

Formulation, Nutrient Composition and Acceptability of Insect Protein-Sourced Ready-To-Eat Therapeutic Foods for Treatment of Severe Acute Malnutrition (Sam) in Zamfara State

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Abstract

Severe Acute Malnutrition (SAM) remains a major contributor to under-five mortality in Nigeria, with Zamfara State among the most affected. Standard Ready-to-Use Therapeutic Food (RUTF) is effective but reliance on imported milk-based RUTF poses sustainability challenges due to high cost, stock-outs and insecurity. Edible insects such as desert locust *Schistocerca gregaria* offer sustainable, protein and mineral-rich alternatives with date fruits (*Phoenix dactylifera*) as an alternative natural sweetener. In global conflicts, war, pandemic and security disadvantaged regions where accesses to Ready-to-Use Therapeutic Foods (RUTF) are limited, locally formulated RUTF, may be a crucial intervention for the treatment of severe acute malnutrition and hidden hunger among under-five. This study aimed to formulate, evaluate nutrient composition and assess acceptability of insect protein-based RUTF for community management of SAM among children under five in Zamfara State, Nigeria. This study formulated RUTF using local ingredients, dried grounded groundnut (*Arachis hypogaea* L.), grasshopper (*Schistocerca gregaria*), Date fruit (*Phoenix dactylifera*), and vegetable oil were sourced from Gusau new market, Zamfara State. Materials were sorted, washed with clean water, dried at room temperature, roasted (180°C for 46 minutes), airing for 30minutes @28°C, milled into powder and mixed at different ratios for RUTF formulation. FMS1 (30% insect, 25% peanut, 15% vegetable oil, 28% date fruit), FMS2 (25%, 30%, 20%, 23%) and FMS3 (20%, 35%, 25%, 18%) and compared with commercial RUTF (CNS) as control in the Home Economics Department laboratory. Proximate, mineral (Fe, Zn, Ca, I), anti-nutrient (tannin, oxalate, phytate) and sensory properties were evaluated using AOAC standard methods and 9-point hedonic scale with 20 semi-trained panelists (mothers). Data were analyzed using ANOVA and Duncan Multiple Range Test at $p < 0.05$ using SPSS v27. Moisture was significantly lower in formulated samples (2.90-4.33%) than CNS (11.39%), meeting WHO <5% requirement for RUTF stability. Protein (14.33-21.68%) and lipid (19.50-22.77%) were significantly higher in formulated samples than CNS (14.10% protein, 11.47% lipid), with FMS1 having highest protein (21.68%). Iron (56.04 mg/100g), zinc (up to 25.93 mg/100g in FMS1) and calcium (up to 137.34 mg/100g in FMS3) were significantly higher than CNS, while iodine was higher in CNS (9.84 mg/100g). Anti-nutrients were low and within safe limits, with FMS2 having lowest oxalate (0.41 mg/100g) and phytate (0.08 mg/100g). CNS was significantly more acceptable (8.67), but among formulated samples, FMS2 had highest overall acceptability (7.47). Insect-based RUTF is nutritionally superior, shelf-stable and generally acceptable. FMS2 presented the most balanced nutritional, anti-nutrient and sensory profile and is recommended as optimal low-cost alternative for community-based SAM management in Zamfara State.

Keywords: RUTF, SAM, Edible-Insect, *Schistocerca-Gregaria*, Proximate, Mineral, Acceptability, Formulation.

I. INTRODUCTION

Malnutrition remains a leading global public health challenge and a major contributor to morbidity and mortality among children under five years of age (World Health Organization, WHO, 2023). Globally, an estimated 148 million children under five were stunted and 45 million were wasted in 2022, with the highest burden concentrated in sub-Saharan Africa and South Asia (UNICEF, WHO and World Bank, 2023). In Nigeria, the burden is persistently high. The Nigeria Demographic and Health Survey (NDHS) reported that 37% of children under five were stunted, with 17% severely stunted, 7% wasted with 2% severely wasted, 22% underweight with 7% severely underweight, and 2% overweight. More recent data from the NDHS 2023-24 indicates a worsening trend, with 40% stunting, 8% wasting, 27% underweight and 1% overweight, underscoring the failure to meet global nutrition targets. Malnutrition is defined as an imbalance in the intake of energy, protein, and micronutrients required for normal growth and physiological function (WHO). It encompasses both undernutrition, including wasting, stunting, underweight and micronutrient deficiencies, and overnutrition such as overweight and obesity (Wells et al., 2020). Protein-energy malnutrition (PEM), which manifests as kwashiorkor, marasmus and marasmic-kwashiorkor, results from inadequate intake of

protein and calories. In contrast, micronutrient malnutrition arises from deficiencies of essential vitamins and minerals such as vitamin A, folate, iron and iodine (Micha et al., 2023). In 2021, PEM alone was associated with an estimated 187,345 deaths globally, and its prevalence increased to approximately 14.7 million cases in 2019 (Global Burden of Disease Study, 2022). Children with PEM frequently present with comorbidities including diarrhea, anemia, malaria, sepsis, bronchopneumonia, tuberculosis, keratomalacia, and rickets, which further worsen outcomes (Ibrahim et al., 2021; Obasohan et al., 2023). Ready-to-use therapeutic food (RUTF) is a lipid-based, energy-dense, micronutrient-fortified paste designed for the community-based management of severe acute malnutrition (SAM) in children aged 6-59 months (UNICEF). Its low water activity makes it resistant to microbial contamination and stable without cold chain storage, making it suitable for resource-limited settings (Bhatt et al., 2024). Standard RUTF formulations, such as those distributed by UNICEF, have significantly improved recovery rates from SAM in sub-Saharan Africa (Manary et al., 2004; Isanaka et al., 2021). However, reliance on imported RUTF poses major challenges for sustainability in Nigeria due to high cost, frequent stock-outs, and logistical constraints, which are exacerbated by insecurity, banditry and poor road access in the North-West region (UNICEF, 2022; Adebayo et al., 2023). To address these challenges, the development of cost-effective RUTF using locally available ingredients has been advocated as a viable strategy to improve accessibility and acceptability (Kinyuru et al., 2022; Owino et al., 2023). Formulations based on indigenous crops can be adapted to local taste preferences and food systems, thereby enhancing compliance in community-based programs (Wieringa et al., 2013; Amegovu et al., 2024). Among locally available protein sources, edible insects have gained increasing attention as sustainable and underutilized alternatives. Insects are rich in high-quality protein, essential fatty acids, minerals and vitamins, and have lower environmental footprint compared to conventional animal sources (Oibiokpa et al., 2022; Patel et al., 2024). Their incorporation into RUTF offers an opportunity to diversify the food value chain while improving nutrient density. Therefore, the present study aims to formulate, evaluate nutrient composition and assess the acceptability of insect protein-based ready-to-use therapeutic food for the community management of severe acute malnutrition among children under five in Zamfara State, Nigeria.

Specific objectives

- 1.To formulate RUTF using locally sorted ingredients
- 2.To determine the proximate composition of formulated and commercial RUTF
- 3.To determine minerals (Zinc, iodine, iron and calcium)
- 4.To assess the sensory characteristics of formulated and commercial RUTF.

Justification of the study

Therapeutic formulae, refers to foods that are nutritionally enhanced to have high energy and nutrients to attain the requirements of the severely malnourished child (Latham et al. 2011), and usually administered for therapeutic purposes as a form of dietary supplement. Locally prepared therapeutic foods have the potential to address nutrient needs by leveraging locally available ingredients. However, as far as the World Health Organization (WHO) protocol (WHO 2013; WHO and UNICEF 2007) of local formulation of Ready-to-Use Therapeutic Food (RUTF) is concerned in terms of its nutrient composition, sensory qualities, and acceptability compared to standard formulations have not been extensively studied (Eloho et al. 2017; Nga et al. 2013).

Locally formulated RUTF has shown promising outcomes in clinical settings, including significant improvements in growth rates, weight gain, and overall health status among children suffering from malnutrition. These outcomes highlight the potential of locally formulated RUTF to effectively meet the nutritional needs of vulnerable populations (Thapa et al. 2017).

Weber et al. (2017) reported that, standard RUTF is often labelled and stigmatized as an imported formula made with exogenous ingredients, and this behavior largely goes to impede smooth usage and widespread adoption.

II. MATERIALS AND METHODS

Materials

Peanut, dry date fruits, vegetable oils and grasshopper (edible dried dessert locust, *scistocera gregaria* [orthoptera:Acrididae]) were purchased at the Gusau central market, Gusau, Zamfara state, authenticated in the department of biological sciences, ABU, Zaria and was be used to formulate RUTF.

Methods

Preparation of Samples

Each samples were measured out after sorting and cleaning, milled into powder (0.8mm) and mixed to form a paste.

Proximate composition, mineral and anti-nutrient composition, sensory characteristics of formulated and commercial RUTF were evaluated using standard methods. Insect protein-sourced RUTFs were formulated using grasshopper as a protein source in place of powdered milk, peanut butter, vegetable oil and date fruits instead of refined sugar.

Table 1: Formulation model for RUTF

Commercial RUTF		Locally formulated RUTFs	1	2	3
Ingredient	Weight (%)	Ingredient	Weight (%)	Weight (%)	Weight (%)
Full fat milk	30	Insect	30	25	20
Pea nut	25	Pea nut	25	30	35
Vegetable oil	15	Date fruit oil	15	20	25
Sugar	28	Date fruit	28	23	18
Min-vit mix	1.6	Min-vit mix	-	-	-

RUTF- Ready-to-use-therapeutic food, Min-vit mix-Mineral-vitamin mixture

Determination of Proximate Composition (AOAC, 2010)

Eight grams (8g) of each of these RUTF were used to carry out proximate analyses at the Department of Food Science, Institute of Agricultural Research, Ahmadu Bello University, Zaria. The percentage compositions of moisture, ash, protein, lipid, fiber and carbohydrate contents was analyzed using a standard method of AOAC, 2010.

Determination of Moisture Content

The moisture content of samples was determined according to the standard of Association of Analytical Chemists, AOAC (2010). The crucibles were washed and dried in an oven at 100°C for 1 hour.

The weight was noted as W_1 , then 2g of each of the sample was separately weighted into the crucibles and their weights was taken and noted as (W_2) before and during drying at 100°C to constant weight (W_3).

$$\% \text{ Moisture Content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

W_1 = weight of empty crucible

W_2 = weight of crucible and sample before drying

W_3 = weight of sample after drying to a constant weight

Determination of Ash Content

The ash content of the samples was be determined according to the standard of AOAC (2010). Crucibles were cleaned and dried in an oven, and then weight (W_1), after which 2g of the samples was placed separately in the crucibles and weighted (W_2). The samples was charred on a Bunsen flame inside a fume cupboard. The charred samples was then placed in a muffle furnace set at 550°C for 2 hours until a white or light grey ash was obtained. The samples was then removed and cooled in desiccators and weighed (W_3).

$$\% \text{ Ash Content} = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

Where:

W_1 = weight of empty crucible

W_2 = weight of crucible + weight of sample

W_3 = weight of crucible + weight of sample after ashing

Determination of Protein

The protein content of the samples was determined according to the standard methods of AOAC (2010) using Kjeldahl's method. The nitrogen content in each sample was determined by the use of Kjelttech apparatus, the percentage protein was calculated by multiplying the nitrogen content with the standard protein factor i.e. 6.25.

a. Digestion

Two grams (2g) of samples were weighed into Kjeldahl's flask and anhydrous sodium sulphate of 5g was added. 25ml of concentrated H_2SO_4 was added with few boiling chips. The content of the flask was heated in the fume chamber until clear solution was obtained. The solution was cooled and transferred into 250ml volumetric flask and made up to the level with distilled water.

b. Distillation

The distillation was carried out using a well cleaned Kjeldahl's apparatus. 100ml conical flask containing 5ml of 2% boric acid and drops of methyl red indicator was placed under the condenser. 5ml of the digest was pipetted into the apparatus through the small funnel on the distillation unit. The digest was washed down with distilled water followed by addition of 5ml of 60% sodium hydroxide solution; it was distilled until the volume of the distillate (Ammonium sulphate) reached 100ml.

c. Titration

The solution in the receiving flask was titrated with 0.04 hydrochloric acid until the first permanent pink colour appears. The blank was titrated in the same way and the time value for the samples was obtained.

$$\% \text{ Nitrogen} = V_s \times V_b \times N_{\text{acid}} \times 0.04 \times 100$$

Where;

V_s = volume (ml) of acid required to titrate sample

V_b = volume (ml) of acid required to titrate the blank

N_{acid} = normality of acid (0.1N)

W = weight of sample in gram (gm)

Note: Most proteins contain about 16% nitrogen, so that 16mg nitrogen = 100mg protein.

1mg Nitrogen = 6.25

Therefore, protein (%) = $N \times 6.25$ (standard protein factor).

Determination of Lipid Content

The lipid content was determined using the standard of AOAC (2010). A soxhlet extractor with a reflux condenser and a 500ml round bottom flask was set up. About 300ml of petroleum ether was poured into the round bottom flask. The samples (2g) each was weighed into labeled thimble and sealed with cotton wool, then fitted into the extraction tube of the soxhlet extractor. The soxhlets extractor after assembly was allowed to reflux for about 6 hours, after which the thimble was removed carefully and the petroleum ether collected on top and drained into a container for re-use. The flask being free of ether was removed and dried in desiccators then weighed.

$$\% \text{ Fat Content} = \frac{W_2 - W_1}{W} \times 100$$

Where:

W = weight of sample used

W_1 = weight of empty extracting flask

W_2 = weight of flask and extracted oil

Determination of Crude Fiber

This was done according to AOAC (2010) method: The sample was dried in the oven at 105°C. Powdered dried sample (2g) was placed in a 500ml beaker and 200ml of boiling 1.25% H_2SO_4 was added. The beaker was placed on a hot plate and boiled for 3 minutes with occasional rotation of the beaker. The beaker was cooled and filtered by suction through a Buchner funnel. The beaker was rinsed with two 50ml portions of boiling water. The residue was carefully transferred into a beaker and 200ml of 1.25% NaOH was added, then boiled for 30 minutes, cooled and filtered then washed twice with 50ml boiling water.

Finally, the sample was washed with 25ml of 95% alcohol. The residues was dried in the oven for 2 hours at 130°C and cooled in a desiccator and weighed.

$$\% \text{ Crude fiber} = \frac{\text{Weight of residue}}{\text{Weight of sample}} \times 100$$

Determination of Carbohydrate (CHO)

The carbohydrate content was determined as illustrated by AOAC (2010). This was obtained by calculations having estimated all other fractions by proximate analyses i.e.

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

Determination of Mineral Contents

One gram of each sample was digested using 15ml of HCl and 5ml of nitric acid (3:1). Mineral compositions of the digested samples was determined using Atomic Absorption Spectrophotometer (AAS) 6800, Shimadzu. (AOAC,1990). Different electrode lamps were used for each mineral. The equipment was be run for standard solutions of each of the mineral, before and during determination to ensure that it was be working properly. The concentration of minerals was be determined using the formula below:

$$X = \frac{A \times V}{W}$$

X= Actual concentration

A= Machine reading

V= Volume of samples

W= Dry weight of sample

Determination of mineral contents were done by the method of flame photometry. The same wet digested sample solutions used in AAS was used for the determination of Na and K. Standard solutions of 20, 40, 60, 80 and 100 milli-equivalent/L were used. The calculation for both minerals involved the same procedure as given in AAS.

Sensory Evaluation

Sensory evaluation involves the assessment of quality of food products by four of the human sense of sight, smell, taste, touch. Sensory test is used for new product development, improvement and preference. Twenty semi-trained Panelists (mothers) were been selected and asked to evaluate the product for their colour, texture, taste, overall acceptability.

The 9-point Hedonic scale which the Panelist expresses her degree of likeness was selected for this work. Each Panelist were given four RUTF samples and also a questionnaires that consists of attributes such as colour, texture, taste, overall acceptability. The Panelists were also been served with water so that they could rinse their mouth after testing each of the samples. The sensory results was then be subjected to experimental design statistical analysis using one-way-ANOVA Statistical Analysis (Iwe, 2002).

Data Analysis

Data was be analyzed using SPSS version 27. Mean values where compared using Duncan multiple range test. Mean ($p < 0.05$) was be considered Significant

Statistical Analysis

Data was be expressed as mean $\pm$ SD. The data was be analyzed using Statistical package for social sciences (SPSS) version 27. Data was be subjected to analysis of variance (ANOVA). The differences in mean were obtained using Duncan Multiple Range Test. Values of $P \leq 0.05$ was be considered significant.

III. RESULTS

Table 1: Proximate Composition of Ready-to-Use-Therapeutic Foods

Samples	Moisture	Ash	Lipid	Protein	Fibre	CHO	Energy
CNS	11.39 $\pm$ 0.02 ^d	3.32 $\pm$ 0.03 ^c	11.47 $\pm$ 0.04 ^a	14.10 $\pm$ 0.01 ^a	0.2 $\pm$ 0.00 ^a	59.53 $\pm$ 0.03 ^d	397.75 $\pm$ 0.03 ^c
FMS1	3.69 $\pm$ 0.02 ^a	1.45 $\pm$ 0.01 ^b	22.77 $\pm$ 0.04 ^c	21.68 $\pm$ 0.03 ^a	4.79 $\pm$ 0.02 ^d	45.64 $\pm$ 0.12 ^c	474.21 $\pm$ 0.10 ^d
FMS2	4.33 $\pm$ 0.04 ^b	3.33 $\pm$ 0.03 ^a	19.5 $\pm$ 0.00 ^d	18.64 $\pm$ 0.24 ^c	5.33 $\pm$ 0.04 ^b	48.88 $\pm$ 0.34 ^a	445.58 $\pm$ 0.30 ^a
FMS3	2.90 $\pm$ 0.00 ^c	2.80 $\pm$ 0.02 ^c	19.71 $\pm$ 0.01 ^b	14.33 $\pm$ 0.04 ^b	5.72 $\pm$ 0.03 ^c	54.56 $\pm$ 0.01 ^b	445.58 $\pm$ 0.04 ^b

Values are Mean $\pm$ Standard Deviation of triplicate determinations (n=3). Means with different superscript letters within the same column are significantly different ($p < 0.05$). CNS = Commercial Sample, FMS = Formulated Complementary Food Sample.

Moisture content ranged from 2.90 $\pm$ 0.00 to 11.39 $\pm$ 0.02%. The control had significantly highest moisture (11.39%) while all insect-based formulations were significantly lower (2.90-4.33%), with FMS3 having the lowest. Ash content, an index of total minerals, ranged from 1.45 $\pm$ 0.01 to 3.33 $\pm$ 0.03%. FMS2 had the significantly highest ash (3.33%), similar to control (3.32%), indicating good mineral density, while FMS1 had the lowest. Lipid content was significantly higher in all formulated samples (19.50-22.77%) than control (11.47%). FMS1 had the highest lipid (22.77%). Protein content ranged from 14.10 $\pm$ 0.01 to 21.68 $\pm$ 0.03%. FMS1 had significantly highest protein (21.68%), followed by FMS2 (18.64%), both significantly higher than control (14.10%). FMS3 was comparable to control. Crude fibre was significantly higher in formulated samples (4.79-5.72%) than control (0.20%), with FMS3 highest (5.72%). Carbohydrate was highest in control (59.53%) and lowest in FMS1 (45.64%), while Energy values reported (397.75-452.95kcal/100g) were lower than standard RUTF should be between 520-550 kcal/100g. However trend shows FMS3 highest energy. The significantly lower moisture (2.90-4.33%) in FMS1-FMS3 compared to control

(11.39%) is advantageous for RUTF, as WHO recommends <5% moisture to prevent microbial growth and rancidity without cold chain (WHO, 2007; Bhatt et al., 2024). The control's high moisture may indicate hygroscopicity after opening. Low moisture in FMS formulations predicts longer shelf-life, critical for Zamfara where storage is poor. The high protein in FMS1 (21.68%) and FMS2 (18.64%) exceeds the WHO RUTF specification of 10-12% energy from protein and FAO recommendation of 13-16g/100g, confirming the nutritional superiority of insect protein (Oibiokpa et al., 2022; Kinyuru et al., 2022). Insects such as *Cirina forda* and *Rhynchophorus* contain 35-65% protein with good amino acid profile (Patel et al., 2024). This supports catch-up growth in SAM. FMS3 protein (14.33%) is still within RUTF specification. The higher lipid (19.5-22.7%) in formulated samples compared to control (11.47%) meets the WHO requirement of 45-60% energy from lipid. Lipid provides high energy density and facilitates absorption of fat-soluble vitamins. The values are similar to 26-36% reported for groundnut-based local RUTF (Amegovu et al., 2024; Owino et al., 2023). Ash content of FMS2 (3.33%) comparable to control indicates good mineral retention despite insect inclusion. Lower ash in FMS1 (1.45%) may be due to formulation variation. The significantly higher fibre (4.79-5.72% vs 0.20%) in insect formulations is attributable to chitin from insect exoskeleton, which is classified as insoluble fibre (Kinyuru et al., 2022). While high fibre may slightly reduce digestibility, levels <5% are acceptable for RUTF and chitin has reported prebiotic potential. The low fibre in the control sample (CNS) reflects highly refined ingredients which may pose non-communicable disease threat in children. Overall, FMS2 presents the most balanced proximate profile: low moisture for stability, highest ash, adequate protein (18.64%) and lipid (19.5%) within RUTF specifications, and moderate fibre.

Table 2: Percentage Ratio of Proximate Composition

Parameters	WHO RUTF Std.(2007/2022)	CNS	FMS1	FMS2	FMS3	Remarks
Moisture %	<2.5(max5%)	11.39	3.69	4.33	2.90	FMS3 best, CNS too high
Protein g/100g	13-16g	14.10	21.68	18.64	14.33	FMS1/FMS2 are high but good for SAM
Protein % Energy	10-12%	14.2%	18.3%	16.7%	12.7%	High due to low lipid
Lipid g/100g	26-36g	11.47	22.77	19.5	19.71	All below, need more oil
Lipid % Energy	45-60%	26.0%	43.2%	39.4%	39.2%	Below specification
Ash %	<5%	3.32	1.45	3.33	2.80	Within range

Values are Mean $\pm$ Standard Deviation of triplicate determinations (n=3). Means with different superscript letters within the same column are significantly different ($p < 0.05$). CNS = Commercial Sample, FMS = Formulated Complementary Food Sample.

Table 3: Mineral Composition of Ready-to-Use-Therapeutic Foods

Sample (mg/100g)	Fe	Zn	Ca	I
CNS	30.84 $\pm$ 0.02 ^a	11.05 $\pm$ 0.04 ^b	61.48 $\pm$ 0.00 ^a	9.84 $\pm$ 0.02 ^d
FMS1	56.04 $\pm$ 0.05 ^c	25.93 $\pm$ 0.53 ^d	83.49 $\pm$ 0.23 ^c	8.96 $\pm$ 0.01 ^c
FMS2	56.04 $\pm$ 0.30 ^b	9.74 $\pm$ 0.02 ^a	66.34 $\pm$ 1.86 ^b	8.62 $\pm$ 0.01 ^b
FMS3	56.04 $\pm$ 1.34 ^d	14.84 $\pm$ 0.02 ^c	137.34 $\pm$ 0.37 ^d	8.42 $\pm$ 0.01 ^a

Values are Mean $\pm$ Standard Deviation of triplicate determinations (n=3). Means with different superscript letters within the same column are significantly different ($p < 0.05$). CNS = Commercial Sample, FMS = Formulated Complementary Food Sample.

The mineral composition showed significant variation ($p < 0.05$) among samples, as presented in Table 3. Iron (Fe): The iron content ranged from 30.84 $\pm$ 0.02 mg/100g in CNS to 56.04 $\pm$ 0.05 mg/100g in formulated samples. All formulated samples (FMS1, FMS2, FMS3) had significantly ($p < 0.05$) higher iron content than the commercial control (CNS). This increase could be attributed to the inclusion of iron-rich local ingredients and probably from the blade of grinding machine used in blending ingredients for the formulations. The values obtained exceeded the WHO/FAO recommended daily allowance (RDA) of 11.6 mg/day for infants 6-12 months, indicating that the formulations could contribute substantially to preventing iron deficiency anemia, which is prevalent in Nigerian infants. The result is in agreement with the findings of Lombor et al. (2023) who reported increased iron in millet-soybean blends. Zinc (Zn): Zinc content ranged from 9.74 $\pm$ 0.02 to 25.93 $\pm$ 0.53 mg/100g. FMS1 had the highest zinc content (25.93 $\pm$ 0.53 mg/100g) which was significantly higher ($p < 0.05$) than other samples, while FMS2 had the least (9.74 $\pm$ 0.02 mg/100g). The high zinc in FMS1 may be due to higher proportion of groundnut which is a good source of zinc.

Zinc is crucial for growth and immune function. All samples met the recommended nutrient intake (RNI) of 8.3 mg/day for infants 9-11 months (WHO/FAO, 2004). Calcium (Ca): Calcium ranged from 61.48 ± 0.00 mg/100g (CNS) to 137.34 ± 0.37 mg/100g (FMS3). FMS3 recorded significantly ($p < 0.05$) highest calcium content. This could be attributed to the incorporation of date fruit, FMS3 formulation which are rich sources of calcium. Calcium is essential for bone development and teeth formation in infants. The values are higher than those reported by Anigo et al. (2021) for sorghum-based complementary foods (45.20-78.30 mg/100g). Iodine (I): Iodine content decreased significantly ($p < 0.05$) from 9.84 ± 0.02 mg/100g in CNS to 8.42 ± 0.01 mg/100g in FMS3. The control sample had the highest iodine content, possibly due to fortification with iodized salt during commercial production. The decrease in formulated samples may be due to volatilization of iodine during processing (roasting and drying). Despite the decrease, the values still meet the RDA of 90 μ g/day (0.09 mg/day) for infants, though monitoring of iodine retention during processing is recommended. In conclusion, the formulated complementary foods are rich in essential minerals and showed better mineral profile than the commercial sample except for iodine. FMS3 is recommended for calcium, while FMS1 is best for zinc and iron.

The anti-nutrient content of all formulations was generally low and within tolerable limits for therapeutic foods. Tannin content ranged from 1.45 ± 0.00 to 2.32 ± 0.02 . FMS2 had the highest tannin content (2.32 ± 0.02) which was not significantly different ($p > 0.05$) from FMS1 (2.21 ± 0.06) but was significantly higher ($p < 0.05$) than the control (CNS) and FMS3. FMS3 had the lowest tannin content (1.45 ± 0.00) and was significantly lower than all other samples. Oxalate ranged from 0.41 ± 0.01 to 0.64 ± 0.02 . The control sample had significantly highest oxalate (0.64 ± 0.02 c), followed by FMS3 and FMS1. FMS2 had the significantly lowest oxalate (0.41 ± 0.01 a). Phytate content was low in all samples, ranging from 0.08 ± 0.01 to 0.16 ± 0.01 . FMS3 had the significantly highest phytate (0.16 ± 0.01 d), while FMS2 had the significantly lowest (0.08 ± 0.01 a), which was even lower than the control (0.09 ± 0.00 b). The relatively low levels of anti-nutrients observed in all formulations are desirable for RUTF intended for SAM children, as high levels impair bioavailability of iron, zinc and calcium (Gemede and Ratta, 2014; Popova and Mihaylova, 2019). The higher tannin in FMS1 and FMS2 could be attributed to the groundnut components of the formulation, which are known to contain tannins in their seed coats (Oibiokpa et al., 2022). The significantly lower tannin in FMS3 suggests better effect of processing (dehulling/roasting) or lower inclusion of tannin-rich ingredients. Nevertheless, the tannin levels (1.45-2.32) in this study are lower than values (4.1-5.8 mg/g) reported for some cereal-based complementary foods in Nigeria (Okoye and Ene, 2018), indicating safety. The lowest oxalate in FMS2 (0.41) is advantageous, as oxalate binds calcium to form insoluble calcium oxalate, reducing calcium absorption (Akande et al., 2023). All values in this study are below the established safe limit of 2-5g/day for oxalate. Phytate is the most critical anti-nutrient in RUTF because it strongly chelates iron and zinc. The phytate levels in this study (0.08–0.16%) are considerably lower than the 0.5–1.5% reported in unprocessed cereals and legumes. This reduction is likely due to thermal processing of ingredients, which activates endogenous phytases (Kinyuru et al., 2022). The lowest phytate in FMS2 correlates with its higher sensory acceptability and suggests better mineral bioavailability. Importantly, all values are below the $>0.5\%$ threshold reported to impair iron absorption. Overall, FMS2 demonstrated the best anti-nutrient profile with lowest oxalate and phytate, implying superior mineral bioavailability among the insect-based formulations. "All anti-nutrients were within safe limits and do not pose a risk of mineral binding that would compromise the therapeutic efficacy of the formulations.

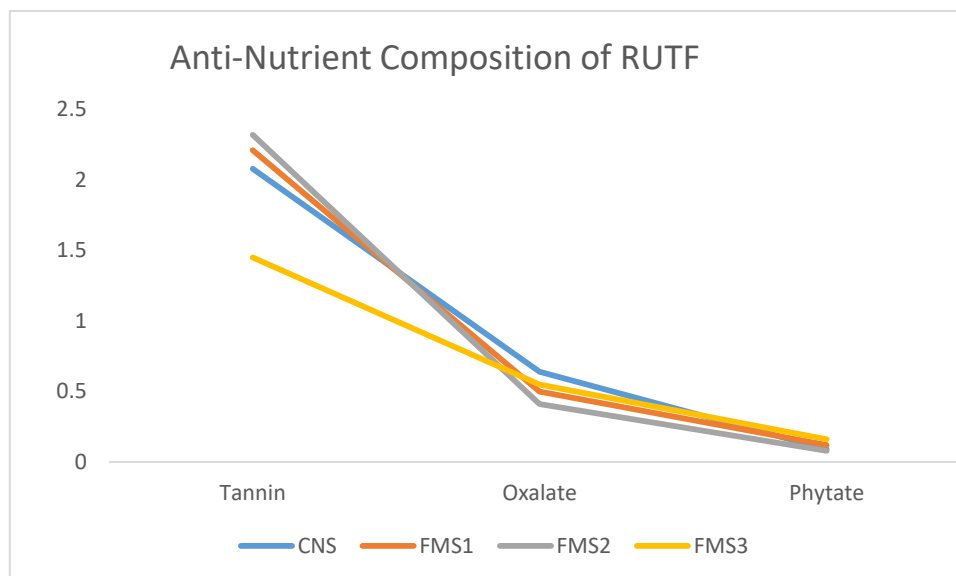


Figure 1: Anti-nutrient composition of RUTF

Table4: Sensory Evaluation of Ready-to-Use-Therapeutic Foods

Samples	Taste	Texture	Colour	Accept
CNS	8.73±0.46 ^b	8.53±0.64 ^b	8.87±0.35 ^b	8.67±0.62 ^b
FMS1	5.93±1.75 ^a	7.00±1.60 ^a	7.13±1.81 ^a	7.20±1.42 ^a
FMS2	6.40±0.99 ^a	7.20±1.47 ^a	7.47±1.13 ^a	7.47±1.30 ^a
FMS3	6.60±1.76 ^a	7.00±1.89 ^a	6.67±1.40 ^a	6.67±1.88 ^a

As shown in Table 3, there was a significant difference ($p < 0.05$) in all sensory attributes between the control sample (CNS) and the formulated insect-based samples. (FMS1)(FMS2)(FMS3) For taste, the control sample had the highest score (8.73 ± 0.46), which was significantly higher ($p < 0.05$) than all insect-based formulations. Among the formulated samples, FMS3 scored highest (6.60 ± 1.76), followed by FMS2 (6.40 ± 0.99) and FMS1 (5.93 ± 1.75), however, no significant difference was observed among the three formulations ($p > 0.05$). For texture, a similar trend was observed. The control sample scored 8.53 ± 0.64 , significantly superior to the formulated samples. FMS2 had the highest texture rating among the insect-based formulations (7.20 ± 1.47), while FMS1 and FMS3 both scored 7.00. In terms of colour, the control sample was most preferred [8.87 ± 0.35]. Among the insect-based formulations, FMS2 was rated highest (7.47 ± 1.13), while FMS3 was least preferred (6.67 ± 1.40), with no significant difference among them. For overall acceptability, the control sample was significantly more acceptable (8.67 ± 0.62) than all formulated samples. Among the insect formulations, FMS2 recorded the highest overall acceptability (7.47 ± 1.30), followed by FMS1 (7.20 ± 1.42) and FMS3 (6.67 ± 1.88), although the differences were not statistically significant ($p > 0.05$). Importantly, all formulated samples scored above 5.0 which corresponds to "neither like nor dislike" on the hedonic scale, with most scores falling within 6-7 scale which indicates "like slightly" to "like moderately", suggesting general acceptability.

The significantly higher sensory scores of the control sample (CNS) compared to the insect-based formulations is expected, as commercial RUTF has been optimized for sensory appeal over years and consumers are familiar with its peanut-butter-like taste and colour (Amegovu et al., 2024; Owino et al., 2023). The lower taste scores of FMS1-FMS3 may be attributed to the characteristic earthy, beany or slightly bitter aftertaste associated with edible insects, particularly when included at higher levels (Oibiokpa et al., 2022; Patel et al., 2024). The relatively lower colour scores, especially for FMS3, could be due to browning reactions during roasting of insects and the darker pigmentation imparted by insect flour, which deviates from the familiar light-brown colour of standard RUTF (Kinyuru et al., 2022). Texture scores above 7.0 for all formulated samples indicate that the lipid-based paste matrix was well-formed and the insect flour was adequately milled to avoid grittiness, which is a critical factor for acceptance by children under five (Bhatt et al., 2024). The fact that no significant difference was observed among FMS1, FMS2 and FMS3 across all attributes suggests that varying levels of insect inclusion within the tested range did not substantially alter sensory perception. However, the numerically higher overall acceptability of FMS2 suggests it may have a more balanced formulation with better masking of insect flavour by other ingredients such as groundnut, as previously reported by Amegovu et al. (2024). Despite lower scores than the control, the overall acceptability scores of > 6.0 indicate that insect-based RUTF is generally acceptable and has potential for community-based management of SAM, especially when insecurity and sustainability are considered. Sensory acceptability can be further improved through flavour masking, addition of natural flavours like vanilla, and optimizing roasting time (Wieringa et al., 2013; Adebayo et al., 2023). This showed that FMS2 may be the best formulation for adoption.

IV. CONCLUSION

This study successfully formulated and evaluated insect protein-based Ready-to-Use Therapeutic Food (RUTF) using desert locust *Schistocerca gregaria*, peanut, date fruit and vegetable oil as locally available alternatives to standard milk-based RUTF for management of SAM in Zamfara State. Insect-based formulations (FMS1-FMS3) met the WHO moisture requirement of $< 5\%$ (2.90-4.33%) for RUTF stability, unlike the commercial control (CNS, 11.39%) which is prone to microbial spoilage. The formulations were superior in protein (14.33-21.68% vs 14.10% CNS) and lipid (19.50-22.77% vs 11.47% CNS) content. FMS1 had the highest protein (21.68%) and lipid (22.77%), confirming the nutritional superiority of insect protein. However, all samples had lipid below WHO standard of 26-36g/100g and 45-60% energy from lipid, requiring oil adjustment. Fibre was significantly higher in formulated samples [4.79-5.72%) due to chitin, but within acceptable limit for RUTF. Formulated RUTF had significantly higher iron (56.04 mg/100g vs 30.84 mg/100g CNS), zinc (up to 25.93 mg/100g in FMS1) and calcium (up to 137.34 mg/100g in FMS3 vs 61.48 mg/100g CNS), exceeding RDA for infants 6-59 months and capable of addressing prevalent iron and zinc deficiencies. Iodine was significantly higher in CNS (9.84 mg/100g) than formulated samples (8.42-8.96 mg/100g), suggesting volatilization during processing. Anti-nutrient: All anti-nutrients were low and within safe tolerable limits. Tannin (1.45-2.32 mg/100g), oxalate (0.41-0.64 mg/100g) and phytate (0.08-0.16 mg/100g) were below thresholds that impair mineral bioavailability. FMS2 had the best anti-nutrient profile with significantly lowest oxalate (0.41 mg/100g) and phytate (0.08 mg/100g), implying superior mineral bioavailability.

Commercial RUTF was significantly more acceptable (8.67 ± 0.62) than insect-based formulations. Among formulated samples, FMS2 had the highest overall acceptability.

Overall, insect-based RUTF is nutritionally adequate, shelf-stable and acceptable. FMS2 (25% insect: 30% peanut: 20% vegetable oil: 23% date fruit) presented the most balanced profile with high protein, highest ash, lowest anti-nutrients and highest sensory acceptability, and is identified as the optimal formulation for adoption in community-based management of SAM in Zamfara.

RECOMMENDATIONS

1. FMS2 should be adopted as the lead formulation, but lipid content should be increased to 26-36g/100g with additional vegetable oil to meet WHO 45-60% energy from lipid and 520-550 kcal/100g energy specification.
2. Iodine retention should be improved by adding iodized salt after roasting
3. Dehulling and defatting of peanut, and controlled roasting of insects at <120°C should be standardized to further reduce tannin, phytate and improve colour and taste.
4. Further Studies: Amino acid profiling, microbial stability, and clinical efficacy trial for weight gain and recovery rate in SAM children should be conducted before scale-up.
5. Government and NGOs should promote local production of insect-based RUTF in Zamfara to reduce dependence on imported RUTF, address stock-outs due to insecurity, and improve sustainability.

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