should evaluate satiety, subsequent energy intake, body weight, waist circumference, body composition, and relevant metabolic outcomes.

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