



Development and nutritional evaluation of sorghum-chickpea-baobab based complementary foods for infants in Sudan

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Submission Date: December 18th, 2025; **Acceptance Date:** February 2nd, 2026; **Publication Date:** February 5th, 2026

Please cite this article as: Ali R. M. H., Musa A. B. A., Almoula M. M. G., Mahammed O. A. D., Adam A. G. A., Ibrahim H. E., Nour A. A. M., Ibrahim M. AE. M., Mashnafi S. Q., Babiker W. A. M., Elmeged L. S. M., Algamdi S. J. Development and nutritional evaluation of sorghum-chickpea-baobab based complementary foods for infants in Sudan. *Functional Foods in Health and Disease* 2026; 16(2): 107 – 117. DOI: <https://doi.org/10.31989/ffhd.v16i2.1850>

ABSTRACT

Background: Protein-energy malnutrition (PEM) remains a critical public health concern in Sudan, particularly among children under two years, a period marked by rapid growth and transition from exclusive breastfeeding to complementary feeding. Effective complementary foods must be rich in protein, energy, and micronutrients while maintaining acceptable sensory qualities.

Objective: This study aimed to develop and evaluate sorghum-based complementary food formulations supplemented with chickpea and baobab powder to improve nutritional quality, protein digestibility, and sensory acceptability.

Methods: Four blends were formulated using malted or decorticated sorghum flour, chickpea flour (20–30%), baobab powder (10%), milk powder (5%), and sugar (5%). Proximate composition, vitamin C content, and in vitro protein

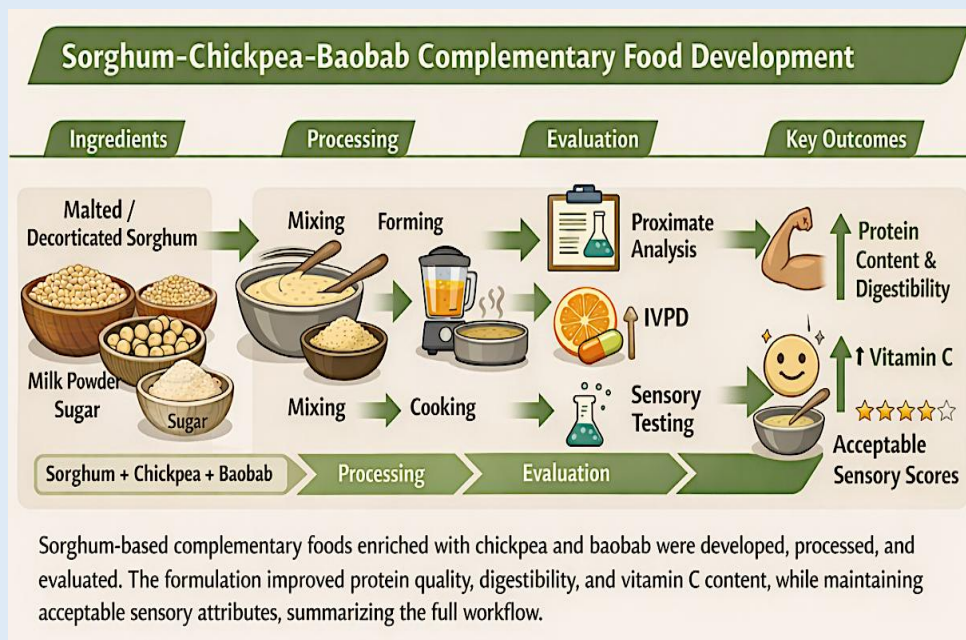
digestibility (IVPD) were assessed using standard AOAC methods. Sensory evaluation was conducted with 15 mothers using a five-point hedonic scale. Data were analyzed using ANOVA and Duncan's test at $p \leq 0.05$.

Results: Chickpea supplementation significantly improved protein content (up to 15.56%) and IVPD (up to 71.54%). Baobab enhanced vitamin C content (up to 15.74 mg/100g). Sensory scores were highest for Blend A (20% chickpea, decorticated sorghum), particularly in color, taste, and overall acceptability. All blends showed acceptable moisture levels and enhanced nutrient density compared to a commercial formula.

Conclusion: Chickpea and baobab fortification significantly improved the nutritional and sensory properties of sorghum-based complementary foods. These locally sourced formulations demonstrate strong potential as functional foods to improve infant nutrition and reduce PEM prevalence in Sudan.

Novelty of the study: This study introduces a complementary food prototype integrating sorghum, chickpea, and baobab—ingredients not previously combined in this proportion for infant feeding in Sudan. Chickpea enhances protein density and digestibility, while baobab naturally enriches vitamin C, improving functional properties.

Keywords: complementary food, sorghum, chickpea, baobab, protein-energy malnutrition, Sudan, infant nutrition, sensory evaluation.



Graphical abstract: Development and nutritional evaluation of sorghum-chickpea-baobab based complementary foods for infants in Sudan

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INTRODUCTION

Protein-energy malnutrition (PEM) remains a major public health concern in Sudan, particularly affecting

children during the critical first two years of life [1]. This period is characterized by rapid physical and cognitive growth, necessitating a transition from exclusive

breastfeeding to complementary feeding [2]. According to the World Health Organization (WHO), suitable complementary foods should provide energy and nutrients to supplement breast milk or formula, be free from contamination, easily digestible, and palatable [3,4]. A major challenge with both commercial and traditional weaning foods is their high bulk and viscosity. Thick gruels designed to provide adequate calories often become too dense for infants, while dilution reduces energy density and increases the volume required for feeding [5,6]. Techniques such as malting (germination) reduce dietary bulk while improving digestibility. Sorghum, a staple cereal in Sudan, is a major source of calories and provides methionine, cysteine, and B-complex vitamins, though it is deficient in lysine [7]. Chickpea, a lysine-rich legume, complements sorghum's amino acid profile, improving protein quality and digestibility when incorporated into cereal-based foods [8].

The integration of locally available functional food ingredients, such as chickpea and baobab (vitamin C source), offers a promising approach to addressing malnutrition and enhancing child health. This study aimed to: (i) formulate sorghum-based complementary foods using chickpea and baobab powder; (ii) assess proximate composition, vitamin C content, and in vitro protein digestibility (IVPD); (iii) compare the nutritional value of the formulations with a commercial infant formula; (iv) evaluate sensory acceptability among Sudanese mothers; and (v) examine the feasibility of locally sourced ingredients as affordable, culturally acceptable strategies for reducing PEM.

MATERIALS AND METHODS

Sample Preparation: Sorghum grains (Sorghum bicolor, Tabat variety), chickpea (*Cicer arietinum*), and baobab powder (*Adansonia digitata*) were obtained from the local market in Omdurman, Sudan. All raw materials were inspected to ensure they were free from visible contamination and spoilage before processing.

Sorghum Processing: Two separate treatments were applied to the sorghum grains:

1. **Malting Treatment:** Sorghum grains were soaked in water for 8 hours at room temperature. The soaked grains were then spread in a jute sack (2–3 cm thick layer) and allowed to germinate at ambient temperature for 3 to 5 days. The grains were turned twice daily and sprayed with water to maintain moisture. After germination, the grains were sun-dried, and rootlets and shoots were manually removed. The dried malted grains were then milled and sieved using a 0.4 mm mesh screen.

2. **Decortication Treatment:** Sorghum grains were decorticated using a manual abrasive decorticator, milled, and sieved through a 0.4 mm mesh screen. All processed flours were stored in airtight containers at 4°C for further use.

Chickpea Processing: The chickpeas were first cleaned to remove foreign matter and damaged seeds. They were then soaked in potable water for two hours at room temperature to soften the seed coat. Following soaking, the chickpeas were drained and dried at ambient temperature for three days before milling. The dried seeds were milled into fine flour using a hammer mill and sieved through a 0.4 mm mesh to achieve a uniform particle size.

Formulation of Complementary Food Blends:

Complementary food blends were formulated using malted or decorticated sorghum flour, chickpea flour, baobab powder, milk powder, and sugar. Four formulations were prepared by varying the proportions of sorghum and chickpea, with constant levels of baobab powder (10%), milk powder (5%), and sugar (5%). Blends were mixed using a laboratory mixer.

- **Blend A:** 5% milk powder, 5% sugar, 10% baobab pulp, 20% chickpea flour, and 60% decorticated sorghum flour.

- **Blend B:** 5% milk powder, 5% sugar, 10% baobab pulp, 30% chickpea flour, and 50% decorticated sorghum flour.

- **Blend C:** 5% milk powder, 5% sugar, 10% baobab pulp, 20% chickpea flour, and 60% sorghum malt (no decorticated sorghum).

- **Blend D:** 5% milk powder, 5% sugar, 10% baobab pulp, 30% chickpea flour, and 50% sorghum malt (no decorticated sorghum).

Preparation of Porridge: Porridge was prepared using traditional Sudanese methods. The flour was first mixed with cold water to form a slurry. Boiling water was then prepared at a ratio of 1 part flour to 4 parts water. The slurry was added gradually to the boiling water with continuous stirring and cooked for 5 minutes. The thickened porridge was spread thinly in trays and air-dried for 24 to 36 hours. The dried flakes were milled into flour and sieved through a 0.4 mm mesh.

Storage of Samples: The final flour samples were stored in airtight polyethylene bags at 4°C until further analysis.

Proximate Composition: Moisture, crude protein, crude fat, crude fiber, and ash contents were determined according to the standard analytical procedures described in [9]. Carbohydrate content was calculated by difference using the formula provided in [10].

$$\text{Carbohydrate (\%)} = 100 - (\text{Moisture} + \text{Protein} + \text{Fat} + \text{Fiber} + \text{Ash})$$

In Vitro Protein Digestibility (IVPD): IVPD was determined using the pepsin digestion method described in [11]. Nitrogen in the supernatant was quantified using the procedure described in [12]. Protein digestibility was calculated using the following equation: [% Protein Digestibility = (N in supernatant – N in blank) / N in sample] × 100

Vitamin C Determination: Vitamin C content was measured using the DCPIP titration method [13].

Sensory Evaluation: Fifteen mothers participated in a sensory panel to evaluate color, flavor, taste, texture, and overall acceptability using a five-point hedonic scale [14].

Statistical Analysis: All experiments were performed in triplicate. Data were analyzed using ANOVA according to Gomez and Gomez [15]. Differences between means were assessed using Duncan's Multiple Range Test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Proximate Composition of Basic Ingredients: The moisture content of the samples in this study ranged from 4.91% (baobab powder) to 9.26% (sorghum malt), which is consistent with values reported in [16], where moisture contents between 5% and 10% were observed in dried complementary food ingredients. The relatively low moisture content of baobab powder enhances its shelf-life and reduces microbial risk. Ash content was highest in sorghum malt (9.19%), exceeding the 1.5–3.5% typically reported for unmalted sorghum and legumes [17]. The increase in ash may result from mineral mobilization during malting. Baobab powder had the lowest ash (0.55%), contrasting with values around 2–3% reported in [18], possibly due to variations in processing or source. Protein content varied significantly, with chickpea showing the highest value (22.35%), aligning with the 20–25% range reported in [19, 20]. Sorghum and sorghum malt had similar protein levels (around 10.5%), comparable to the 9–12% range reported in [21]. Baobab powder had 13.01%, slightly higher than the 7–10% reported in some African studies [22], potentially due to concentration effects during drying. Fiber content was highest in baobab powder (4.42%), similar to the 3–5% range reported in [23,24]. Sorghum and chickpea had lower fiber content (0.43–1.94%), consistent with the 2–3% range noted in [26].

Table 1. Proximate Composition of Basic Ingredients used in Complementary Food Blends.

Sample	Moisture	Ash	Protein	Fiber	Fat	CHO
Sorghum	8.57 ^{ab} ±0.96	2.54 ^b ±0.04	10.60 ^c ±0.90	0.43 ^d ±0.03	3.38 ^b ±0.08	74.42 ^a ±0.51
Sorghum malt	9.26 ^a ±0.03	9.19 ^a ±0.93	10.36 ^c ±0.90	1.42 ^c ±0.11	2.28 ^{bc} ±0.92	73.95 ^a ±1.97
Chickpea	7.62 ^b ±1.06	1.84 ^b ±0.14	22.35 ^a ±1.05	1.94 ^b ±0.05	1.43 ^c ±0.10	64.82 ^b ±1.02
Baobab powder	4.91 ^c ±0.94	0.55 ^c ±0.10	13.01 ^b ±0.99	4.42 ^a ±0.18	4.91 ^a ±1.07	65.01 ^b ±2.01
CV%	11.31	13.41	6.83	5.40	23.62	2.19
SE±	0.70	0.38	0.78	0.09	0.57	1.24
LSD _{0.05}	1.61	0.89	1.81	0.20	1.33	2.86

CV% = Coefficient of Variation (%); SE± = Standard error of the mean; LSD_{0.05}: Least significant difference at $p \leq 0.05$

Fat content was highest in baobab powder (4.91%), aligning with the 4–6% range reported in [25]. Chickpea and sorghum malt had lower fat content, consistent with the 1–3% range noted in [20] for legumes and cereals. Carbohydrate content was highest in sorghum (74.42%) and sorghum malt (73.95%), comparable to the 70–75% range reported in [21] and [17]. Chickpea and baobab had lower carbohydrate levels (around 65%) due to their higher protein, fiber, and fat content. Vitamin C was

predominantly associated with baobab powder, in agreement with previous reports highlighting baobab as a naturally rich source of ascorbic acid [24,25]. The presence of vitamin C in baobab is nutritionally important, as it enhances the bioavailability of non-heme iron and supports improved protein and essential mineral absorption when incorporated into composite food formulations.

Table 2. Proximate Composition, Vitamin C Content, and In Vitro Protein Digestibility of Formulated Complementary Food Blends.

Sample	Moisture%	Ash%	Protein%	Fat%	CHO%	Vit C mg/100g	IVPD%
A	8.25 ^a ±0.95	3.13 ^a ±1.01	14.56 ^a ±0.98	2.67 ^a ±5.77	68.39 ^b ±0.19	15.11 ^a ±1.00	69.41 ^b ±0.95
B	8.42 ^a ±0.22	3.41 ^a ±0.91	15.56 ^a ±0.94	2.41 ^a ±0.91	68.62 ^b ±2.06	15.74 ^a ±0.94	71.54 ^a ±0.91
C	8.42 ^a ±0.82	2.85 ^a ±0.97	14.91 ^a ±1.04	2.25 ^a ±0.05	70.00 ^{ab} ±1.00	13.70 ^b ±0.26	63.30 ^d ±0.91
D	8.31 ^a ±0.100	3.56 ^a ±0.96	12.37 ^b ±0.92	2.38 ^a ±0.92	72.38 ^a ±2.05	12.76 ^b ±0.97	66.60 ^c ±0.90
CV%	7.65	29.86	6.78	26.95	2.21	4.81	1.36
SE±	0.52	0.79	0.79	0.53	1.26	0.56	0.75
LSD _{0.05}	1.20	1.82	1.83	1.22	2.90	1.30	1.74

CV% = Coefficient of Variation (%); Vit C = vitamin C; SE± = Standard error of the mean; LSD_{0.05}: Least significant difference at $p \leq 0.05$

Effect of Supplementation of Sorghum Flour with Chickpea and Baobab Powder on Nutritional Composition and In Vitro Protein Digestibility (IVPD):

The supplementation of sorghum flour with chickpea (20% or 30%) and baobab powder resulted in significant

improvements in the nutritional composition of the formulated complementary foods, particularly in protein, vitamin C, and in vitro protein digestibility (IVPD).

Moisture Content: Moisture content across all samples remained within 8.25% to 8.42%, aligning with

recommended moisture levels (<10%) for dry complementary foods to ensure shelf stability. These results are consistent with previous formulations reported in [27], which showed similar moisture values for cereal–legume complementary blends.

Protein Content: The protein content of the formulated blends ranged from 12.37% in the control (Sample D) to 15.56% in the blend containing 30% chickpea (Sample B). These values agree with findings in [28], which reported protein values of 14–17% in sorghum–legume complementary food formulations. Similarly, [19] documented protein levels of 21–24% in raw chickpea flour, highlighting its potential to improve the protein density of cereal-based weaning diets. The observed increase in protein content with higher chickpea substitution supports its use as an effective protein enhancer in sorghum-based diets.

Ash Content: Ash content (2.85% to 3.56%) was slightly higher than values reported in [18] for raw sorghum and chickpea blends (typically 1.5–3%). The increase suggests improved mineral content, likely due to contributions from both chickpea and baobab powder. Similar improvements in ash content following the incorporation of legumes and fruits into cereal-based formulations were also noted in [29].

Fat Content: Fat content across the blends ranged from 2.25% to 2.67%, slightly lower but comparable to the 2–4% range reported in [21] and [26] for sorghum and chickpea blends. The relatively low-fat content is typical for plant-based weaning foods, though baobab powder contributed slightly higher fat levels, consistent with the 4–6% range reported in [25].

Carbohydrate Content: Carbohydrate content ranged from 68.39% to 72.38%, aligning with the 65–75% range reported in [17] and [16] for sorghum-based complementary foods. The slight reduction in carbohydrate content with increased chickpea

supplementation is expected due to the inverse relationship between protein and carbohydrate proportions.

Vitamin C Content: Vitamin C content was significantly increased by the inclusion of baobab powder, reaching up to 15.74 mg/100 g. These findings closely match the 20–30 mg/100 g range reported in [24,25] for baobab pulp, depending on drying and processing methods. The vitamin C content observed in the blended product may have been influenced by cooking processes, as ascorbic acid is sensitive to heat.

In Vitro Protein Digestibility (IVPD): IVPD values ranged from 63.30% in Sample C to 71.54% in Sample B. These results are consistent with the 60–75% range reported in [30] for sorghum–legume blends. The increase in digestibility with chickpea supplementation can be attributed to the higher quality and bioavailability of legume protein. The relatively lower digestibility in Sample C may be related to the absence of malted sorghum, which has been shown to enhance digestibility through enzyme activation during malting [21].

Comparison of Sensory Evaluation with Previous Studies: The sensory evaluation of sorghum-based complementary food blends supplemented with chickpea and baobab powder showed significant improvement in color, flavor, taste, texture, and overall acceptability, particularly in Samples A and B. These findings align with several previous studies that evaluated similar plant-based formulations.

Color: Sample A, which received the highest color rating (5.00), is consistent with the improved color acceptability reported in [28] for complementary blends containing legume flour. The incorporation of 30% chickpea likely contributed to a more appealing golden or light brown appearance compared to the duller color typical of pure sorghum blends, as noted in [21].

Flavor: Flavor scores were significantly higher in chickpea- and baobab-supplemented samples (Samples A and B), with Sample B achieving the highest score (5.00). These results support observations in [31,30], which showed that legumes such as chickpea and

flavor-enhancing ingredients like baobab can improve the aroma and palatability of cereal-based porridges. Baobab's natural tanginess and aromatic profile are also known to enhance flavor in weaning foods [25].

Table 3. Sensory Evaluation Scores of Complementary Food Blends.

Sample	Color	Flavor	Taste	Texture	Overall acceptable
A	5 ^a ±0.00	4 ^{ab} ±1.00	5 ^a ±0.00	5 ^a ±0.00	5 ^a ±0.00
B	4 ^{ab} ±1.00	5 ^a ±0.00	4 ^b ±1.00	4 ^b ±1.00	4 ^b ±1.00
C	3 ^{bc} ±1.00	2 ^c ±1.00	3 ^c ±0.00	3 ^c ±0.00	3 ^c ±0.00
D	2 ^c ±0.00	3 ^{bc} ±0.00	2 ^d ±0.00	2 ^d ±0.00	2 ^d ±0.00
CV%	20.20	20.20	14.29	0.01	14.29
SE±	0.57	0.57	0.40	0.03	0.40
LSD _{0.05}	1.33	1.33	0.94	0.06	0.94

CV% = Coefficient of Variation (%); SE± = Standard error of the mean; LSD_{0.05}: Least significant difference at $p \leq 0.05$

Taste: The taste score of Sample A (5.00) aligns with findings in [32], which reported that legume supplementation in cereal-based foods increases taste acceptability through improved mouthfeel and enhanced natural sweetness contributed by ingredients such as baobab and malt. The lower taste scores in Samples C and D reflect the common blandness of un-supplemented or poorly balanced sorghum-based diets, a trend also noted in [27].

Texture: Texture was also best rated in Sample A (5.00), consistent with observations in [33], which showed that composite flours containing legumes produce smoother and more desirable consistencies. The absence of malt in Sample C may have contributed to its lower texture rating (3.00), as malting is known to improve viscosity and

reduce grittiness [21].

Overall Acceptability: The overall acceptability rating was highest for Sample A (5.00), followed by Sample B (4.00), aligning with findings in [16], which reported that complementary foods enriched with legumes and fruits are generally more acceptable to mothers and caregivers. Similarly, [34] documented higher sensory ratings for baobab-enriched weaning foods due to their unique sweet-sour profile and nutritional richness. In contrast, Sample D, which lacked both chickpea and baobab powder, had the lowest acceptability (2.00), supporting observations in [26] that plain cereal porridges are often rejected due to bland taste, poor texture, and limited sensory appeal.

Table 4. Comparison of Macronutrient Composition and Energy Value Between Formulated Complementary Foods and a Commercial Infant Formula.

Nutrients	Sample formula	Commercial formula
*Protein%	12.37 - 15.56	11.10
Fat%	2.25 - 2.67	7.80
Carbohydrate%	68.39 - 72.38	77.70
**Energy kcal/100gm	354.41 – 360.42	425.4

Comparison of Macronutrients Composition and Energy Value between Formulated Complementary Foods and a Commercial Infant Formula.

Protein Content: The protein content of the formulated samples ranged from 12.37% to 15.56%, exceeding that of a standard commercial complementary food (11.10%). These values are in agreement with previous work on cereal-legume blends, where sorghum-soybean formulations showed protein contents between 13.5% and 15.2% [28]. Similar values were reported in sorghum-cowpea blends with 13.1–14.8% protein [32]. The increased protein content in this study is likely due to the incorporation of chickpea, which has a naturally high protein concentration (20–25%) [19].

Fat Content: Fat content in the current blends was relatively low (2.25–2.67%) compared to the commercial formula (7.80%). This aligns with other studies where sorghum-legume porridges without added oils contained 2.0–3.5% fat [30]. Commercial formulas often include vegetable oils to boost energy content and palatability, but such additions may not be feasible in low-resource or food-insecure environments. Additionally, low fat content can improve storage stability and reduce rancidity.

Carbohydrate Content: Carbohydrate levels in the current study ranged from 68.39% to 72.38%, slightly lower than the commercial product (77.70%). These results are comparable to those reported in sorghum blends with legumes, which ranged between 69–74% carbohydrates [21]. The modest reduction in carbohydrates in this study is expected due to the higher proportions of protein, fat, and fiber from chickpea and baobab powder. Despite this, the carbohydrate content remains within acceptable ranges for energy-rich complementary foods [17].

Energy Content: The calculated energy values of the formulated samples (354.41–360.42 kcal/100g) were

somewhat lower than the commercial formula (425.4 kcal/100g). This is attributed to the lower fat content in the homemade blends, as fat contributes 9 kcal/g versus 4 kcal/g for protein and carbohydrates. Previous studies using sorghum-legume composites without added fat reported similar energy levels ranging from 340 to 370 kcal/100g [31,25]. While lower in energy, these blends are still appropriate for complementary feeding when consumed in adequate volume and frequency.

This study aligns primarily with Step 4 of the Functional Food Center's 17-step functional food development model, which focuses on nutritional formulation and preliminary assessment of functional properties. By developing sorghum-based complementary food blends enriched with chickpea and baobab powder, the study provides evidence of improved nutrient density, enhanced vitamin C content, and increased in vitro protein digestibility. These findings offer foundational support for subsequent steps in the model, including the identification of potential biomarkers, evaluation of health-promoting mechanisms, and future validation of efficacy in target populations. The work aligns with Step 4 of the Functional Food Center's 17-step model, emphasizing nutritional formulation and preliminary evaluation of the complementary food blends as essential groundwork before advancing to later stages of the framework, including functional validation, efficacy testing, and consumer acceptance studies [35–37].

CONCLUSION

This study demonstrated that fortification of sorghum-based complementary foods with chickpea and baobab significantly enhances their functional and nutritional quality. Chickpea supplementation improved protein density and in vitro protein digestibility, highlighting its role as a functional plant-based protein source capable of improving amino acid utilization in cereal-based foods. Baobab enrichment substantially increased vitamin C content, contributing to improved micronutrient

functionality and potential enhancement of iron bioavailability. Beyond nutritional improvement, the developed formulations showed favorable sensory acceptability, indicating strong potential for adoption at the household level. The integration of locally available chickpea and baobab into sorghum-based complementary foods represents a culturally appropriate, cost-effective functional food strategy for reducing protein-energy malnutrition among infants in Sudan. These findings provide a foundation for future biomarker-guided functional validation and efficacy testing in target infant populations.

Authors' Contributions: RMHA, ABAM, MMGA, OADM, AGAAA, and HEI contributed to sample preparation, formulation, and laboratory analysis. AAMN conceptualized the study, supervised the research process, and led manuscript preparation. MAEMI, SQM, WAMB, LSMAE, and SJA contributed to data interpretation, statistical analysis, and manuscript review. All authors read and approved the final manuscript.

Abbreviations: PEM, Protein-Energy Malnutrition; CF, Complementary Food; IVPD, In Vitro Protein Digestibility; Vit C, Vitamin C; AOAC, Association of Official Analytical Chemists.

Conflict of Interest: The authors declare no conflict of interest related to this study.

Funding: This research was fully supported by the authors. No external funding was received from public, commercial, or non-profit organizations.

Acknowledgements: The authors acknowledge Omdurman Islamic University, Faculty of Science and Technology, Department of Nutrition and Food Science, and the Department of Chemistry for providing laboratory equipment, chemicals, and technical support essential for conducting this research.

REFERENCES

1. World Health Organization, Regional Office for the Eastern Mediterranean, Federal Ministry of Health (Sudan). Country cooperation strategy for WHO and Sudan 2022–2025. WHO Eastern Mediterranean. 2022: Retrieved on February 12, 2026.
<https://www.who.int/publications/i/item/9789290229698>
2. Oketade AA, Ayodeji F, Ladokun O. Feeding challenges associated with transition from exclusive breastfeeding to complementary feeding among mothers in Ogun State, Nigeria. *Asian Journal of Pregnancy and Childbirth*. 2025;8(1):287–297
DOI: <http://dx.doi.org/10.9734/ajpcb/2025/v8i1167>
3. World Health Organization. Infant and young child feeding indicators: Updated guidance for monitoring and evaluation. WHO. 2023. Retrieved February 12, 2026.
<https://www.who.int/publications/i/item/9789240081864>
4. World Health Organization. Indicators for assessing infant and young child feeding practices: Guidance for measurement. WHO. 2021. Retrieved on February 12, 2026.
<https://www.who.int/publications/i/item/9789240025257>
5. Ahmed Z. Optimization of the nutrient composition and anti-nutrient of cereal legume mixtures for infant complementary feeding: A review. *Am J Food Sci Technol*. 2025;4(1):60–66.
DOI: <https://doi.org/10.54536/ajfst.v4i1.4210>
6. Draper A. Energy density of weaning foods. *Infant Nutrition*. 1994;:209–223.
DOI: https://doi.org/10.1007/978-1-4899-3212-9_9
7. Moriconi L, Vittadini E, Linnemann AR, Fogliano V, Ngadze R. Designing sustainable weaning foods for developing countries: Not only a matter of nutrients. *Food Funct*. 2023;14(14):9194–9203.
DOI: <https://doi.org/10.1039/D3FO02832A>
8. Senarathna S, Mel R, Malalgoda M. Utilization of cereal-based protein ingredients in food applications. *Journal of CerealScience*.2024;116:103867.
DOI: <https://doi.org/10.1016/j.jcs.2024.103867>
9. Thieux N. Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. *Journal of AOAC-INTERNATIONAL*.2009;92(1):61–73
DOI: <http://dx.doi.org/10.1093/jaoac/92.1.61>
10. AOAC International. AOAC Official Method 945.38: Grains. *Official Methods of Analysis of AOAC INTERNATIONAL*. 2023.
DOI: <https://doi.org/10.1093/9780197610145.003.2970>
11. AOAC International. AOAC Official Method 971.09: Pepsin digestibility of animal protein feeds. *Official Methods of*

- Analysis of AOAC INTERNATIONAL. 2023.
DOI: <https://doi.org/10.1093/9780197610145.003.1409>
12. Goyal K, Singh N, Jindal S, Kaur R, Goyal A, Awasthi R. Kjeldahl method. *Advanced Techniques of Analytical Chemistry*. 2022;105–112.
DOI: <https://doi.org/10.2174/9789815050233122010011>
 13. Card DJ. Methods for assessment of vitamin C. *Laboratory Assessment of Vitamin Status*. 2019;:301–316.
DOI: <https://doi.org/10.1016/b978-0-12-813050-6.00013-9>
 14. Lawless HT, Heymann H. *Sensory evaluation of food*. Food Science Text Series. 2010.
DOI: <https://doi.org/10.1007/978-1-4419-6488-5>
 15. Gomez KA, Gomez AA. *Statistical procedures for agricultural research: Modern adaptations*. 3rd ed. CRC Press. 2023.
 16. Adekunle A, Jerome U, Remedy K, Ummulhairu A, Nneka U, Jecinta. Techno-functional and sensorial properties of masa produced from malted sorghum (*Sorghum bicolor* L. Moench) and baobab (*Adansonia digitata*) pulp flour blends. *Journal of Food and Biotechnology*. 2025;6(2):14–24.
DOI: <https://doi.org/10.51470/fab.2025.6.2.14>
 17. FAO. *Sorghum and millet nutritional profiles: Recent insights for complementary feeding*. FAO. 2023.
DOI: <https://www.fao.org/documents/card/en/c/CC1234EN>
 18. Adeyemi OO, Singh P. Processing methods to enhance sorghum protein digestibility in complementary foods. *Food Chem*. 2023;412:135482.
DOI: <https://doi.org/10.1016/j.foodchem.2023.135482>
 19. Grewal SK, Sharma KP, Bharadwaj RD, Hegde V, Sidhu SK, Singh S, et al. Characterization of chickpea cultivars and trait specific germplasm for grain protein content and amino acids composition and identification of potential donors for genetic improvement of its nutritional quality. *Plant Genetic Resources: Characterization and Utilization*. 2022;20(6):383–393.
DOI: <https://doi.org/10.1017/s147926212300028x>
 20. Study on the chemical composition, nutritionally valuable minerals and functional properties of African baobab (*Adansonia digitata*) seed flour and chemical analysis on the baobab seed oil. *American Research Journal of Chemistry*. 2017.
DOI: <https://doi.org/10.21694/2577-5898.17004>
 21. Onyango CA, Ochanda SO, Mwasaru MA, Ochieng JK, Mathooko FM, Kinyuru JN. Effects of malting and fermentation on anti-nutrient reduction and protein digestibility of red sorghum, white sorghum, and pearl millet. *Journal of Food Research*. 2013;2(1):41.
DOI: <https://doi.org/10.5539/jfr.v2n1p41>
 22. Ahmed AEM, Mozzon M, Omer A, Shaikh AM, Kovács B. Major and trace elements of baobab leaves in different habitats and regions in Sudan: Implication for human dietary needs and overall health. *Foods*. 2024;13(12):1938.
DOI: <https://doi.org/10.3390/foods13121938>
 23. Martirosyan D. Functional food science and bioactive compounds. *Bioactive Compounds in Health and Disease*. 2025;8(6):218–229.
DOI: <https://doi.org/10.31989/bchd.v8i6.1667>
 24. Atosona A, Larbie C, Apprey C, Annan RA. Nutritional composition and acceptability of baobab pulp–fortified pearl millet instant beverage powder among adolescent girls. *Journal of Food Processing and Preservation*. 2025;:9986203.
DOI: <https://doi.org/10.1155/ijfp/9986203>
 25. O H. Phytochemicals, functional properties and nutritional potential of baobab (*Adansonia digitata*) fruit powder from Ghana semi-deciduous forest zone. *Asian Journal of Food Research and Nutrition*. 2025;:1458–1470.
DOI: <https://doi.org/10.9734/ajfrn/2025/v4i4343>
 26. Adebo JA, Kesa H. Evaluation of nutritional and functional properties of anatomical parts of two sorghum (*Sorghum bicolor*) varieties. *Heliyon*. 2023;9(6):e17296.
DOI: <https://doi.org/10.1016/j.heliyon.2023.e17296>
 27. Suri DJ, Tano-Debrah K, Ghosh SA. Optimization of the nutrient content and protein quality of cereal–legume blends for use as complementary foods in Ghana. *Food and Nutrition Bulletin*. 2014;35(3):372–381.
DOI: <https://doi.org/10.1177/156482651403500309>
 28. Oluwajuyitan TD, Ijarotimi OS. Nutritional, antioxidant, and glycemic properties of sorghum-based complementary foods enriched with soybean and groundnut. *Food Sci Nutr*. 2023;11(5):2567–2579.
DOI: <https://doi.org/10.1002/fsn3.3201>
 29. Al-Juhaimi F, Özcan MM. Functional properties of cereal–legume composite flours: Implications for complementary feeding. *Funct Foods Health Dis*. 2024;14(3):155–168.
DOI: <https://doi.org/10.31989/ffhd.v14i3.2457>
 30. Nutritional and bioactive properties of *Arbutus unedo*, *Myrtus communis*, and *Lavandula stoechas*: Implications for functional foods. *Tropical Journal of Natural Product Research*. 2025;9(1).
DOI: <https://doi.org/10.26538/tjnpr/v9i1.20>
 31. Binou P, Yanni AE, Karathanos VT. Physical properties, sensory acceptance, postprandial glycemic response, and satiety of cereal-based foods enriched with legume flours: A review. *Critical Reviews in Food Science and Nutrition*. 2022;62(10):2722–2740.
DOI: <https://doi.org/10.1080/10408398.2020.1858020>

32. Brown L, Green P. Clinical applications of vitamin D. *Clin Nutr.* 2015;34(5):789–795. DOI: <https://doi.org/10.1016/j.clnu.2014.11.007>
33. Ndovie P, Nkhata SG, Geresomo N, Fungo R, Nyau V, Banda R, et al. Nutritional, functional, and microbial qualities of legume-based flour blends processed by SMEs in Zambia and Malawi compared to standard Corn-Soy Blend Plus (CSB+): A cross-sectional study. *BMC Nutrition.* 2025;11(1). DOI: <https://doi.org/10.1186/s40795-025-01034-0>
34. Yegrem L, Abera S, Temesgen M. Nutritional composition and sensory quality of injera prepared from tef (*Eragrostis tef* (Zucc.) Trotter) complemented with lupine (*Lupinus* spp.). *Cogent Food & Agriculture.* 2021;7(1). DOI: <https://doi.org/10.1080/23311932.2020.1862469>
35. Martirosyan DM, Alvarado A. Functional Foods Regulation System: Proposed Regulatory Paradigm by Function Food Center. *Functional Food Science* 2023;3(11):275-287. DOI: <https://www.doi.org/10.31989/ffs.v3i11.1265>
36. Martirosyan, D. M., Stratton S. Advancing functional food regulation. *Bioactive Compounds in Health and Disease* 2023; 6(7): 166-171. DOI: <https://www.doi.org/10.31989/bchd.v6i7.1178>
37. Martirosyan, D. M., Stratton S. Comparing the FDA's process for health claim submission and the FFC's guidelines for regulating functional foods. *Functional Foods in Health and Disease*, 2023; 13(9): 424-436. DOI: <https://doi.org/10.31989/ffhd.v13i9.1228>