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Evaluation of the effectiveness of *Spirulina platensis* for the nutritional rehabilitation of malnourished children aged 6–59 months: The case of the Mont-Ngafula II health zone

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ABSTRACT

Introduction
Childhood malnutrition remains a major public health challenge, particularly in resource-limited settings such as the Democratic Republic of the Congo (DRC). Effective, affordable, and sustainable nutritional interventions are urgently needed to improve the recovery of malnourished children. *Spirulina platensis*, a microalga with high nutritional density, represents a promising option; however, evidence from controlled trials in this context remains limited.

Purpose
To evaluate the nutritional effectiveness of *Spirulina platensis* supplementation on the nutritional status and biological parameters of malnourished children aged 6–59 months in the Mont-Ngafula II health zone in Kinshasa.

Methods
A single-blind randomised controlled trial was conducted among 100 malnourished children allocated to two groups over a 120-day period. One group received maize porridge enriched with spirulina (4 g every other day), while the control group received non-enriched maize porridge. Anthropometric indicators (mid-upper arm circumference, weight, and height) and biological parameters (haemoglobin, serum iron, albumin, total proteins, urea, and creatinine) were assessed before and after the intervention. Multivariate logistic regression was used to identify independent determinants of nutritional recovery.

Results
At the end of follow-up, 32% of children achieved complete nutritional recovery. The prevalence of severe acute malnutrition decreased from 71% to 47%. A highly significant improvement in mid-upper arm circumference was observed in the spirulina group ($p < .001$), along with significant increases in serum iron, albumin, and total protein levels. Spirulina consumption was strongly associated with nutritional recovery (OR = 357.2, 95% CI [5.24, 24,344.7], p = .006), with excellent model performance (AUC = 0.98).

Conclusion
Supervised supplementation with *Spirulina platensis*, integrated into a staple food, significantly improves both nutritional and biological status in malnourished children. This strategy appears well suited to resource-limited settings and merits thoughtful integration into child malnutrition management programmes, pending confirmation through larger-scale and longer-term studies.

INTRODUCTION

Background and Rationale

Childhood malnutrition remains a major global public health concern, affecting tens of millions of children under five years of age worldwide. It manifests in several forms, including stunting, wasting, and overweight, which makes its prevention and eradication particularly complex. According to the most recent estimates published by the World Health Organization (WHO, 2024), approximately 149 million children under five years were stunted, 45 million were wasted, and 37 million were overweight or obese in 2022.

Data from the Joint Child Malnutrition Estimates indicate that in 2022, about 148.1 million children under five years of age, representing 22.3% globally, were underweight. During the same year, approximately 45 million children (6.8%) experienced acute malnutrition, including 13.6 million (2.1%) with severe acute malnutrition (UNICEF, WHO, & World Bank, 2023).

Malnutrition is also a major determinant of child mortality. In 2022, nearly 4.9 million children died before reaching the age of five worldwide, with undernutrition contributing to approximately 45% of these deaths, underscoring its substantial impact on child survival (WHO, 2024).

The burden of malnutrition is unevenly distributed across regions. In 2022, approximately 22% of children affected by severe acute malnutrition lived in Africa (UNICEF et al., 2023). The prevalence of wasting on the African continent reached 5.8%, with a particularly alarming situation in sub-Saharan Africa, where acute malnutrition remains highly prevalent. In the Democratic Republic of the Congo (DRC), the prevalence of wasting among children under five was estimated at 6.4% in 2022, which is higher than the continental average and reflects persistent nutritional vulnerability among young children (Global Nutrition Report, 2024).

This critical nutritional situation occurs within a broader context of food insecurity. In 2023, the DRC was ranked as the country most severely affected by acute food insecurity worldwide, recording the highest number of affected individuals according to the Global Report on Food Crises (Global Network Against Food Crises, 2024). The accumulation of structural and contextual factors places children under five at particularly high risk of undernutrition, thereby justifying the implementation and evaluation of appropriate nutritional interventions.

The adverse health consequences of nutritional deficiencies in childhood, together with their economic implications, highlight the urgency of adopting local, accessible, and sustainable solutions. In this context, nutritional interventions such as spirulina supplementation emerge as potentially valuable strategies for the rehabilitation of malnourished children. Early intervention substantially facilitates the correction of nutritional deficiencies. Moreover, several studies have demonstrated that spirulina improves nutritional indicators owing to its richness in amino acids, nucleic acids, iron, carotenoids, and other bioactive components (Branger et al., 2003; Clément et al., 1967).

Spirulina, often described as a microalga, is in fact a microscopic cyanobacterium belonging to the genus *Arthrospira*, which primarily grows in brackish aquatic environments. The species most commonly considered suitable for human consumption include *Arthrospira platensis*, *A. maxima*, and *A. fusiformis*, commonly referred to as *Spirulina platensis*, *S. maxima*, and *S. fusiformis*, respectively (Zarzycka et al., 2016).

Evaluating the effectiveness of innovative nutritional interventions targeting malnourished children is essential in addressing this public health challenge. Such an approach enables the implementation of cost-effective and context-appropriate solutions while refining nutritional recommendations based on specific needs. However, in the Democratic Republic of the Congo, evidence regarding the effectiveness of spirulina supplementation among malnourished children remains scarce, particularly with respect to biochemical parameters, optimal dosage, and modes of administration, whether in care centres or at home. Addressing these gaps is therefore crucial to provide decision-makers and practitioners with robust and relevant scientific evidence.

Accordingly, the present study is based on the hypothesis that nutritional supplementation with *Spirulina platensis* contributes to improving the nutritional status of malnourished children aged 6–59 months. The study specifically investigates a supplementation regimen consisting of 4 g of *Spirulina platensis* administered every other day for 120 days under direct supervision at a nutritional rehabilitation centre.

Research Question

What is the effectiveness of spirulina supplementation on the nutritional status and health indicators of children aged 6–59 months, as assessed by anthropometric parameters (mid-upper arm circumference and weight) and biochemical markers (haemoglobin, serum iron, total proteins, albumin, urea, and creatinine), compared with a placebo group?

Research Hypothesis

Nutritional supplementation with spirulina improves the nutritional status of malnourished children aged 6–59 months.

Objectives

General Objective

To evaluate the nutritional effectiveness of spirulina supplementation in malnourished children aged 6–59 months.

Specific Objectives

Three specific objectives were defined:

1. To describe the characteristics of the two groups of children included in the study (with and without spirulina supplementation);
2. To analyse changes in anthropometric indices and selected haematological and biochemical parameters among 100 malnourished children aged 6–59 months living in the Mont-Ngafula II health zone;
3. To compare the nutritional effectiveness between two groups: one receiving maize porridge enriched with spirulina and a control group receiving standard maize porridge.

METHODS

Study Site

The study was conducted in three health areas of the Mont-Ngafula II Health Zone in Kinshasa, Democratic Republic of the Congo, namely Saya, Ngombe, and Musangu.

Follow-up activities were carried out at the Laboratory of Pharmacognosy Research for Health and Nutritional Support (LRPSN), located within the same health zone. This site was selected based on its geographical proximity to the study areas, ease of access, and the availability of a biomedical laboratory capable of performing the blood analyses required for the study.

Study Design

This study was a randomised, controlled, single-blind clinical trial designed to evaluate the effectiveness of a nutritional rehabilitation protocol among children presenting with malnutrition.

Study Population

The target population consisted of children aged 6–59 months residing in the Mont-Ngafula II Health Zone, specifically in the health areas of Saya, Ngombe, and Musangu.

Inclusion Criteria

Children were eligible for inclusion if they met all of the following criteria:

- Aged 6–59 months at the time of the first consultation at the LRPSN;
- Presented with nutritional imbalance defined by a mid-upper arm circumference (MUAC) ≤ 125 mm;
- Were not receiving any other nutritional treatment during the observation period;
- Were able to attend the LRPSN regularly throughout the study period;
- Had a legal guardian who provided written informed consent;
- Had an identifiable residential address and a valid telephone contact.

Exclusion Criteria

Children were excluded if they met any of the following criteria:

- Already enrolled in another therapeutic programme for malnutrition;
- Younger than 6 months or older than 59 months at the first consultation;
- Demonstrated irregular attendance or prolonged absence during the follow-up period;
- Lack of informed consent from the legal guardian.

Data Collection

At study initiation, each child attending a nutritional consultation was assigned a unique identification number. All documents submitted to the study sponsor identified participants exclusively by this study number. Names and other directly identifiable personal information were not included in the study database to ensure confidentiality.

Data were collected using an electronic consultation and follow-up form that included an interview section. The form was pre-tested to ensure clarity, reliability, and consistency. Collected data were exported to Microsoft Excel® 2013 for processing.

The data collection form included the following categories:

- Sociodemographic characteristics;
- Anthropometric measurements;
- Biological (blood) parameters;
- Clinical signs.

Biological variables required laboratory analyses, whereas anthropometric variables were obtained through standardised physical measurements.

Sampling

A simple random sampling method was used.

The sample size was set at 100 children, equally distributed between the two study groups (50 per group; 1:1 allocation). With a two-sided alpha level of 0.05 and a statistical power of 80%, this sample size was sufficient to detect, for the primary anthropometric outcome (ΔMUAC = MUAC_B − MUAC_A), a minimum between-group difference of approximately 0.64 cm, assuming a pooled standard deviation of approximately 1.12 cm.

For the primary clinical outcome, defined as achieving normal nutritional status at the end of follow-up (time B), this sample size allowed detection of a minimum absolute difference of approximately 19 percentage points, assuming a recovery rate of approximately 6% in the control group, with the same statistical power.

The trial comprised two arms:

- **Intervention group:** maize porridge enriched with spirulina;
- **Control group:** non-enriched maize porridge.

Missing values were observed for a limited number of key post-intervention variables, including nutritional status at time B, biochemical parameters at time B, and variables used as outcomes in regression models.

For overall descriptive analyses, the full sample size was N = 100. For specific analyses (regression models, group comparisons, and odds ratios), participants with missing data on any variable included in the model were excluded from that analysis, resulting in an analytical sample size of N = 99.

Randomisation and Blinding

Initially, community health workers identified and registered 198 malnourished children who met the inclusion criteria and assigned them sequential identification numbers from 1 to 198. The randomisation sequence was generated using the RAND() function in Microsoft Excel® 2013 by a member of the research team (an information technology specialist) who was independent of participant recruitment and assessment procedures.

Participant enrolment was conducted by LRPSN health personnel, including two nurses and one nutritionist, following verification of eligibility criteria and receipt of written informed consent from legal guardians. Allocation concealment was ensured by maintaining the randomisation list confidentially and accessible only to the principal investigator and the statistician, neither of whom was involved in participant recruitment or data collection. Personnel responsible for enrolment had no access to the randomisation sequence.

This methodological organisation was intended to minimise selection and allocation biases.

The study followed a single-blind design. Participants and their legal guardians were not informed of group allocation. The two porridge formulations had identical organoleptic characteristics to maintain blinding. Due to practical constraints, the staff responsible for porridge preparation were not blinded; however, they were not involved in outcome assessment. Laboratory personnel performing biomedical analyses were blinded to group allocation, as samples were labelled using anonymised numerical codes.

Although complete blinding of all staff was not feasible, the risk of bias was mitigated through the use of standardised anthropometric measurements, objective biological parameters analysed under blinded conditions, and rigorous and uniform supervision of porridge consumption in both groups within the same setting.

To further support blinding, an organoleptic assessment of the two supplementation products was conducted among six final-year pharmaceutical technology students at the University of Kinshasa. The packaging of the two products showed slight differences to prevent confusion among preparation staff; however, only this team had access to the packaged products. Other study personnel encountered the products only at the time of distribution, when they were already portioned and served in bowls.

Study Period

Children recruited for this study were enrolled between 5 March and 7 April 2025. The nutritional intervention was implemented from Tuesday, 8 April to Saturday, 9 August 2025, corresponding to a total duration of 120 days.

Table A:
Activity Schedule for the Study Period

Study Activity	Mar 5–19, 2025	Mar 20	Mar 21–25, 2025	Apr 4–6, 2025	Apr 8–Aug 9, 2025	Aug 11–14, 2025
Recruitment of children (MUAC screening)	✓					
Random selection of 100 children		✓				
Malaria prophylaxis			✓			
Baseline anthropometric and biological measurements (Time A)				✓		
Nutritional intervention					✓	
Post-intervention anthropometric and biological measurements (Time B)						✓

The study activities followed a predefined schedule that included participant recruitment and screening, random selection of eligible children, administration of antimalarial prophylaxis, baseline measurements of anthropometric and biological parameters (Time A), implementation of the nutritional intervention, and post-intervention measurements (Time B).

Study Variables

Dependent Variable

Nutritional status

• Nutritional recovery: 1 = normal nutritional status; 0 = malnutrition

• Nutritional improvement: severe acute malnutrition (SAM) or moderate acute malnutrition (MAM)

Nutritional recovery was defined as the primary outcome of the study. In addition to this binary outcome, nutritional improvement was also assessed.

Nutritional improvement, evaluated through changes in mid-upper arm circumference (ΔMUAC), reflects a continuous quantitative progression of nutritional status (SAM → MAM → normal nutritional status). In contrast, nutritional recovery corresponds to achieving a normal nutritional state at the end of follow-up and represents a binary clinical threshold.

Main Exposure Variable

- Spirulina consumption: 1 = maize porridge enriched with spirulina; 0 = maize porridge without spirulina

Adjustment Variables (Potential Confounders)

- Age (months)
- Total proteins at the end of follow-up (g/dL)
- Final height (cm)
- Weight (kg)

Biological Sampling and Antimalarial Prophylaxis

Blood sampling and biological analyses were performed at the Laboratory of Pharmacognosy Research for Health and Nutritional Support (LRPSN). Blood samples were collected in ethylenediaminetetraacetic acid (EDTA) tubes to ensure optimal preservation prior to analysis.

Following the random selection of the 100 study participants, all children received standardised antimalarial prophylaxis with artemether–lumefantrine in accordance with national treatment protocols, administered over three days. The initial collection of anthropometric and biological data (Time A) was conducted ten days after completion of antimalarial treatment to allow for clinical and biological stabilisation.

The nutritional intervention was initiated shortly after the baseline measurements and continued for 120 days.

Nutritional Intervention

Regular consumption of porridge in both study groups took place at the LRPSN under the direct supervision of an expert nutritionist, thereby ensuring strict adherence to the experimental protocol. This supervised approach minimised potential biases associated with unsupervised home-based supplementation.

The spirulina used in this study was produced locally in Kinshasa by the LRPSN as part of an initiative led by the non-governmental organisation CORPUS SANA, with support from the Italian association AGAPE ETS. Production followed the standard model developed by TEREGROUP, an Italian company specialising in organic spirulina cultivation.

The preparation of maize porridge was carefully standardised to maintain similar organoleptic characteristics between the two formulations. Each child received a 52 g portion of maize porridge every other day. Only the porridge administered to the intervention group was enriched with 4 g of spirulina per serving.

Control of Potential Biases and Mitigation Measures

Several potential sources of bias that could influence the assessment of the nutritional effectiveness of spirulina supplementation were considered during the study design to limit their impact and strengthen the internal validity of the results.

Malaria (paludism), a major confounding factor in endemic areas, was controlled through the systematic administration of standardised antimalarial treatment with artemether–lumefantrine to all participants, in accordance with national guidelines. This approach ensured a homogeneous malaria status across study groups. To reduce the influence of transient biological effects related to malaria recovery, baseline anthropometric and biological parameters were measured ten days after completion of antimalarial treatment, corresponding to a period of clinical and biological stabilisation. The nutritional intervention was initiated only after this phase, ensuring a clear temporal separation between the effects of antimalarial treatment and those of spirulina supplementation.

Performance bias was minimised by providing identical medical care and follow-up to all participants, irrespective of group allocation. Selection bias was reduced through the application of uniform inclusion and exclusion criteria and by verifying baseline comparability between groups

with respect to sociodemographic, anthropometric, and biological characteristics. Measurement bias was limited through the use of standardised procedures, calibrated equipment, and uniform analytical conditions for all participants.

Despite these precautions, residual bias related to unmeasured factors cannot be entirely excluded. Nevertheless, the standardisation of antimalarial treatment and nutritional follow-up strengthened the robustness of intergroup comparisons and the credibility of the study conclusions.

Phytochemical Analysis of Spirulina platensis

Each compound was analysed using a specific method selected according to its physicochemical properties. Although some components can be assessed using multiple techniques, the methods described below were chosen based on accessibility and feasibility within the available resources. All phytochemical analyses were conducted at the Laboratory of Pharmacognosy and Chemistry of Natural Substances, University of Kinshasa.

The principal analytical methods included:

- Ultraviolet–visible (UV–Vis) spectrophotometry for phycocyanin;
- Kjeldahl method and UV–Vis spectrophotometry for total proteins;
- Dry ashing for total ash content;
- Energy-dispersive X-ray fluorescence (EDXRF) spectrometry for minerals and heavy metals.

Phycocyanin

Phycocyanin content was determined by UV–Vis spectrophotometry using an LTS-UV756 spectrophotometer (LabTex). Extraction was performed in phosphate buffer (pH 7.0), prepared from monobasic and dibasic sodium phosphate, with aluminium chloride added for stabilisation.

Approximately 100 mg of dried spirulina powder was extracted in 25.0 mL of buffer, vortexed, incubated at 4 °C for 24 hours, and centrifuged at 3,500 rpm for 4 minutes. The supernatant was analysed at wavelengths of 620 nm and 650 nm using a 1 cm quartz cuvette, with the buffer serving as the blank. Analyses were performed in six replicates.

C-phycocyanin content was calculated using a standard equation and expressed as a percentage of dry matter, with an acceptance threshold of ≥ 6.0%.

Crude Proteins

Crude protein content was determined using the Kjeldahl method with a semi-automatic micro-Kjeldahl apparatus (OBNKA-2010EM). One gram of spirulina powder was digested with 10 mL of concentrated sulphuric acid and a selenium catalyst under heating until complete clarification was achieved.

After cooling, the digest was diluted, alkalinised with 40% sodium hydroxide (NaOH), and immediately distilled. Released ammonia was collected in a 5% boric acid solution containing a mixed indicator and titrated with 0.1 N hydrochloric acid until the endpoint (pink colouration). Crude protein content was calculated using the standard formula based on titrant volume and expressed as a percentage of dry matter.

Total Ash

Total ash content was determined by dry ashing in a muffle furnace. A pre-weighed sample was incinerated at 600 °C for 6 hours until complete elimination of organic matter. After cooling, the crucible was reweighed, and ash content, corresponding to the mineral fraction, was calculated from the mass difference.

Mineral Elements and Heavy Metals

Mineral elements and heavy metals were quantified using energy-dispersive X-ray fluorescence spectrometry (EDXRF) with a Spectro Xepos Standard spectrometer. Approximately 5 g of dried spirulina was homogenised, mixed with 1 g of binder (fluoxane), and compressed into a pellet.

Analyses were conducted according to the manufacturer's specifications using calibration curves established with certified reference standards. Detection limits ranged from 1 to 5 mg/kg, depending on the element analysed. Concentrations were expressed in mg/kg of dry matter. Each sample was analysed in triplicate, and results were reported as mean values.

Total Carbohydrates

Total carbohydrate content was determined using the phenol–sulphuric acid colourimetric method, which is based on the formation of a coloured complex proportional to sugar concentration. Absorbance was measured by UV–Vis spectrophotometry (LTS-UV756, LabTex) following incubation in a water bath. Quantification was performed using a calibration curve prepared with a standard glucose solution. Results were expressed as g/100 g or mg/g of dry matter, in glucose equivalents.

Total Lipids

Total lipids were quantified using Soxhlet extraction followed by gravimetric determination with an organic solvent (hexane or petroleum ether). After solvent evaporation, the lipid residue was dried and weighed. The method detection limit was approximately 0.1% of dry matter. Results were expressed as percentages (%) or g/100 g of dry matter.

Microbiological Analysis

Microbiological analyses were conducted in accordance with applicable standards to assess the sanitary quality of spirulina. Samples were aseptically homogenised, serially diluted, and inoculated onto appropriate culture media, then incubated under controlled temperature conditions (aerobic or anaerobic), depending on the microorganisms investigated.

Microbial counts were determined electronically and expressed as colony-forming units per gram (CFU/g), with detection thresholds of 10 CFU/g for enumeration and 1 CFU/25 g for the detection of *Salmonella* spp.

Microcystin

Microcystin content was measured by enzyme-linked immunosorbent assay (ELISA) following methanolic extraction of spirulina, using a microplate reader (BioTek). The detection limit ranged from 0.05 to 0.10 µg/kg. Results were expressed as µg/kg of dry matter.

Statistical Analysis

Statistical analyses were performed using R software (version 2025.05.1). Measurements collected before and after the intervention (spirulina or placebo) were denoted as Time A and Time B, respectively. For example, mid-upper arm circumference measured before supplementation was recorded as MUAC_A, and that measured after supplementation as MUAC_B.

Quantitative variables were described using mean ± standard deviation (SD) when approximately normally distributed, or median and interquartile range (IQR) when distributions were non-normal. Qualitative variables were summarised as frequencies and percentages. The level of statistical significance was set at $\alpha = .05$, and all tests were two-sided.

Baseline Comparisons

At baseline (Time A), characteristics of children in the spirulina-enriched maize porridge group and the control group were compared to assess initial comparability.

Quantitative variables were analysed using the independent-samples Student's *t* test when normality assumptions were satisfied, or the Mann–Whitney *U* test otherwise. Qualitative variables were compared using the Pearson chi-square test.

These analyses were performed to verify baseline balance between groups and to identify potential confounding factors.

Within-Group and Between-Group Comparisons

Changes in anthropometric indicators (weight, height, and mid-upper arm circumference) and biological parameters (haemoglobin, albumin, serum iron, urea, creatinine, and total proteins) were assessed separately within each group between baseline (Time A) and end of follow-up (Time B). Within-group comparisons (A vs B) were performed using the paired Student's *t* test for normally distributed variables or the Wilcoxon signed-rank test for non-normally distributed paired data.

Between-group comparisons of changes were conducted using the independent-samples Student's *t* test or the Mann–Whitney *U* test, depending on data distribution.

Primary Outcome Measures

Two primary outcomes were defined a priori.

Primary Anthropometric Outcome (Nutritional Improvement)

The change in mid-upper arm circumference (ΔMUAC = MUAC_B − MUAC_A), expressed in centimetres, was used as the primary anthropometric indicator of nutritional improvement. Nutritional effectiveness was evaluated by comparing ΔMUAC between the two study groups. Effect size was estimated using Cohen's *d*, calculated from the between-group differences in MUAC change.

Primary Clinical Outcome (Nutritional Recovery)

Nutritional recovery was defined as achieving normal nutritional status at the end of the study period (Time B). Recovery proportions were compared between groups using the chi-square test or Fisher's exact test, depending on expected cell counts.

Multivariate Analysis

A multivariate logistic regression model was constructed to identify factors independently associated with nutritional recovery at time B. Predictor variables were selected based on their clinical and biological relevance, as well as findings from univariate analyses.

The final model included the following variables: spirulina consumption (yes/no), child age (months), baseline total protein level (A), and total protein level at the end of follow-up (B).

Results were expressed as odds ratios (ORs) with 95% confidence intervals (95% CIs). Model performance was

assessed using several complementary indicators. Discriminative ability was evaluated by calculating the area under the receiver operating characteristic curve (AUC). Calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test. Model stability was examined by determining the number of events per variable (EPV).

Sample Size and Statistical Power

A total sample size of 100 children (50 per group) was considered adequate to detect clinically meaningful differences for both predefined primary outcomes.

For the anthropometric outcome (ΔMUAC), assuming a two-sided alpha level of 5%, equal allocation (1:1), and 80% statistical power, the study was powered to detect a minimum between-group difference of approximately 0.6 cm. The observed effect size (Cohen's d > 2) indicated a very large effect, resulting in an observed statistical power close to 100%.

For the clinical outcome of nutritional recovery, the sample size allowed detection of a minimum absolute difference of approximately 19 percentage points between groups with 80% power. The observed difference substantially exceeded this threshold, ensuring high statistical power for this outcome.

Ethics

The study protocol, informed consent form, and all relevant research documents were submitted to the Ethics Committee of the School of Public Health, University of Kinshasa (ESP/UNIKIN), for review and approval. Following evaluation, the Committee authorised the conduct of the study under reference number ESP/CE/10/2025, dated 21 January 2025. All official correspondence with the Ethics Committee is securely archived by the principal investigator.

Prior to enrolment, the legal guardians of participating children received a detailed informed consent document describing the study objectives, procedures, potential benefits, and possible risks associated with participation. The information was provided in the language most easily understood by the guardians to ensure full comprehension and voluntary participation. Written informed consent was obtained from each child's legal representative and countersigned by an authorised member of the research team.

Participant confidentiality was strictly maintained in accordance with ethical and regulatory standards. Each child was assigned an anonymous numerical identification code to ensure the protection of personal data.

At the conclusion of the study, children in the control group were provided with an adequate supply of spirulina powder for home-based supplementation.

RESULTS

Phytochemical Composition of the Spirulina platensis Used

The *Spirulina platensis* employed in this study underwent comprehensive phytochemical analysis. The results indicated a high protein content of approximately 60%, together with 11.2% total carbohydrates, 6.1% total lipids, and a phycocyanin concentration of 8%, reflecting the high biological and nutritional quality of the product.

Table 1a:
Mineral composition of *Spirulina platensis*

Mineral	Method	Recommended Daily Intake	Result (mg/kg)	Conclusion
Iron	X-ray Fluorescence	18 mg	450 ± 0.0019	Good
Calcium	X-ray Fluorescence	1 g	336 ± 0.0025	Good
Zinc	X-ray Fluorescence	10 mg	490 ± 0.00028	Good
Potassium	X-ray Fluorescence	1–3 g	706 ± 0.0040	Good
Sodium	X-ray Fluorescence	2 g	420 ± 0.0042	Good
Magnesium	X-ray Fluorescence	0.2 g	222 ± 0.0041	Good
Copper	X-ray Fluorescence	26 mg	1.2 ± 0.0009	Good
Selenium	X-ray Fluorescence	0.15 mg	0.05 ± 0.0001	Good
Germanium	X-ray Fluorescence	–	0.05 ± 0.0001	Good

Table 1b:
Heavy metal composition of *Spirulina platensis*

Toxic heavy metal	Method	Unit	Acceptance criteria	Result	Conclusion
Arsenic	X-ray fluorescence	µg/g	≤ 0.50 µg/g (USP)	Not detected	Compliant
Cadmium	X-ray fluorescence	µg/g	≤ 0.20 µg/g (USP)	0.0000011 µg/g	Compliant
Mercury	X-ray fluorescence	µg/g	≤ 1.00 µg/g (International standard)	Not detected	Compliant

Note: USP = United States Pharmacopeia. "Not detected" indicates concentrations below the analytical detection limit.

The mineral composition complied with established nutritional reference standards. Per 100 g of *Spirulina platensis*, the average mineral contents were as follows: iron (450 mg), calcium (336 mg), zinc (490 mg), potassium (706 mg), magnesium (222 mg), sodium (420 mg), copper (1.2 mg), selenium (0.05 mg), and germanium (0.05 mg).

This profile highlights the exceptional nutritional richness of *Spirulina platensis* and supports its use as a strategic dietary supplement in programmes aimed at paediatric nutritional rehabilitation.

Table 2a:
Assay results for protein, lipid, carbohydrate, and phycocyanin in *Spirulina platensis*

Analysis	Method	Criteria	Result (%)	Conclusion
Proteins	USP	≥ 50%	60 ± 0.0009	Compliant
C-Phycocyanin	USP	≥ 6%	8 ± 0.0116	Compliant
Total carbohydrates	Phenol–sulfuric acid (UV-Vis)	10–20%	11.2 ± 0.0007	Compliant
Total lipids	Soxhlet extraction	5–8%	6.1 ± 0.0009	Compliant

Table 2b:
Mycocystin and nucleoside assay in *Spirulina platensis*

Analysis	Method	Unit	Criteria	Result	Conclusion
Mycocystin	USP	µg/g	≤ 0.50	Not detected	Compliant
Total ash	Calcination (600 °C, 6 h)	g/100 g	6–10%	7.860 ± 0.0003	Compliant

Table 2c:
Microbiological analysis of *Spirulina platensis*

Microorganism tested	Standard / Method	Acceptance criteria (CFU/g)	Result (CFU/g)	Conclusion
Total aerobic microorganisms (30 °C)	NF EN ISO 4833-1:2013	≤ 100,000	80,000	Compliant
Thermotolerant coliforms (44 °C)	NF V08-060	≤ 100	< 10	Compliant
Sulfite-reducing anaerobes (46 °C)	NF V08-061	≤ 100	< 40	Compliant
Clostridium perfringens	NF EN ISO 7937:2004	≤ 10	< 6	Compliant
Coagulase-positive staphylococci	NF V08-057-1 (Spiral method)	≤ 100	< 90	Compliant
Salmonella spp.	BKR 23/07-10/11 (valid until 2027)	Absence required	Not detected	Compliant

Note: CFU = colony-forming units. "Not detected" indicates absence within the analytical detection limit.

Descriptive Results

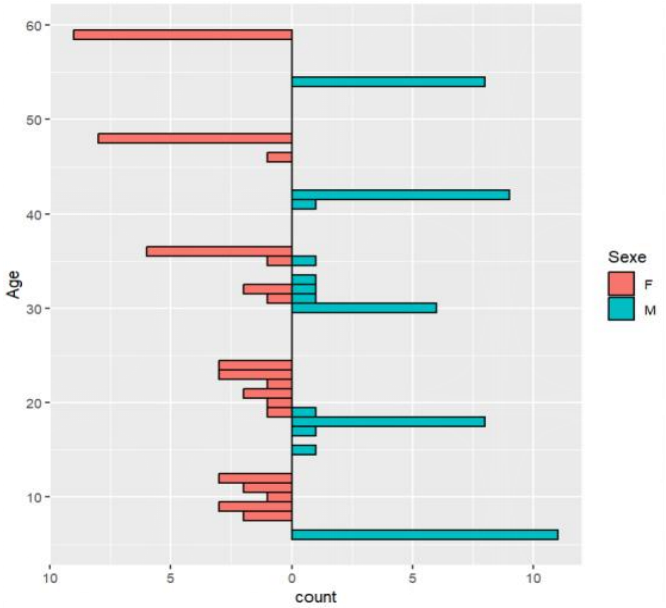
The study population comprised children aged 6–59 months. Among the 100 participants, the 48–59 month age group was the most represented (25%), followed by those aged 12–23 months (21%). Children aged 6–11 months constituted the smallest proportion (17%). The mean age was 24.6 months (SD = 10.8).

Table 3:
Distribution by age, sex, and parental presence: Comparison of the two groups

Characteristic	Without spirulina (N=50)	Spirulina (N=50)	Total (N=100)	P-value
Age, median (Q1–Q3)	***31 (18–48)***	***31 (18–42)***	***31 (18–47)***	***0.5***
Age group				
6–11 months	6 (35%)	11 (65%)	17 (100%)	–
12–23 months	10 (48%)	11 (52%)	21 (100%)	–
24–35 months	12 (67%)	6 (33%)	18 (100%)	–
36–47 months	8 (42%)	11 (58%)	19 (100%)	–
48–59 months	14 (56%)	11 (44%)	25 (100%)	–
Sex				**<0.001**
Female	39 (78%)	11 (22%)	50 (100%)	–
Male	11 (22%)	39 (78%)	50 (100%)	–
Parents (child lives with…)				**<0.001**
Neither parent	7 (70%)	3 (30%)	10 (100%)	–
Both parents	20 (32%)	43 (68%)	63 (100%)	–
One parent	23 (85%)	4 (15%)	27 (100%)	–

Notes: 1. Median (Q1–Q3); n (%) 2. Wilcoxon–Mann–Whitney test; Chi-square test of independence

Figure 1:
Age pyramid of children under study



Sex distribution was evenly balanced, with 50% boys and 50% girls.

Table 4:
Tutor occupation and Domestic Hunger Index

Characteristic	Without spirulina (N=50)	Spirulina (N=50)	Total (N=100)	P-value
Tutor's profession				**0.004**
Farmer	11 (73%)	4 (27%)	15 (100%)	–
None	0 (0%)	8 (100%)	8 (100%)	–
Others	4 (57%)	3 (43%)	7 (100%)	–
Shopkeeper	11 (73%)	4 (27%)	15 (100%)	–
Teacher	0 (0%)	2 (100%)	2 (100%)	–
Housekeeper	18 (43%)	24 (57%)	42 (100%)	–
Sentinel	6 (55%)	5 (45%)	11 (100%)	–
Hunger index				**0.014**
Severe hunger	33 (61%)	21 (39%)	54 (100%)	–
No hunger	11 (31%)	25 (69%)	36 (100%)	–
Little hunger	6 (60%)	4 (40%)	10 (100%)	–

Notes: 1. n (%) 2. Fisher's exact test; Chi-square test

Regarding living arrangements, 63% of children resided with both biological parents, 27% with one parent, and 10% with neither parent. Most guardians were homemakers (42%), followed by farmers (15%) and traders (15%). With respect to food security, more than half of households experienced severe hunger, while 36% reported no household hunger.

Evolution of Nutritional Status

Nutritional improvement and nutritional recovery represented two distinct but complementary outcomes of the intervention.

Table 5a:
Nutritional evolution before and after intervention

Nutritional status	Without spirulina (N=50)	With spirulina (N=50)	Total (N=100)	P-value
Normal	3 (9%)	29 (91%)	32 (100%)	<0.001
MAM	10 (48%)	11 (52%)	21 (100%)	–
SAM	37 (79%)	10 (21%)	47 (100%)	–
Malnutrition	47 (69%)	21 (31%)	68 (100%)	<0.001

At baseline, all enrolled children were classified as malnourished, and none had normal nutritional status. At the end of follow-up, 32% of participants achieved normal nutritional status, indicating substantial overall improvement.

Table 5b:
Nutritional status before and after intervention

Nutritional status	Before (N=100)	After (N=100)
Moderate acute malnutrition	29 (29%)	21 (21%)
Severe acute malnutrition	71 (71%)	47 (47%)
No malnutrition	0 (0%)	32 (32%)
Total	100	100

The prevalence of moderate acute malnutrition (MAM) decreased from 29% at baseline to 21% at follow-up. Similarly, severe acute malnutrition (SAM) declined from 71% to 47%, demonstrating an overall reduction in malnutrition severity.

Overall, 32 children (32%) achieved complete nutritional recovery, defined as restoration to normal nutritional status.

Statistical analyses showed that improvements in both nutritional status and recovery were highly significant ($p < 0.001$), indicating a meaningful difference between pre- and post-intervention measurements.

In settings characterised by severe and chronic malnutrition, such as the Mont-Ngafula II Health Zone, distinguishing between improvement and full recovery is particularly important, as many children may demonstrate measurable gains without achieving complete recovery within the follow-up period.

Comparative Analysis of Sociodemographic Variables

Baseline comparisons revealed statistically significant differences between the two groups for sex distribution ($p < 0.001$) and parental presence ($p < 0.001$). Guardian occupation ($p = 0.004$) and household hunger index ($p = 0.014$) were also significantly associated with group allocation, with guardian occupation demonstrating the strongest association.

Table 6:
Distribution by Health Area

Health Area	Without spirulina (N=50)	Spirulina (N=50)	Total (N=100)	P-value
Musangu	16 (46%)	19 (54%)	35 (100%)	0.7
Ngombe	17 (57%)	13 (43%)	30 (100%)	–
Saya	17 (49%)	18 (51%)	35 (100%)	–

Notes: 1. n (%) 2. Chi-square test

In contrast, the distribution of participants across health areas (Saya, Ngombe, and Musangu) was homogeneous and did not differ significantly between groups.

Comparison of Anthropometric and Biological Variables

Following the intervention, mid-upper arm circumference (MUAC_B) differed significantly between the two groups ($p < 0.001$).

Table 7:
Anthropometric and biological parameters (Wilcoxon test)

Parameter	Without spirulina	With spirulina	Total	P-value
Height 2	83 (74–90)	87 (77–97)	85 (76–94)	0.15
Height 1	83 (74–90)	87 (77–97)	85 (76–94)	0.15
Weight 2	10.0 (7.6–11.6)	10.6 (8.5–11.9)	10.45 (8.2–11.75)	0.3
Weight 1	10.35 (8.0–12.0)	10.5 (8.5–12.0)	10.5 (8.5–12.0)	0.9
MUAC 2	10.2 (9.2–11.6)	14.0 (12.0–15.0)	11.7 (10.15–14.0)	<0.001
MUAC 1	10.6 (9.2–11.6)	10.8 (9.4–11.8)	10.65 (9.4–11.7)	0.6
Iron 2	66 (59–71)	67 (61–73)	66 (61–72)	0.4
Iron 1	67 (59–72)	60 (52–68)	65 (57–69)	0.003
Urea 2	15 (14–16)	24 (22–27)	18 (15–24)	<0.001
Urea 1	20 (17–22)	20 (17–23)	20 (17–23)	0.9
Creatinine 2	0.8 (0.7–1.0)	0.6 (0.5–0.8)	0.8 (0.6–0.9)	<0.001
Creatinine 1	0.9 (0.6–1.1)	0.9 (0.7–1.2)	0.9 (0.65–1.15)	0.4
Protein 2	5.4 (5.0–5.9)	6.6 (6.1–6.8)	6.1 (5.4–6.7)	<0.001
Protein 1	5.7 (5.2–6.2)	5.6 (5.4–6.0)	5.6 (5.4–6.0)	0.7

Notes: 1 Median (Q1–Q3), 2 Wilcoxon–Mann–Whitney test

Table 8a:
Comparison of biological and anthropometric parameters between groups (Student's t-test)

Variable	t	df	p-value	Difference in group mean (Spirulina)	Difference in group mean (Without Spirulina)
Anthropometric parameters					
Size	0.571	86.89	0.570	−0.038	−0.022
Weight	0.649	92.68	0.518	−0.214	0.222
Brachial circumference	13.05	57.61	<0.001	−2.846	0.088
Biological parameters					
Hemoglobin (g/dL)	−0.494	48.22	0.623	−0.682	−1.700
Albumin (g/dL)	5.890	87.47	<0.001	−0.245	0.154
Serum iron (µg/dL)	6.923	96.92	<0.001	−6.854	1.204
Urea (mg/dL)	12.42	95.62	<0.001	−4.48	5.12
Creatinine (mg/dL)	−3.906	74.27	0.0002	0.248	0.032
Total protein (g/dL)	11.711	78.04	<0.001	−0.984	0.208

Note: Differences reflect mean change between groups. df = degrees of freedom.

Table 8b:
Changes in biochemical markers relative to baseline (Δ = B − A)

Biochemical parameter	Without Spirulina Δ (B−A)	With Spirulina Δ (B−A)
Hemoglobin (g/dL)	+0.20 ± 0.50 [0.06, 0.34]	+2.40 ± 0.70 [2.21, 2.59]
Albumin (g/dL)	+0.03 ± 0.15 [−0.01, 0.07]	+0.40 ± 0.18 [0.35, 0.45]
Serum iron (µg/dL)	+1.5 ± 4.8 [0.1, 2.9]	+8.1 ± 5.3 [6.6, 9.6]
Urea (mg/dL)	+0.8 ± 2.9 [0.0, 1.6]	+9.6 ± 3.5 [8.6, 10.6]
Creatinine (mg/dL)	−0.01 ± 0.04 [−0.02, 0.01]	−0.22 ± 0.06 [−0.24, −0.20]
Total protein (g/dL)	+0.07 ± 0.21 [0.01, 0.13]	+1.19 ± 0.30 [1.11, 1.27]

Note: Values are mean ± SD with 95% confidence intervals.

Significant post-intervention differences were also observed for serum total proteins (p = 0.001), creatinine (p = 0.001), urea (p = 0.001), and serum iron (p = 0.003).

Conversely, no statistically significant differences were detected between groups for height, weight, or haemoglobin levels.

Multivariate Regression Analysis

In multivariate analysis, spirulina consumption was strongly associated with nutritional recovery at the end of follow-up (OR = 357.2; 95% CI: 5.24–24,344.7; p = 0.006), independent of age and baseline protein status. Final total protein levels were also independently associated with recovery (OR = 15.1 per g/dL; 95% CI: 1.25–182.1; p = 0.033) **(Table 9)**.

Table 9:
Multivariate logistic regression predicting nutritional recovery

Variable	β (log-odds)	Standard error	Odds ratio (OR)	95% CI OR	p-value (Wald)
Spirulina (yes vs no)	5.88	2.15	357.18	[5.24, 24,344.74]	0.006
Total protein B (g/dL)	2.72	1.27	15.11	[1.25, 182.08]	0.033
Age (months)	0.27	0.08	1.31	[1.12, 1.54]	<0.001
Total protein A (g/dL)	−1.57	1.31	0.21	[0.02, 2.70]	0.229

Note: B = end of follow-up; A = baseline.

Table 10:
Effect of Spirulina and covariates on nutritional status

Variable	Coefficient (β)	p-value	Interpretation
Spirulina consumption	+2.91	0.181	Positive effect, not statistically significant
Total protein (B)	+1.93	0.039	Significant positive effect
Final size (B)	+0.51	0.096	Positive trend, marginal significance
Age	−0.07	0.678	Not significant

Table 11:
Effect size and statistical power for nutritional recovery

Setting	Value
Difference in proportions ($p_1 - p_0$)	0.520
95% CI difference	0.348 to 0.692
Effect size (Cohen's h)	1.237
α (two-tailed)	0.05
Observed power	1.000
Minimum detectable difference ($p_1 - p_0$) for 80% power (if p_0 observed)	0.194
Minimum detectable p_1 for 80% power (if p_0 observed)	0.254

Table 12:
Diagnostics of the multivariate logistic regression model

Indicator	Value	Interpretation
Number of participants (N)	99	Complete data
Events (normal recovery)	32	Positive outcome
Number of covariates	4	Model fitted
EPV (events per variable)	8	Moderate, acceptable risk
AUC (ROC)	0.98	Excellent discrimination
Hosmer–Lemeshow χ^2	≈6.0	Good calibration
Hosmer–Lemeshow df	≈8	–
Hosmer–Lemeshow p-value	0.64	Well-calibrated model

The logistic regression model demonstrated excellent discriminative ability (AUC = 0.98) and good calibration, as indicated by the non-significant Hosmer–Lemeshow test (p = 0.64). The number of events per variable (EPV = 8) suggested a moderate but acceptable risk of model instability. Overall, the model was considered robust and stable.

DISCUSSION

Nutritional Composition of Spirulina platensis

The phytochemical analysis of the *Spirulina platensis* used in this study underscores its high nutritional value, characterised by a high protein content (60%) and a substantial phycocyanin concentration (8%), consistent with previous reports for high-quality spirulina (Goulamabasse, 2018). Such a composition confers particular relevance to spirulina in the management of childhood malnutrition, where protein and micronutrient deficiencies are major determinants of morbidity (Chamorro et al., 2002).

The high protein density of spirulina represents a major advantage in malnutrition contexts, providing essential amino acids required for growth, tissue repair, and weight recovery in children. The improvement in protein status observed in this study—particularly reflected by increases in total proteins and albumin—may be partially attributed to this high-quality protein intake.

Phycocyanin, a bioactive pigment present at high concentrations, may further contribute to nutritional recovery through its antioxidant and anti-inflammatory properties. These effects could mitigate chronic inflammation associated with severe malnutrition and enhance nutrient utilisation.

Additionally, spirulina is rich in minerals such as iron, zinc, calcium, and magnesium, reinforcing its potential role in correcting micronutrient deficiencies frequently observed in malnourished children. Iron is central to preventing and correcting iron-deficiency anaemia, while zinc and magnesium are essential for immune function and growth processes. These findings align with in vivo and in vitro studies showing the mineral richness of *Spirulina platensis* and its effectiveness in improving iron status and immune function (Chamorro et al., 2002).

Overall, the nutritional composition of spirulina analysed in this study provides a strong biological rationale for its observed beneficial effects on child nutritional status and supports its use as a strategic dietary supplement in resource-limited settings.

Research Intervention Protocol

This study was conducted as a single-blind, randomised controlled trial involving 100 children aged 6–59 months, randomly assigned to two groups of 50 participants each. The 120-day intervention consisted of administering 52 g of maize porridge enriched with 4 g of spirulina every other day to the intervention group, while the control group received an equivalent quantity of non-enriched maize porridge. This design ensured regular and controlled exposure to spirulina while promoting acceptability and adherence.

Table 13:
Comparison of Spirulina supplementation trials in children

Study (Country, Year)	Population	Intervention (Dose)	Duration / Design	Main Results
Branger et al. (Burkina Faso, 2003)	Malnourished young children	Spirulina 5 g/day + nutritional support vs nutritional support alone	90 days, comparative test	No significant benefit in weight/height/weight-for-height gain; dose and care context may explain lack of effect
Simpore et al. (Burkina Faso, 2006)	Malnourished children, including severe forms	Spirulina + Misola (millet/soy/peanut) vs traditional meals	8 weeks, nutritional intervention	Anthropometric and biological improvements reported in Spirulina group; nutritional effect evident
Matondo et al. (DRC, Kisantu, 2016)	Malnourished children under 5	Spirulina 10 g/day + local ration vs local ration alone	30 days, follow-up at Day 0–15–30	Rapid improvement in nutritional indicators; biological monitoring (albumin, hematology) reported
Barennes et al. (Cambodia, 2022)	Preschool children in disadvantaged areas	Spirulina 2 g/day (total 100 g) vs placebo	Crossover trial with washout	Modest improvement in growth/weight and anemia parameters at institutional dose
Kashyap et al. (India, 2022)	Children (community program)	Spirulina in "chikki/granules" (fortified food)	9–10 months	Significant improvement in MUAC and nutritional categories; prolonged use enhanced effect
Recent study (2025, ScienceDirect)	Children with chronic malnutrition	Spirulina (supplement)	According to article	Positive effect on weight and MUAC; no clear effect on height, consistent with early weight/MUAC gains

Comparable approaches have been reported in the literature. For instance, Kamian (2009) conducted a study in Mali evaluating malnourished children receiving either SINBA porridge alone, SINBA with spirulina (5 g/day), or SINBA with fish over two months, highlighting the benefits of integrating nutritional supplementation into a food-based vehicle.

In contrast, several earlier studies—including Bucaille (1990), Habou (2003), and Sall et al. (1999)—did not include a control group, limiting the ability to attribute observed effects specifically to spirulina. Bucaille (1990) initially planned a control group receiving spirulina-free cakes but abandoned it for logistical reasons, while Habou (2003) administered spirulina as an isolated supplement added to the habitual diet.

The originality of the present protocol lies in integrating spirulina into a staple food consumed under supervision,

rather than as an isolated home-based supplement. This modality may explain the more pronounced effects observed compared with those reported by Branger et al. (2003), who did not observe significant benefits with a 5 g/day dose over 90 days, potentially due to adherence challenges or competing nutritional factors.

The findings of this study are consistent with Simpore et al. (2006) and Kashyap et al. (2022), who reported significant improvements in anthropometric indicators—particularly mid-upper arm circumference—when spirulina was administered as part of fortified foods or within prolonged community-based programmes. This further confirms the sensitivity of MUAC to protein and micronutrient intake.

Compared with the study conducted in Kisantu, Democratic Republic of the Congo, by Matondo et al. (2016), the present protocol shared contextual similarities but differed in its longer intervention duration and inclusion of a control group, thereby strengthening causal attribution of the observed effects to spirulina supplementation. Conversely, the more modest effects reported by Barennes et al. (2022) in Cambodia, using a lower dose (2 g/day) and shorter duration, suggest that cumulative dose, supplementation duration, and administration modality are critical determinants of nutritional effectiveness.

Finally, the combined assessment of anthropometric and biological parameters in this study provides a comprehensive understanding of the mechanisms underlying nutritional recovery. The observed improvement in protein and micronutrient status supports a biologically plausible, synergistic effect of spirulina, which has been suggested in previous literature but rarely documented in such an integrated manner.

Overall, comparison with previous studies indicates that the nutritional impact of spirulina is highly context-dependent. Factors including mode of administration, dosage, duration, and level of supervision influence effectiveness, with incorporation into a staple food emerging as a particularly appropriate strategy in settings characterised by severe nutritional insecurity.

Age and Sex

In this study, age emerged as a significant determinant of nutritional recovery. Multivariate regression analysis indicated that each additional month of age increased the likelihood of achieving normal nutritional status by approximately 31% (see **Table 9**). This positive association suggests that slightly older children may respond more favourably to nutritional interventions, potentially due to more mature digestive and metabolic functions and a greater capacity to utilise nutrients effectively.

These findings align with observations in chronic malnutrition contexts, where very young children—particularly those under 12 months—are more vulnerable due to a higher burden of infections, feeding difficulties, and persistent inflammatory states, which may limit responsiveness to nutritional interventions (Black et al., 2008).

Regarding sex, no significant association with nutritional recovery was observed, indicating comparable responses to spirulina supplementation among boys and girls. This absence of a sex-based differential effect is consistent with previous studies in childhood malnutrition, which report that when access to interventions and follow-up conditions are equivalent, sex does not significantly influence recovery outcomes (Wells et al., 2022). Nevertheless, indirect sociocultural factors may sometimes influence nutritional status by sex through differences in access to food, healthcare, or caregiving. In this study, randomization and standardization of protocols likely mitigated such effects, strengthening the validity of comparisons between boys and girls.

Overall, these findings suggest that age is an important modulating factor for nutritional recovery, whereas sex does not appear to significantly influence response to spirulina supplementation. These results highlight the need to tailor nutritional strategies according to age while ensuring equitable intervention access for both sexes.

Parental Presence, Guardian Occupation, and Household Hunger Index

Socio-familial factors play a central role in child nutritional status and in the effectiveness of nutritional interventions. In this study, parental presence, guardian occupation, and household hunger index were considered key contextual determinants likely to influence nutritional recovery by affecting food access, caregiving quality, and household stability.

The presence of a parent—particularly the mother or primary caregiver—strongly influences meal regularity, adherence to nutritional recommendations, and appropriate utilisation of health services. Conversely, prolonged parental absence for economic or social reasons can hinder adherence to nutritional interventions and contribute to persistent malnutrition. In this study, sustained parental presence likely facilitated better adherence to the intervention and closer monitoring of children's nutritional progress. These findings are consistent with Hingle et al. (2010), who reported that

active parental involvement improves child nutritional outcomes by enhancing adherence to dietary recommendations.

Guardian occupation serves as an indirect indicator of household socioeconomic status and livelihood stability. Guardians engaged in informal or precarious employment often face income instability, which can limit the household's ability to secure sufficient and diversified food. Conversely, more stable employment may provide a more favourable environment for food security and, consequently, child nutritional recovery. However, in contexts of structural poverty, even households with regular income may remain vulnerable to food insecurity. Nambuwa (2021) emphasises that parental occupation and family stability are major determinants of household food security, with employment precarity and parental absence frequently linked to poor dietary quality.

The household hunger index integrates food availability, access, and stability at the household level. A high hunger score reflects severe food insecurity, which may limit the effectiveness of child-targeted nutritional interventions. Even effective supplementation may be constrained in settings of chronic food insecurity.

Taken together, these socio-familial factors interact closely with nutritional interventions and influence their effectiveness. The findings suggest that while spirulina supplementation demonstrated a clear beneficial effect on nutritional recovery, its optimal impact also depends on family and socioeconomic context. This supports the need for integrated approaches combining targeted nutritional supplementation with strategies to strengthen household food security, maximising benefits among the most vulnerable children.

Evolution of Nutritional Status

The evolution of nutritional status in this study highlights two complementary dimensions of response: nutritional improvement and complete recovery. Distinguishing these levels allows for a nuanced interpretation of supplementation effectiveness, particularly in severe malnutrition contexts.

At baseline, all enrolled children were malnourished, with no cases of normal nutritional status. By the end of follow-up, 32% of children achieved normal nutritional status, indicating clinically meaningful improvement. Moderate acute malnutrition (MAM) decreased from 29% to 21%, and severe acute malnutrition (SAM) declined from 71% to 47%, reflecting an overall attenuation of malnutrition severity and a progressive transition from severe to less severe forms.

Complete nutritional recovery was observed in 32 children (32%), a notable outcome given the severity of baseline malnutrition and the limited duration of the intervention. Pre- and post-intervention differences were highly statistically significant ($p < 0.001$), indicating a robust and meaningful intervention effect.

In contexts of severe and chronic malnutrition, substantial improvement often precedes full recovery. This dynamic—characterised by transitions from SAM to MAM before normalisation—is consistent with the literature, which notes that sustained recovery typically requires prolonged, integrated interventions addressing infections, food insecurity, and broader socioeconomic determinants (Black et al., 2008).

These findings align with Kamian (2009), who observed a marked reduction in overall, moderate, and severe wasting following spirulina supplementation. Differences across studies may be attributed to variations in anthropometric criteria, supplementation dose and duration (4 g every other day for 120 days in the present study versus 5 g/day for 60 days), and study design (two-group versus three-group comparisons).

Anthropometric Parameters: Height, Weight, and Mid-Upper Arm Circumference

Regarding anthropometric outcomes, height and weight did not show statistically significant changes between baseline and end-of-study measurements ($p > 0.05$). In contrast, mid-upper arm circumference (MUAC) demonstrated a highly significant improvement ($p < 2.2 \times 10^{-16}$), confirming its sensitivity for detecting early changes in nutritional status.

The mean difference suggests modest weight gain in the spirulina-supplemented group compared with relative stagnation in the control group. MUAC is known to respond more rapidly to nutritional interventions than height or weight-for-age, particularly in acute malnutrition contexts, making it a valuable indicator for monitoring short- to medium-term recovery.

These results are consistent with Simpore et al. (2006), who reported greater weight gain with supplementation combining spirulina and Misola, suggesting a synergistic effect. Barennes et al. (2022) observed a favourable trend in weight gain among Cambodian children supplemented with spirulina, while Kashyap et al. (2022) demonstrated significant improvements in MUAC following prolonged supplementation.

Collectively, these findings reinforce spirulina's potential as an effective nutritional intervention, particularly for

improving sensitive anthropometric indicators such as MUAC, which closely reflect short-term nutritional status and survival risk in malnourished children.

Biological Parameters

Multivariate analysis using a generalized linear model identified several independent factors associated with nutritional recovery at the end of follow-up, after adjustment for major confounders. The results highlight a decisive effect of spirulina supplementation, alongside significant influences of biological status and age on the dynamics of nutritional recovery.

Spirulina consumption emerged as the strongest predictor of achieving normal nutritional status, with an exceptionally high odds ratio (OR ≈ 357). Nutritional recovery was observed in 58% of children in the spirulina group compared with only 6% in the control group. Such a distribution produces near-complete separation of the data, a phenomenon well-described in logistic regression when the outcome is rare in the reference group. In this context, very large odds ratio estimates reflect the true magnitude of the intervention effect rather than model instability (Heinze & Schemper, 2002; Peduzzi et al., 1996).

The model demonstrated excellent diagnostic performance, including near-perfect discrimination (AUC = 0.98) and satisfactory calibration, as confirmed by a non-significant Hosmer–Lemeshow test. Although the number of events per variable (EPV = 8) suggests a moderate risk of instability, this is acceptable given the consistency of the associations with univariate analyses and large anthropometric effect sizes (particularly MUAC, Cohen's d = 2.61).

Total protein levels at the end of follow-up were also a major independent predictor of nutritional recovery (OR ≈ 15 per 1 g/dL increase), reflecting the central role of protein status in tissue restoration, weight gain, and normalization of metabolic functions in malnourished children (Black et al., 2008). Spirulina, rich in high-biological-value proteins and essential micronutrients, likely exerts both a direct effect through protein provision and an indirect effect via overall metabolic improvement.

Age was positively associated with nutritional recovery, with each additional month corresponding to an approximate 31% increase in the odds of recovery. This observation, reported in chronic malnutrition contexts, suggests that slightly older children may exhibit greater metabolic adaptability or a more efficient response to nutritional interventions (Black et al., 2008).

The convergence of results from multivariate regression, anthropometric analyses, and biological measurements, together with favourable model diagnostics, supports the existence of a strong and biologically plausible effect of spirulina supplementation on nutritional recovery. These findings reinforce the use of spirulina in severe malnutrition contexts while highlighting the need for larger-scale studies to refine effect estimates and confirm predictive model stability.

However, these results contrast with a study conducted in Burkina Faso, in which daily supplementation with 5 g of spirulina for 90 days did not yield significant advantages over traditional renutrition (Branger et al., 2003). Such discrepancies may reflect differences in spirulina quality and composition, adherence to unsupervised supplementation, and intervention duration—all of which strongly influence observed nutritional effects.

CONCLUSION

This randomized controlled trial demonstrates that nutritional supplementation with *Spirulina platensis*, integrated into maize porridge and administered under supervision for 120 days, constitutes an effective intervention for improving the nutritional status of malnourished children aged 6–59 months in a context of high nutritional vulnerability in the Democratic Republic of the Congo.

The intervention produced significant improvements in both anthropometric and biological outcomes. Mid-upper arm circumference (MUAC), a sensitive indicator of acute malnutrition, showed marked improvement, while several biological parameters reflecting protein and metabolic status—including total proteins, albumin, serum iron, and urea—improved significantly in the supplemented group. Clinically, nearly one-third of children achieved complete nutritional recovery, and a substantial proportion experienced a reduction in malnutrition severity, indicating overall nutritional improvement.

Multivariate analysis confirmed that spirulina consumption was a major independent determinant of nutritional recovery, even after adjusting for age and biological status. The magnitude of the observed effect, together with excellent diagnostic performance of the model, indicates a real and biologically plausible impact of spirulina, consistent with its high content of high-biological-value proteins and essential micronutrients. Age emerged as a modulating factor, while sex did not influence response, suggesting comparable effectiveness among boys and girls when access to care and follow-up conditions are equitable.

The results also underscore the influence of socio-familial context—particularly parental presence and household

food security—on intervention effectiveness. These findings highlight that while nutritional supplementation is essential, optimal impact is achieved when integrated with broader approaches addressing social and economic determinants of child malnutrition.

Despite limitations, including sample size and follow-up duration, this study provides robust, original evidence in a context where local data on spirulina efficacy are limited. Supervised administration integrated into a staple food proved to optimise adherence and nutritional benefits.

In conclusion, *Spirulina platensis* supplementation appears to be a promising, context-appropriate nutritional strategy for improving nutritional status and initiating recovery among malnourished children in resource-limited settings. These findings support the integration of spirulina into child malnutrition management programs, pending confirmation through larger-scale and longer-term studies to assess sustainability of effects and optimise implementation strategies.

Author Contributions

Author	Contributions
Mupemba J.	Study conception, drafting and supervision of the experimental protocol, supervision of data collection, and manuscript preparation.
Kalenda N.	Contribution to study design, drafting of the experimental protocol, and responsibility for phytochemical analysis of spirulina.
Batumbo D.	Biostatistical data analysis, development of tables and figures, interpretation of results, and contribution to manuscript writing.
Mufusama J.P.	Contribution to study design, critical review and revision of the manuscript, and final validation of the submitted version.
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Kiliyo L.	Responsibility for nutritional follow-up and collection and interpretation of anthropometric parameters.
Bakana L.	Participation in age assessment and confirmation of study participants, supervision of sample collection, and interpretation of blood analysis results.
Tujibikila A.	Pharmacist responsible for quality control of spirulina.

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