Effectiveness and cost-effectiveness of 4 supplementary foods for treating moderate acute malnutrition: results from a cluster-randomized intervention trial in Sierra Leone

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ABSTRACT

Background: Moderate acute malnutrition (MAM) affects 33 million children annually. Investments in formulations of corn-soy blended flours and lipid-based nutrient supplements have effectively improved MAM recovery rates. Information costs and cost-effectiveness differences are still needed.

Objectives: We assessed recovery and sustained recovery rates of MAM children receiving a supplementary food: ready-to-use supplementary food (RUSF), corn soy whey blend with fortified vegetable oil (CSWB w/oil), or Super Cereal Plus with amylase (SC + A) compared to Corn Soy Blend Plus with fortified vegetable oil (CSB+ w/oil). We also estimated differences in costs and cost effectiveness of each supplement.

Methods: In Sierra Leone, we randomly assigned 29 health centers to provide a supplement containing 550 kcal/d for ∼12 wk to 2691 children with MAM aged 6–59 mo. We calculated cost per enrollee, cost per child who recovered, and cost per child who sustained recovery each from 2 perspectives: program perspective and caregiver perspective, combined.

Results: Of 2653 MAM children (98.6%) with complete data, 1676 children (63%) recovered. There were no significant differences in the odds of recovery compared to CSB+ w/oil [0.83 (95% CI: 0.64–1.08) for CSWB w/oil, 1.01 (95% CI: 0.78–1.3) for SC + A, 1.05 (95% CI: 0.82–1.34) for RUSF]. The odds of sustaining recovery were significantly lower for RUSF (0.7; 95% CI 0.49–0.99) but not CSWB w/oil or SC + A [1.08 (95% CI: 0.73–1.6) and 0.96 (95% CI: 0.67–1.4), respectively] when compared to CSB+ w/oil. Costs per enrollee [US dollars (USD)/child] ranged from $105/child in RUSF to $112/child in SC + A and costs per recovered child (USD/child) ranged from $163/child in RUSF to $179/child in CSWB w/oil, with overlapping uncertainty ranges. Costs were highest per sustained recovery (USD/child), ranging from $214/child with the CSB+ w/oil to $226/child with the SC + A, with overlapping uncertainty ranges.

Conclusions: The 4 supplements performed similarly across recovery (but not sustained recovery) and costed measures. Analyses of posttreatment outcomes are necessary to estimate the full cost of MAM treatment. This trial was registered at clinicaltrials.gov as NCT03146897. *Am J Clin Nutr* 2021;114:973–985.

Keywords: cost-effectiveness, wasting, moderate acute malnutrition, supplementary feeding program, relapse, sustained recovery

Introduction

The United Nations Decade of Action on Nutrition (2016–2025) includes an emphasis on improving the nutritional status of vulnerable populations (1). Such goals must be accomplished

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Abbreviations used: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; FBFs, fortified blended foods; FVO, fortified vegetable oil; LNS, lipid-based nutritional supplements; MAM, moderate acute malnutrition; MT, metric tons; MUAC, midupper arm circumference; RUSF, ready-to-use supplementary food; SAM, severe acute malnutrition; SC + A, Super Cereal Plus with amylase; SLL, Sierra Leone Leones; SNF, specialized nutritious foods; USD, US dollar.

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with a limited, and in some cases declining, national budget for the treatment of acute malnutrition (2). The burden for moderate acute malnutrition (MAM) is high, affecting about 33 million children annually, in addition to an estimated 14 million who suffer from severe acute malnutrition (SAM) (3, 4). To maximize the impact of scarce resources for this vulnerable group of children, governments and donors must consider the costs, in addition to the effectiveness, of different treatment options for MAM (5).

Outside of clinical care, MAM treatments are chosen from different formulations of supplementary foods known widely as specialized nutritious foods (SNFs), such as fortified blended foods (FBFs) and lipid-based nutritional supplements (LNS), some with standardized specifications and some in novel forms (6–8). Apart from supplementary foods, elements such as procurement channels, the delivery modality, and context also affect the cost and effectiveness of MAM treatment programs (9). Given the growing array of supplementary foods available, implementers have choices but relatively little guidance on how to navigate decisions that influence the cost of delivering treatment effectively and efficiently to children suffering from MAM.

Because of variation across study designs, product specifications, and intervention contexts, evidence is inconsistent concerning the comparative effectiveness of different supplementary foods (10). Further, few studies have examined relapses to MAM among children who achieved recovery (11–13). Even fewer studies have examined the relative cost-effectiveness of different supplementary foods for MAM treatment, and few such cost-effectiveness studies incorporate alternative perspectives (14). For example, valuing beneficiary caregivers' and program volunteers' time would enable program designers and implementers to understand the burden to participation that is experienced by program participants and community stakeholders.

To address these gaps, we examined the comparative cost-effectiveness of 4 different supplementary foods for the treatment of MAM from 2 different effectiveness and cost-effectiveness perspectives. The study was conducted in Sierra Leone among children aged 6–59 mo enrolled in a supplementary feeding program. As part of this trial, we estimated recovery [achieving a midupper arm circumference (MUAC) ≥12.5] and sustained recovery rates after 4 wk, as well as costs and cost-effectiveness, measured as cost per enrolled child, cost per recovered child, and cost per child who sustained recovery. We explore topics related to preparation, consumption, and household use of the food in a separate manuscript (15).

Methods

Study design and setting

This study was a nonblinded, cluster-randomized, community-based effectiveness trial with 4 treatment arms (registered at clinicaltrials.gov as NCT03146897) conducted in Pujehun District, Sierra Leone, from April 2017 to November 2018, with recruitment from April 2017 to August 2018. Pujehun District is the southernmost district of Sierra Leone and is characterized by high rates of stunting (26.4% of children under age 5) (16) and a prevalence of MAM, measured by MUAC (≥11.5 cm and <12.5 cm), of 3.1% (17). In addition to MAM, endemic malaria, diarrheal disease, and upper respiratory infections affect the overall health of children under 5 (16).

Trial participants and sample size

Eligible subjects were 6–59 months old with MAM (defined as an MUAC ≥11.5 cm and <12.5 cm), without bipedal edema or cerebral palsy. Children whose caregivers provided informed consent during a distribution day were enrolled in the study. Those subjects whose caregivers declined enrollment in the study still received care and treatment in the feeding program apart from the study. Children recovering from SAM and receiving ready-to-use-therapeutic food (RUTF) were eligible for the study when they progressed from SAM to MAM. If caregivers consented to participate in the study, their children were enrolled and switched from RUTF to the supplement assigned to that health center.

Local health centers were used as both the food distribution sites and the units of randomization. Initially, 28 health centers were sampled (7/arm); an eighth cluster was added to the Corn Soy Whey Blend with fortified vegetable oil arm (CSWB w/oil) in January 2018 due to arm-specific low enrollment (total health centers = 29). PASS 14 Software (NCSS Statistical Software, East Kaysville, UT) was used to estimate a sample size of 5320 (∼190 cases/cluster, 7 clusters/arm) by assuming a 70% recovery rate, an intracluster correlation of 0.006, estimated possibilities of 0.05 for a Type I error and 0.2 for a Type II error (power of 0.8) to detect a 7–percentage point difference in recovery rates. The actual sample size (n = 2653) allowed for a minimum 9–percentage point detectable difference.

Intervention

The 4 supplementary foods were distributed in isocaloric rations (∼550 kcal/d) for a total ration size designed to last 14 d if prepared and consumed as instructed. The 4 foods were chosen from previous research, representing a test of recommendations to update the formulation of Corn Soy Blend Plus (CSB+) to include a dairy protein, increase the quantity of fortified vegetable oil (FVO), and trial LNS for MAM treatment (18). The supplementary foods include 3 FBFs, which are CSB+ with FVO (CSB+ w/oil), CSWB w/oil, and Super Cereal Plus with amylase (SC + A); and 1 LNS, a ready-to-use supplementary food (RUSF; **Table 1**). Where SC + A was distributed in standard 1.9-kg packages, CSB+ and CSWB were distributed in novel 1.2-kg packages with separate 0.5-liter bottles containing 0.32 liters of FVO for addition during preparation. These 3 FBFs also required caregivers to add water and spend time preparing the food at home prior to consumption, whereas the RUSF could be eaten straight from the sachet. CSWB and SC + A were novel formulations at the time of the study, CSB+ and RUSF were in standard form, and CSB+ w/oil was the only food lacking a dairy component. CSB+ w/oil served as the comparison group. The FBFs and FVO were imported from the United States, while the RUSF was procured in Sierra Leone.

Distribution teams were composed of a nurse fluent in Mende and Krio (the local languages), a clinic manager, and a driver who transported the necessary supplies and supplement to the health center every 14 d, which we refer to as a "mobile clinic." At each visit, the team recorded beneficiaries' anthropometric

TABLE 1 Nutrient content and ration size of the supplements provided to children with moderate acute malnutrition in this trial[1]

	CSB+ w/oil		CSWB w/oil		SC + A	RUSF
Ingredient[2]	Flour	Oil	Flour	Oil	Flour	Paste
Daily recommended serving, g/d	85.7	25.7	135.7	25.7	135.7	100
Characteristics						
Packaging	Novel[3]	Rebottled[4]	Standard	Rebottled[4]	Standard	Standard
Formulation type	Standard		Novel[5]		Novel	Standard
Preparation and feeding	Cook with boiling water		Cook with boiling water		Cook with boiling water	Ready to eat
Nutritional content per daily serving[6]						
Energy maximum,[7] kcal	552.85		552.85		556.37	560
Protein, g	12		12		21.71	16
Fat, g	30.84		30.84		12.21	36
Vitamins						
Vitamin A, IU	4507.22		4509.39		4703.36	3833.33
Niacin, mg	6.86		6.86		10.86	—
Pantothenic acid, mg	1.37		1.37		2.17	—
Vitamin B6, mg	0.86		0.86		1.36	1.8
Folate, mcg	94.27		94.27		149.27	—
Vitamin B12, mcg	1.71		1.71		2.71	2.7
Vitamin C, mg	77.13		77.13		122.13	60
Vitamin D, mcg	411.2		411.2		—	20
Vitamin D3, IU	378.45		378.45		599.25	—
Vitamin E, mg	9.22		9.22		11.26	—
Vitamin K, mcg	72.97		72.97		40.71	—
Vitamin B1 (thiamine), mg	0.17		0.17		0.27	—
Vitamin B2 (riboflavin), mg	1.2		1.2		1.9	—
Minerals						
Iron (ferrous fumarate), mg	3.43		3.43		5.43	14
Iron (iron-sodium EDTA), mg	2.14		2.14		3.39	—
Zinc, mg	4.29		4.29		6.79	14
Iodine, mcg	34.28		34.28		54.28	140
Potassium, mg	119.98		119.98		189.98	1400
Phosphorus, mg	248.53		239.96		314.82	750
Calcium, mg	387.36		310.23		613.36	750
Biotin, mcg	7.03		7.03		—	—
Copper, mg	—		—		—	1.9
Magnesium, mg	—		—		—	225
Selenium, mcg	—		—		—	40

Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; RUSF, ready-to-use supplementary food; SC+ A, Super Cereal Plus with amylase.

[1]SC+A, Super Cereal Plus with amylase; CSB+w/oil, corn soy blend plus with fortified vegetable oil; CSWBw/oil, corn soy whey blend with fortified vegetable oil; RUSF, ready-to-use supplementary food.

[2]Represents type of ingredient that is provided by the supplementary feeding program as part of the ration.

[3]From standard specifications data provided by USAID, all data shown in maximum allowable cutoffs for the entire ration (i.e. for CSB+w/oil = flour+oil nutrient content).

[4]Represents maximum kcal in a standard daily serving. Reference technical specifications in Codex Alimentarius for minimum and maximum values (http://www.fao.org/fao-who-codexalimentarius/en/).

[5]1.2-kilogram (kg) packages polyethylene, hermetically sealed bags.

[6]Poured from 4-liter (L) aluminum cans to 0.5L plastic bottles to equivalent of 0.32L of oil.

[7]Only the flour formulation is novel; the fortified vegetable oil formulation is equivalent to that used with CSB+.

measurements (3 nonconsecutive measures of MUAC from 2 different team members, and 2 of length and weight per visit) and comorbidities in the previous 14 d on a paper card before providing another 14-d ration, as applicable. Length measures were taken using a Seca 417 height board and weight measures using a Seca 304 scale. Anthropometric measures were averaged for each visit; a third measure of height was taken if the difference of the 2 initial measures was greater than 0.5 cm. Team members were trained in proper methods for collecting length, weight, and MUAC at the beginning of the study and as a group during 2 additional occasions during the study. New members to the distribution team were trained by clinic managers for a minimum of 4 wk or until they were approved by the clinic manager to conduct anthropometric data for the study.

Graduation occurred when a child achieved an average MUAC ≥12.5 cm (**Table 2**) (19). Children who recovered received a final 14-d ration and were asked to return 4 wk, 3 mo, and 6 mo later for follow-up measures. Children who developed SAM or failed to recover were referred to the health center for an appropriate intervention. Children who relapsed to MAM were reenrolled into the feeding program for treatment but were not reenrolled back into the study.

TABLE 2 Outcomes and their definitions in this trial

Outcome	Definition
Recovery[1]	Achieving MUAC ≥12.5 cm by the seventh visit and no bipedal edema
Developed SAM	MUAC <11.5 cm or presence of bipedal edema
Death	As reported by health worker
Default	Missed 3 consecutive ration collection visits
Failure	Did not achieve MUAC ≥12.5 cm after receiving 6 rations

Abbreviations: MUAC, midupper arm circumference; SAM, severe acute malnutrition.
[1]A child, once enrolled, could receive a maximum of 7 rations; if they never missed a visit, that would equal 12 wk enrolled in the program. Missing a visit would extend the duration in the program but would not impact the number of rations the child was entitled to receive.

At enrollment, all caregivers participated in an intake interview where standard demographic information was gathered by a trained enumerator. Those receiving an FBF waited to participate in a cooking demonstration at the end of clinic, while those receiving the RUSF participated in a taste test during counseling and departed when ready. All supplements were distributed using a uniform protocol after the enrollment visit.

Ethical oversight

This study received ethical approval from the Tufts University Health Sciences Institutional Review Board, the Washington University in St. Louis School of Medicine Institutional Review Board, and the Sierra Leone Ethics and Scientific Review Committee. Permission to conduct the study was obtained from the Pujehun District Medical Officer and the Sierra Leone Ministry of Health and Sanitation.

Data management and analysis: effectiveness outcomes

Data were entered by 2 trained data entry clerks into KoboCollect webforms, compared against each another, and verified against paper clinic cards to resolve discrepancies. For baseline characteristics, continuous measures were tabulated (means ± SDs) and categorical or dichotomous measures were recorded as *n* (%). We used an intention-to-treat analysis with mixed-effects logistic regression, including the health facility as the random intercept, to compare recovery rates by supplement as our primary outcome. We used a conceptual model to identify potential confounders and predictors for inclusion in the logistic regression model. Secondarily, we used Kaplan-Meier curves and Cox proportional hazards models to estimate HRs of the recovery rate per day for each supplement compared to CSB+ w/oil as a comprehensive survival analysis.

We also explored supplement-specific differences in sustained recovery after 4 wk. This time frame was chosen because the proportion of missed visits was too high for reliable analyses at the 3- and 6-mo follow-up appointments. Sustained recovery was defined as when 2 conditions were met: MUAC at the 4-wk follow-up was ≥12.5 cm without edema and "relapse" was never specified on the paper clinic card to indicate a child relapsed in the period between recovery and follow-up. A backward stepwise approach was employed to identify potential confounders or predictors in the adjusted mixed-effects logistic regression models. To evaluate whether proportions of missed follow-up visits affected the parameter estimates, 3 models were compared for the sensitivity analysis: Model A excluded observations with missed visits (main model), Model B categorized observations with missed visits as relapsed cases, and Model C categorized observations with missed visits as sustained recovery cases. Data were analyzed using Stata 15 (StataCorp, College Station, TX).

Data analysis: cost-effectiveness outcomes

An activity-based costing approach with ingredients was used to identify 11 cost components (20). To estimate international freight costs for a typical feeding program context, we used commodity price quotes at scaled production [>500 metric tons (MT)] from US-based producers and international freight quotes for a 12-foot shipping container (**Supplemental Tables 1**, **2**, and **3**). To estimate the supplement's total cost and compare the small-scale production of the study to at-scale procurements typical of large MAM feeding programs, we compared historical costs and/or supplier-provided price quotes to the study's actual incurred costs (Supplemental Table 2). Data were estimated via 5 cost measures by arm: cost per MT, cost per ration, cost per enrolled child, cost per recovered child, and cost per child who sustained recovery.

We estimated and compared costs from 2 perspectives: the program perspective (combining donors, implementers, the government, and lead mother/community health volunteers) and the caregiver perspective (costs to caregivers for participating in the program). The sum of the cost components in each perspective equaled the total cost per enrolled child, which was calculated by ration size and number of rations received. The uncertainty ranges around program-perspective cost estimates were calculated using the minimum and maximum product price ranges. Caregivers' time spent on activities (mean ± 1 SD) that were treatment specific were used to construct uncertainty ranges for caregiver-perspective cost estimates. Time use was estimated using 2 observation methods: a subsample was observed during a typical ration collection at the facility and another subsample participated in 5 in-home observations on consecutive days.

We also incorporated the estimated 95% CI marginal mean effects from the predicted probabilities of the adjusted logistic model for recovery into the uncertainty ranges' calculations. We assessed whether differences were present by evaluating the final uncertainty ranges; where uncertainty ranges overlapped, we deemed no differences were present. In determining the cost per child who sustained recovery, average point estimates and uncertainty ranges were calculated using the same method but from simulations that accounted for effects of variation among the arms in missing data. Differences among the arms from the caregivers' perspective were deemed of significance if the uncertainty ranges did not overlap.

Results were converted to 2018 US dollars based on the average annual exchange rates between Sierra Leone Leones (SLL) and US dollars after adjusting for inflation using the appropriate GDP implicit price deflator (21–23). Lead mothers', volunteers', and caregivers' opportunity costs were measured as hours spent and valued at the Sierra Leone minimum wage (SLL 500,000/mo, approximately $0.38 per hr assuming 8 h/d, 5 d/wk, with 10 holidays/y). All cost and cost-effectiveness analyses were conducted using Microsoft Excel 2016 and R Studio version 3.4.1 (R Studio). The Supplemental Materials section contains more detail on the costing ingredients, cost-effectiveness values, relapsed missed visits, and additional effectiveness analyses.

Results

Baseline characteristics

A profile of the 2691 beneficiaries who consented and were enrolled is detailed in **Figure 1**, and the baseline characteristics of the 2653 beneficiaries retained for analysis are presented in **Table 3**. Overall, 1676 (63%) children recovered from MAM, with the highest proportion among those receiving SC + A ($n = 415$). Of the 500 beneficiaries who deteriorated to SAM, proportionately more were receiving RUSF ($n = 165$) compared to the other 3 supplements, whereas proportionately more defaulters were receiving CSWB w/oil ($n = 49$) than among the other 3 supplements (Figure 1). At enrollment, beneficiaries' mean age was 13.3 ± 7.9 mo, mean MUAC was 11.97 ± 0.27 cm, mean length was 68 ± 6.13 cm, and mean weight was 6.1 ± 1.02 kg. Most beneficiaries ($n = 2081$; 80%) were still breastfeeding and/or living in severely food insecure households ($n = 1590$; 60%). About 25% of beneficiaries ($n = 672$) entered the feeding program having graduated from SAM to MAM, most of whom received RUSF ($n = 218$). For each characteristic, less than 2% of data were missing, and no adverse reactions were reported for any supplements.

Recovery

Over the course of treatment, beneficiaries gained a mean weight of 13.1 ± 17.5 g/kg/d and a mean MUAC of approximately 0.4 ± 0.03 cm/d, with no significant differences among the arms in either measure (data not shown in tables). The overall mean time to recovery was 35.8 ± 22.9 d, again with no significant differences across arms. Compared to CSB+ w/oil, there were no differences in the Cox proportional HRs in either the adjusted or unadjusted models. As expected, the survival curves were nearly identical for all 4 study arms (**Supplemental Table 4** and **Supplemental Figure 1**).

Table 4 presents the results for both the crude and adjusted mixed-effects logistic regressions, showing no significant differences in recovery between any of the 3 foods and CSB+ w/oil. Enrollment during the rainy season (adjusted OR, 1.55; 95% CI: 1.29–1.87), having 1 or more females over age 65 y in the home (adjusted OR, 1.43; 95% CI: 1.08–1.9), beneficiaries' average MUAC at enrollment (adjusted OR, 11.76; 95% CI: 8.0–17.29), the average length-for-age z-score at enrollment (adjusted OR, 1.17; 95% CI: 1.06–1.28), and reported incidents of diarrhea in the 2 wk prior to enrollment (adjusted OR, 1.67; 95% CI: 1.12–2.48) were all associated with significantly higher odds of recovery ($P < 0.01$). Transferring to the feeding program having graduated from SAM to MAM was associated with significantly lower odds of recovery (adjusted OR, 0.56; 95% CI: 0.45–0.7; $P < 0.01$).

Sustained recovery

Supplemental Table 5 details the differences in attendance at follow-up visits by arm. Of the 1676 subjects who recovered from MAM, most returned 4 wk later for a follow-up visit ($n = 1530$; 91%) with attendance highest among CSB+ w/oil beneficiaries ($n = 399$; 94%) and lowest among RUSF beneficiaries ($n = 429$; 90%). Of the beneficiaries that came for the 4-wk follow-up, 22% had relapsed to MAM ($n = 339$).

Table 5 presents the results of the mixed-effects logistic regression models, showing significantly lower odds of sustaining recovery among those receiving RUSF compared to CSB+ w/oil in both the unadjusted (OR, 0.7; 95% CI: 0.51–0.96; $P = 0.03$) and adjusted (OR, 0.7; 95% CI: 0.49–0.99; $P = 0.04$) main model, which did not account for differences in missing values (Model A). Results from 2 sensitivity models were consistent with each other and with Model A. Compared to CSB+ w/oil, RUSF had significantly lower odds of sustained recovery in Model B when all missing values were set as the cases having relapsed (OR, 0.64; 95% CI: 0.46–0.88, $P = 0.01$), while the significance of the effect was attenuated in Model C when all missing values were set as the cases having sustained recovery (OR, 0.74; 95% CI: 0.52,1.04, $P = 0.08$). There were no significant differences in sustained recovery between those receiving either CSWB w/oil or SC + A and CSB+ w/oil in unadjusted or adjusted analyses.

Cost per enrolled child

Table 6 details the cost per enrolled child ($/child) by the 2 perspectives of the caregiver and program. From the program perspective, the point estimates ranged from ∼$90/child for CSB+ w/oil to ∼$94/child for SC + A, and were much higher than estimates from the caregiver perspective. Beneficiaries receiving RUSF experienced the lowest point estimate from the caregiver's perspective (∼$12/child), while beneficiaries receiving SC + A experienced the highest (∼$19/child), albeit with overlapping uncertainty ranges between arms. Though there were no observable differences in the uncertainty ranges when combining the estimates of these 2 perspectives, SC + A was the most expensive point estimate (∼$112/child), while the other 3 supplements were nearly equivalent (∼$108/child for CSB+ w/oil, $107/child for CSWB w/oil, and ∼$105/child for RUSF).

We examined the different cost components of the program perspective in **Supplemental Table 6**. Though the costs of implementing the program (i.e., the daily operational costs) were equivalent between the CSB+ w/oil and CSWB w/oil arms, they were ∼$2/child higher than the RUSF arm and ∼$1/child higher than the SC + A arm. These differences occurred because those receiving an FBF were required to attend a cooking demonstration and those receiving CSB+ and CSWB required

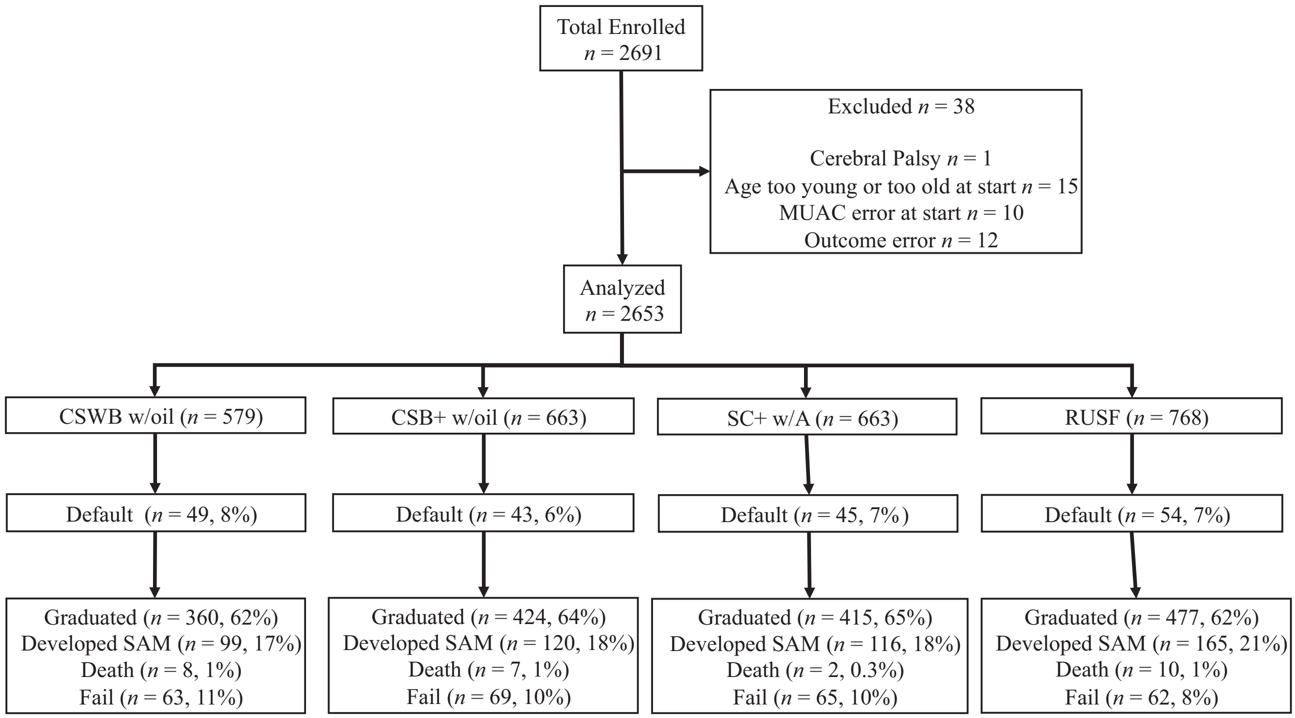

FIGURE 1 Trial profile. MUAC error at start was defined as mean of 3 MUAC measurements >12.5 cm or <11.5. Default was when a child did not come to clinic for treatment for 3 consecutive clinic visits. Fail was defined as not achieving MUAC ≥ 12.5 cm by the seventh ration (i.e., seventh visit to the supplementary feeding program). Note that a subject could miss any number of visits but would only be defined as defaulted at 3 consecutive visits. As such, some subjects were in the study for longer than 12 wk because of missed nonconsecutive visits. Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; MUAC, midupper arm circumference; RUSF, ready-to-use supplementary food; SAM, severe acute malnutrition; SC+ w/A, Super Cereal Plus with amylase.

more time to pick up the oil with the flour (i.e., 2 commodities instead of 1). Regardless of arm, the last-mile costs—defined as in-country costs—accounted for more than half of total costs, with the feeding program itself being the largest component, illustrating that time devoted to the program comprised both the largest cost and the largest source of variation among the foods (Supplemental Table 6).

To understand which factors alter the cost to caregivers, we present a detailed breakdown in **Supplemental Table 7**. Time is a major source of variation in the estimates and was lowest in the home among beneficiaries receiving RUSF ($0.90) because it required no preparation, in contrast to SC + A, in which the most time was spent preparing and feeding ($4.70). The time caregivers spent at clinic to collect a ration was also a source of variation across arms, but a minor source, with a difference of about $0.30/child. The average number of rations collected was similar across arms (∼3 rations collected); to collect a ration, caregivers reported traveling on average 3 h round trip, for an average opportunity cost of $3.80/child during treatment. Apart from collecting and using the ration, the opportunity cost to caregivers who were engaged in community-level activities was $0.60/child, with no differences among the supplements (data not shown in tables).

Cost per recovered child

We estimated the cost per recovered child ($/recovery) using the equation detailed in **Supplemental Method 1** and found that the estimates were similar across supplements, as illustrated in **Figure 2**. Examining the program perspective only, CSB+ w/oil had the lowest point estimate ($142/recovery) and CSWB w/oil the highest ($152/recovery), with overlapping uncertainty ranges. There were also no observable differences in costs per recovered child as examined from the caregiver perspective, with the lowest point estimated in the RUSF arm (∼$19/recovery) and the highest in the SC + A arm (∼$30/recovery). Since uncertainty ranges overlapped from the caregiver and the program perspectives separately, it was unsurprising that uncertainty ranges overlapped when the perspectives were combined: the RUSF arm had the lowest point estimate ($163/recovery) and the CSWB w/oil arm had the highest ($179/recovery).

Cost per child who sustained recovery

We present results of the analysis of costs per child who sustained recovery ($/sustained recovery) in **Figure 3**. From the program perspective, the cost per child sustaining recovery was lowest in the CSB+ w/oil arm ($179/sustained recovery), about $18 less than the highest point estimate, in the RUSF arm ($196/sustained recovery), with overlapping uncertainty ranges. Consistent with the results of costs per recovered child as examined from the caregiver perspective, the RUSF arm had the lowest point estimate (∼$24/sustained recovery) and the SC + A arm had the highest (∼$38/sustained recovery), with overlapping uncertainty ranges. When the perspectives were combined, there

TABLE 3 Child and household characteristics at enrollment, by food supplement group[1]

Characteristics	CSB+ w/oil, $n = 663$	CSWB w/oil, $n = 579$	SC + A, $n = 643$	RUSF, $n = 768$	Total, $n = 2653$
Sex, female	365 (55)	329 (57)	399 (62)	430 (56)	1523 (58)
Age, in months	13.1 ± 7.7 [10.5 (5.7, 55.6)]	13.2 ± 7.9 [10.7 (5.8, 59.5)]	13.2 ± 8.1 [10.5 (5.8, 58.1)]	13.5 ± 8 [11.1 (5.6, 59.3)]	13.3 ± 7.9 [10.7 (5.6, 59.5)]
Breastfeeding	523 (80)	453 (80)	510 (80)	595 (79)	2081 (80)
Rainy season at enrollment	399 (60)	363 (63)	421 (66)	441 (57)	1624 (61)
Transferred from SAM	166 (25)	114 (20)	174 (27)	218 (28)	672 (25)
Twin at birth	39 (6)	23 (4)	32 (5)	20 (3)	114 (4)
Mother is caregiver	608 (92)	546 (95)	589 (92)	700 (91)	2443 (92)
Caregiver is married	571 (86)	490 (85)	541 (85)	647 (85)	2249 (85)
Caregiver's age, in years	28.3 ± 8.4 [27 (17, 65)]	28.1 ± 8.2 [27 (16, 80)]	27.1 ± 7.4 [25 (17, 65)]	27.5 ± 8.2 [26 (16, 69)]	27.7 ± 8.1 [26 (16, 80)]
Caregiver's education					
None	369 (56)	321 (56)	340 (54)	389 (51)	1419 (54)
Some or completed primary	146 (22)	141 (24)	146 (23)	200 (26)	633 (24)
Some, completed, or more than secondary	145 (22)	116 (20)	150 (24)	176 (23)	587 (22)
HFIAS category, mild/moderate collapsed					
Food secure	178 (27)	134 (23)	148 (23)	220 (29)	680 (26)
Mildly or moderately food insecure	77 (12)	80 (14)	93 (15)	124 (16)	374 (14)
Severely food insecure	406 (61)	365 (63)	395 (62)	424 (55)	1590 (60)
SES wealth index[2]					
Lowest	122 (19)	123 (22)	115 (18)	162 (21)	522 (20)
Mid-low	115 (18)	138 (24)	105 (17)	165 (22)	523 (20)
Medium	123 (19)	110 (19)	122 (20)	164 (22)	519 (20)
Mid-high	145 (22)	111 (19)	133 (21)	134 (18)	523 (20)
Highest	148 (23)	89 (16)	152 (24)	135 (18)	524 (20)
Child's anthropometry					
Weight, kg	6.7 ± 1.01 [6.5 (4.7, 11.6)]	6.7 ± 1.01 [6.6 (4.9, 12.8)]	6.7 ± 1.06 [6.5 (4.7, 15.0)]	6.7 ± 1.01 [6.5 (4.1, 13.13)]	6.7 ± 1.02 [6.5 (4.09, 15.01)]
MUAC, cm	11.99 ± 0.27 [12 (11.5, 12.47)]	11.98 ± 0.28 [12 (11.5, 12.47)]	11.96 ± 0.26 [11.97 (11.5, 12.47)]	11.95 ± 0.27 [11.9 (11.5, 12.47)]	11.97 ± 0.27 [11.97 (11.5, 12.47)]
Length, cm	67.9 ± 6.1 [66.6 (55.75, 93.85)]	67.9 ± 5.96 [66.9 (57.9, 103.4)]	67.9 ± 6.27 [66.8 (56.5, 108.2)]	68.3 ± 6.17 [67.1 (53.2, 107.5)]	68.0 ± 6.13 [66.9 (53.15, 108.2)]
WAZ	−2.9 ± 0.8 [−2.9 (−5.35, 0.2)]	−2.8 ± 0.83 [−2.8 (−5.45, 1.26)]	−2.8 ± 0.78 [−2.8 (−5.77, −0.26)]	−2.9 ± 0.8 [−2.9 (−6.14, 0.8)]	−2.9 ± 0.8 [−2.9 (−6.14, 1.26)]
WHZ	−2.8 ± 1.3 [−2.7 (−7.4, 3.5)]	−2.8 ± 1.3 [−2.7 (−8.4, 5.6)]	−2.7 ± 1.3 [−2.6 (−9.4, 1.8)]	−2.8 ± 1.3 [−2.7 (−9.19, 2.6)]	−2.8 ± 1.3 [−2.7 (−9.4, 5.6)]

Data are presented as n (%) or mean ± SD [median (min, max)]. Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; HFIAS, Household Food Insecurity Access Score; RUSF, ready-to-use supplementary food; SAM, severe acute malnutrition; SC + A, Super Cereal Plus with amylase; SES, socioeconomic status; MUAC, midupper arm circumference; WAZ, weight-for-age *z*-score; WHZ, weight-for-height *z*-score.

[1]Percentages are of nonmissing values, <2% missing for each variable.

[2]Quintiles of score derived from principal component analysis.

TABLE 4 Odds of recovery from moderate acute malnutrition,[1] unadjusted and adjusted mixed-effects logistic regression

	Unadjusted, $n = 2653$			Adjusted, $n = 2529$		
	OR	95% CI	*P* value	OR	95% CI	*P* value
CSB+ w/oil	*Ref.*	—		*Ref.*	—	
CSWB w/oil	0.93	(0.74–1.17)	0.52	0.83	(0.64–1.08)	0.16
SC + A	1.03	(0.82–1.29)	0.82	1.01	(0.78–1.3)	0.95
RUSF	0.92	(0.74–1.15)	0.47	1.05	(0.82–1.34)	0.69
Child's sex: female	—	—	—	*Ref.*	—	
Male	—	—	—	1.26	(0.97–1.64)	0.09
Child's age, mo	—	—	—	1.02	(1–1.04)	0.07
Breastfeeding[2]	—	—	—	0.93	(0.69–1.26)	0.65
Enrolled during dry/hot season	—	—	—	*Ref.*	—	
Enrolled during rainy season	—	—	—	1.55	(1.29–1.87)	<0.01
Child transferred from SAM+[2]	—	—	—	0.56	(0.45–0.7)	<0.01
Received supplementary food last month[2]	—	—	—	0.90	(0.62–1.31)	0.59
Child had twin at birth[2]	—	—	—	1.11	(0.7–1.74)	0.66
Caregiver's age	—	—	—	1.01	(0.99–1.02)	0.21
No formal education	—	—	—	*Ref.*		
Some or completed primary	—	—	—	0.93	(0.74–1.16)	0.51
Some, completed, or more than secondary	—	—	—	0.98	(0.76–1.27)	0.91
Child has no living siblings	—	—	—	*Ref.*	—	
1	—	—	—	0.89	(0.69–1.16)	0.40
2	—	—	—	1.20	(0.9–1.6)	0.20
3 or more	—	—	—	1.04	(0.78–1.38)	0.79
No males aged 0–5 y in household	—	—	—	*Ref.*	—	
1	—	—	—	0.94	(0.74–1.19)	0.59
2 or more	—	—	—	0.97	(0.74–1.28)	0.83
No females aged 0–5 y in household	—	—	—	*Ref.*	—	
1	—	—	—	0.79	(0.61–1.04)	0.09
2 or more	—	—	—	0.82	(0.61–1.1)	0.18
1 or more females aged 65+ in household[2]	—	—	—	1.43	(1.08–1.9)	0.01
Radio[2]	—	—	—	1.04	(0.87–1.26)	0.65
Mattress with bed[2]	—	—	—	1.00	(0.82–1.23)	0.98
Motorcycle/scooter/okada[2]	—	—	—	0.97	(0.74–1.26)	0.81
Agricultural land[2]	—	—	—	0.94	(0.74–1.2)	0.63
Private household toilet	—	—	—	*Ref.*	—	
Shared/public	—	—	—	0.96	(0.79–1.17)	0.71
Unprotected well as drinking water source[2]	—	—	—	1.52	(0.94–2.48)	0.09
Zinc roof type[2]	—	—	—	0.81	(0.66–1)	0.05
Average MUAC[3]	—	—	—	11.76	(8–17.29)	<0.01
Length-for-age *z*-score[3]	—	—	—	1.17	(1.06–1.28)	<0.01
BMI-for-age *z*-score[3]	—	—	—	1.27	(0.85–1.9)	0.24
Weight-for-length *z*-score[3]	—	—	—	0.99	(0.68–1.44)	0.96
Fever[4]	—	—	—	0.78	(0.61–0.99)	0.04
Diarrhea[4]	—	—	—	1.67	(1.12–2.48)	0.01
Cough[4]	—	—	—	1.15	(0.89–1.49)	0.27
Model Wald chi[2] (*P* value)	1.31	—	0.73	351.21	—	<0.01

Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; MUAC, midupper arm circumference; RUSF, ready-to-use supplementary food; SAM, severe acute malnutrition; SC + A: Super Cereal Plus with amylase.

[1]Recovery defined as reaching an MUAC ≥12.5 cm within 12 wk and mixed-effects logistic regression model was used with clinic site as the random effect.

[2]Indicates binary (yes/no) indicator with reference being compared to "No."

[3]Recorded at enrollment.

[4]Self-reported by caregiver, defined as instance of morbidity (yes/no) in 2 wk preceding enrollment.

were again no discernable differences in the costs per child who sustained recovery. Comparing the costs per recovered child to the costs per child who sustained recovery, point estimates increased for all supplements, ranging from an additional $43 (CSWB w/oil) to $57 (RUSF), with differences in uncertainty ranges observed in the RUSF arm only.

Discussion

In this cluster-randomized, controlled effectiveness trial, 63% of children achieved a MUAC ≥12.5 cm by the end of treatment, and 71% of those remained healthy 4 wk after recovery was measured by MUAC. There were no significant differences in recovery rates among children receiving the 4 supplements, nor

TABLE 5 Odds of sustaining recovery[1] from moderate acute malnutrition, unadjusted and adjusted mixed-effects logistic regression

	Unadjusted,[2] $n = 1530$			Model A,[2] $n = 1489$			Model B,[3] $n = 1657$			Model C,[4] $n = 1657$		
	OR	95% CI	*P* value	OR	95% CI	*P* value	OR	95% CI	*P* value	OR	95% CI	*P* value
CSB+ w/oil (ref.)	*Ref.*	—		*Ref.*	—		*Ref.*	—		*Ref.*	—	
CSWB w/oil	1.11	(0.77–1.61)	0.57	1.08	(0.73–1.6)	0.71	0.94	(0.67–1.34)	0.75	1.12	(0.76–1.65)	0.56
SC + A	0.96	(0.68–1.36)	0.83	0.96	(0.67–1.4)	0.85	0.85	(0.61–1.19)	0.35	0.98	(0.68–1.41)	0.91
RUSF	0.70	(0.51–0.96)	0.03	0.70	(0.49–0.99)	0.04	0.64	(0.46–0.88)	0.01	0.74	(0.52–1.04)	0.08
Child's age (in months)	—	—		1.04	(1.02–1.06)	<0.01	1.02	(1–1.03)	0.01	1.04	(1.02–1.06)	<0.01
Breastfeeding	—	—		0.995	(0.98–1.01)	0.55	0.993	(0.98–1.01)	0.39	0.996	(0.98–1.01)	0.62
Child transferred from SAM[5]	—	—		0.996	(0.97–1.02)	0.71	0.993	(0.97–1.01)	0.51	0.997	(0.97–1.02)	0.77
Child admitted to hospital[5,6]	—	—		1.57	(0.71–3.46)	0.26	1.55	(0.8–3)	0.19	1.48	(0.68–3.24)	0.32
Diarrhea at recovery[5,7]	—	—		0.94	(0.65–1.37)	0.75	1.01	(0.99–1.02)	0.47	0.94	(0.64–1.37)	0.73
Weight gain velocity, kg/d	—	—		1.03	(1.01–1.04)	<0.01	1.02	(1.01–1.03)	<0.01	1.02	(1.01–1.04)	<0.01
Average MUAC at recovery	—	—		15.03	(6.5–34.75)	<0.01	3.93	(2.14–7.21)	<0.01	15.59	(6.82–35.63)	<0.01
Caregiver's age	—	—		1.00	(0.99–1.01)	0.55	1.004	(1–1.01)	0.26	1.002	(0.99–1.01)	0.59
Household food insecurity												
Food secure	—	—		*Ref.*	—		*Ref.*	—		*Ref.*	—	
Mild/moderate food insecure	—	—		1.18	(0.78–1.8)	0.43	1.15	(0.8–1.65)	0.46	1.20	(0.79–1.8)	0.39
Severely food insecure	—	—		1.38	(1.02–1.85)	0.03	1.28	(0.99–1.67)	0.06	1.40	(1.05–1.87)	0.02
Socioeconomic status												
Low	—	—		*Ref.*	—		*Ref.*	—		*Ref.*	—	
Mid-low	—	—		0.73	(0.49–1.1)	0.13	0.86	(0.61–1.23)	0.42	0.73	(0.49–1.09)	0.12
Medium	—	—		1.01	(0.67–1.52)	0.97	1.13	(0.79–1.63)	0.50	0.96	(0.64–1.44)	0.85
Mid-high	—	—		1.09	(0.71–1.66)	0.70	1.01	(0.71–1.46)	0.94	1.08	(0.71–1.64)	0.73
Highest	—	—		0.89	(0.58–1.37)	0.61	0.80	(0.56–1.15)	0.24	0.95	(0.63–1.44)	0.80
Season of graduation												
Dry season	—	—		*Ref.*	—		*Ref.*	—		*Ref.*	—	
Rainy season	—	—		1.39	(1.05–1.82)	0.02	1.29	(1.01–1.63)	0.04	1.35	(1.03–1.77)	0.03
Model Wald chi[6] (*P* value)	—	8.76	0.03		115.01	<0.01		93.49	<0.01		115.31	<0.01

Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; MUAC, midupper arm circumference; RUSF, ready-to-use supplementary food; SAM, severe acute malnutrition; SC + A: Super Cereal Plus with amylase.

[1]Sustained recovery defined as still having a health mid-upper arm circumference ≥12.5cm 4 wk after graduation and mixed effects logistic regression model was used with clinic site as the random effect.

[2]Unadjusted and Model A data include listed covariates but exclude children that missed the 1-mo visit.

[3]Model B imputes into the model all children that missed the 1-mo visit as if they had relapsed.

[4]Model C imputes into the model all children that missed the 1-mo visit as if they had sustained recovery.

[5]Indicates binary (yes/no) indicator with reference being compared to "No."

[6]Self-reported by caregiver that the beneficiary child had been admitted to the hospital at least once during the 2 wk preceding enrollment.

[7]Self-reported by the caregiver that the beneficiary had at least 1 instance of diarrhea within 2 wk prior to graduation.

TABLE 6 Cost per enrolled child by perspective and supplementary food[1]

Perspective	CSB+ w/oil	CSWB w/oil	SC + A	RUSF
Donor and implementer	83	83.5	86.5	86
Government and volunteer[2]	7.1	7.1	7.1	7.1
Caregiver	17.6 (7.6, 36.4)[3]	16.4 (7.5, 32.7)[3]	18.7 (8.0, 38.6)[3]	11.7 (6.1, 26.7)[3]
Program	90.1	90.6	93.6	93.1
Program and caregiver	107.7 (97.7, 126.5)[4]	107 (98.1, 123.3)[4]	112.3 (101.6, 132.2)[4]	104.7 (99.2, 119.8)[4]

Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; RUSF, ready-to-use supplementary food; SC + A: Super Cereal Plus with amylase.

[1]All estimates are of costs per enrolled child.

[2]Includes storage space provided by government, community health worker base pay by government, and volunteer opportunity cost of lead mothers involved in community-level activities.

[3]Confidence Interval constructed based on mean ± 1 SD of time per occasion for caregiver activities that were sources of across-arm differences.

[4]Constructed by incorporating the ranges for caregiver perspective cost.

were there differences among the 4 supplements in costs per recovered child, either from specific perspectives (program or caregiver) or from the combined perspective. Beneficiaries receiving RUSF experienced significantly lower odds of sustaining recovery for 4 wk compared to those receiving CSB+ w/oil and had higher costs per child who sustained recovery from the program perspective, though not from the combined perspective.

Our results are consistent with the growing scientific evidence that improved formulations of FBFs achieve similar recovery rates compared to LNS products. In a systematic review of SNFs for the treatment of MAM, Lazzerini et al. (24) concluded that LNS and FBF were equally effective at preventing mortality, progression to SAM, and attrition, but that children were significantly more likely to recover from MAM when receiving LNS compared to standard FBFs (RR, 1.10). In the review, a novel formulation of CSB+ (currently branded as SC+) performed similarly to LNS, warranting more research into updated formulations of FBF to improve recovery rates (24). Lenters et al. (25) found similar results in a meta-analysis published around the same time. In an updated systematic review and meta-analysis, Das et al. (10) found no difference in recovery rates between children receiving standard RUSF

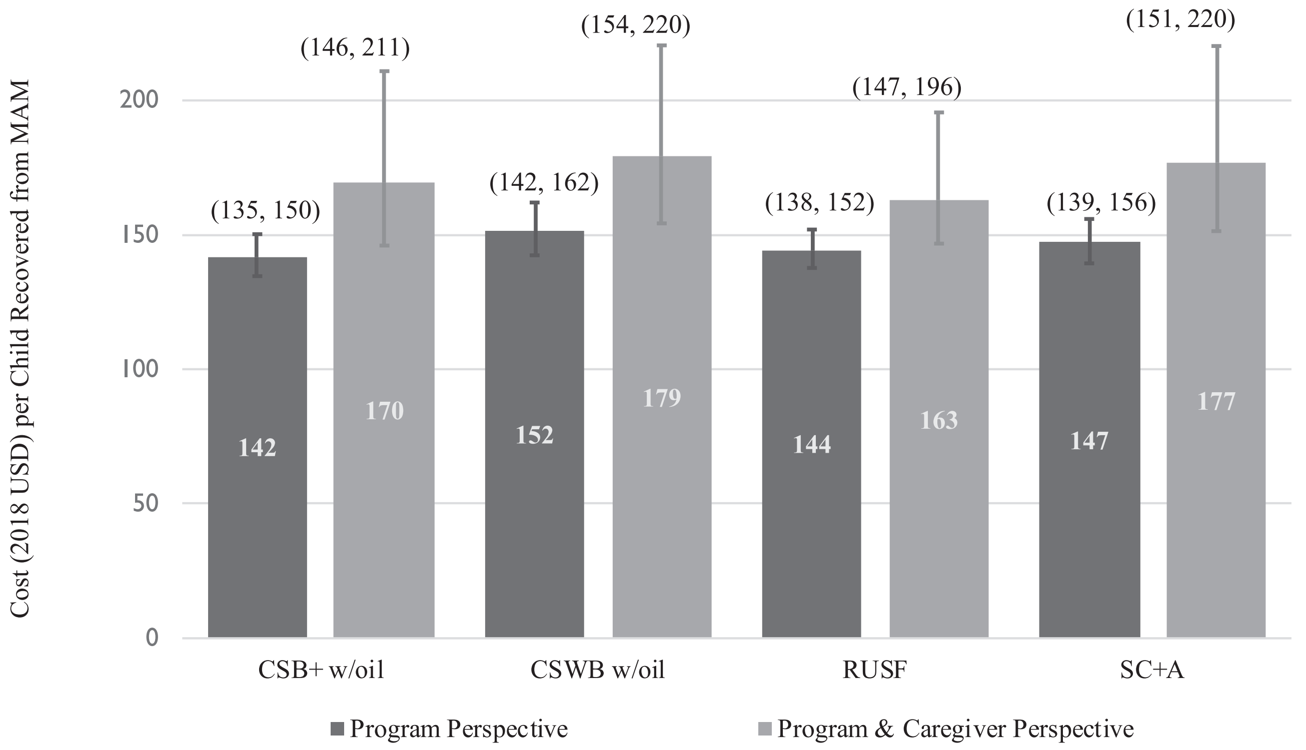

FIGURE 2 Cost per child who recovered from MAM: program perspective compared to program + caregiver perspectives. Error bars for both perspectives use 95% CIs of recovery rate from the adjusted effectiveness model. Error bars for program and caregiver perspectives also incorporate uncertainty around the time cost of caregivers (±1 SD). Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; MAM, moderate acute malnutrition; RUSF, ready-to-use supplementary food; SC+ A, Super Cereal Plus with amylase; USD, United States dollar.

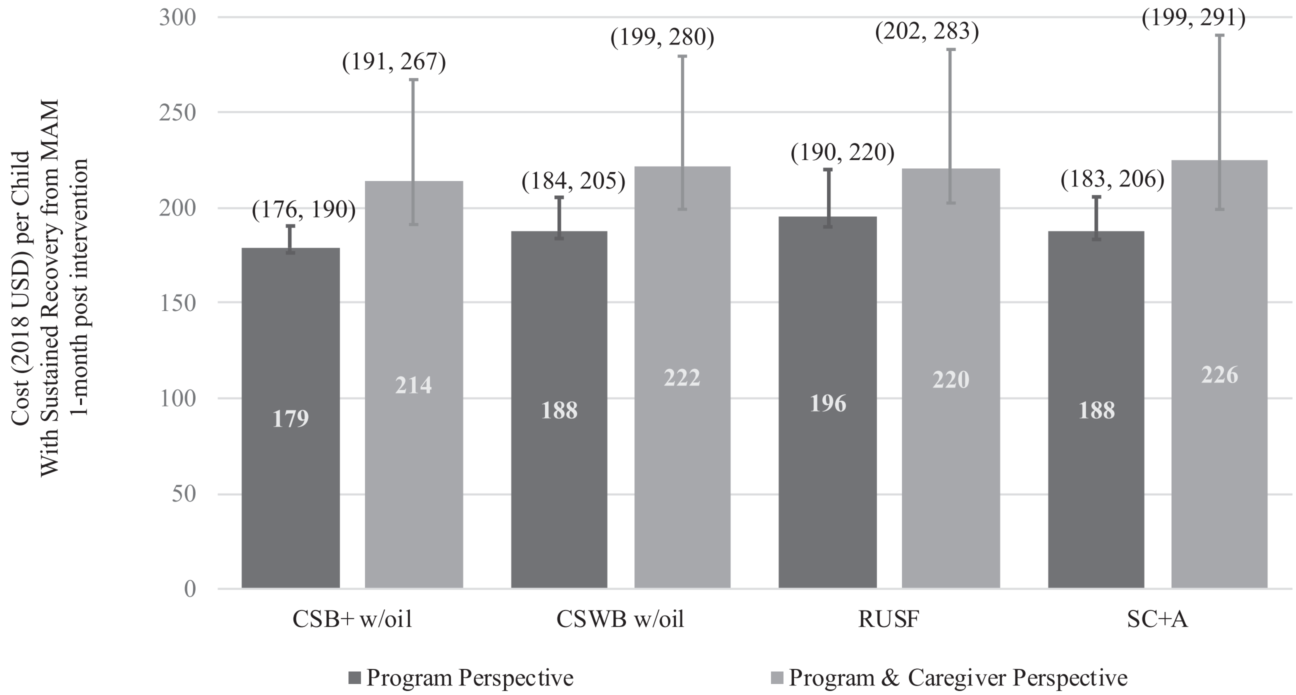

FIGURE 3 Cost per child who sustained recovery from MAM 1 mo after recovery: program perspective compared to program + caregiver perspectives. Error bars for both perspectives used point estimates of sustained recovery from 2 adjusted models that treated missed visits at 1 mo postintervention, as all sustained recovery and as all relapsed. Error bars for program and caregiver perspectives also incorporate uncertainty around the time cost of caregivers (±1 SD). Abbreviations: CSB+ w/oil, Corn Soy Blend Plus with fortified vegetable oil; CSWB w/oil, corn soy whey blend with fortified vegetable oil; MAM, moderate acute malnutrition; RUSF, ready-to-use supplementary food; SC+ A, Super Cereal Plus with amylase; USD, United States dollar.

and local/homemade food, but those in the RUSF arm achieved higher recovery rates compared to those receiving standard CSB (RR: 1.07). Unfortunately, Das et al. (10) did not separate outdated from updated FBF formulations, nor was the additional provision of FVO considered. Nonetheless, in the pooled analysis, the RR fell by 0.03 (significance values not reported). This reduction in the RR captures the significant improvements to achieving higher recovery rates when children with MAM were treated with updated FBF formulations and, potentially, additional FVO, which could also impact cost-effectiveness estimates.

Our finding that the program's activities were the greatest overall cost component are consistent with findings reported by Goudet et al. (26) using a different modality in India. Our results are also consistent with a cost-effectiveness study by Puett et al. (27) evaluating community-based management of acute malnutrition for SAM children, which found that program management costs exceeded 50% of total costs. Our results differ somewhat from those reported by Isanaka et al. (28) of a SAM treatment program in Niger, in which commodity costs were a larger share of costs than management for an outpatient program. These differences suggest that there are different cost drivers in MAM treatment programs compared to SAM. Relative costs may differ for inpatient-based compared with community-based programs and, for MAM treatment, the SNF may not always be the greatest cost component, though this does not mean that the cost of commodities is irrelevant.

This study also examined costs from the caregiver perspective, contrasting the cost to implementers with the cost to the family in preparing the supplement and caring for the child. For example, we estimated a lower cost to caregivers whose children received RUSF but a higher cost to the program when compared to those whose children received CSB+ w/oil or CSWB w/oil. Though we conclude that differences among the cost-effectiveness estimates were statistically negligible, the differences in the point estimates within the perspectives should be viewed as quite operationally meaningful when choosing which supplement to use for specific contexts. Having previously used this approach to differentiate these perspectives' costs in a blanket feeding program, estimating costs from the caregiver perspective is a necessary ingredient for a "full cost accounting" approach (29).

To our knowledge, there are only 4 studies that have assessed sustained recovery among children who recovered from MAM (11, 13, 30, 31). Our results are consistent with the sustained recovery rates reported by Stobaugh et al. (13) at 0–1 mo after recovery. Chang et al. (11) and Lelijveld et al. (31) did not report sustained recovery rates less than 3 mo after recovery, but Chang et al. (11) found that 79% of children remained well nourished 3 mo after exiting the program, while Lelijveld et al. (31) found rates of 88%–90%, potentially indicating higher rates of sustained recovery than we found. Chang et al. (11) also found that a novel LNS outperformed both a standard FBF and a novel soy RUSF in achieving sustained recovery, findings inconsistent with our results. A potential explanation for these differences relates to context: the culturally appropriate complementary foods in Sierra Leone resemble the preparation and consistency of the FBFs; meanwhile, the environment in Sierra Leone, with high rates of malaria and diarrheal disease, may expose the children to more harmful pathogens. Use of LNS in contexts where the paste is unfamiliar may change behaviors during the period of feeding, resulting in short-term recovery but a reversion back to practices that led to MAM during the posttreatment period, resulting in relapse. These results confirm that more research is warranted to understand the determinants of sustained recovery rates among children who have graduated from MAM treatment programs (15).

There are no estimates of the degree to which children relapse and reenter feeding programs for repeated treatment but, to the extent that they do, ignoring these children in costing and cost-effectiveness analyses leads to underestimates of the costs of MAM treatment. Equally important is the need to take a "full cost accounting" approach in determining both the designs of such programs and the choices of products used. The "cheapest" product (in terms of price per unit) and the fastest treatment (number of days to recovery) may not be the most cost-effective investment if a program does not take the full net cost of sustained recovery into account.

A limitation in this study was the inability to account for food product losses along the supply chain or between different packaging types. Furthermore, the mobile clinic model we used was costly to implement; other modalities could have resulted in lower costs but potentially lower "reach." The lower-than-planned sample size limited analyses to a 9–percentage point detectable difference and may also be a limitation, but given the subtle differences among the arms, we believe that a larger sample size would have yielded similar conclusions.

This study has important strengths. It is the largest cost-effectiveness trial to date of supplementary foods for MAM treatment in a politically stable but resource-poor setting. The analysis was also unique in capturing start-up costs; measuring the monetary and opportunity costs from different perspectives, particularly the beneficiary caregiver perspective; and attempting to measure SNF-specific differences in sustained recovery. Using multiple data collection methods, including direct observations to measure opportunity costs, was unique and replicable in many contexts and could lead to more accurate estimates of opportunity costs (29).

This study found no differences in the effectiveness or the cost-effectiveness of these 4 supplementary foods in achieving recovery from MAM. However, differences did emerge when evaluating their effectiveness at sustaining recovery for 4 wk posttreatment. While different contexts could result in alternative conclusions because of local variability in the cost components, the time devoted to food preparation, or simply food insecurity, our results suggest that more efficient programs that improve sustained recovery and decrease reentry (relapse) could reduce the cost of delivering a supplement, allowing more children to be treated.

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The authors' responsibilities were as follows—BLR, PW, MJM, SAV, and IHR: designed the study; SPG and AH: enrolled the participants and conducted the study; SPG, BLR, PW, IHR, and MJM: supervised implementation of the study; SPG, BKL, YS, and IRC: cleaned and analyzed the data; SPG: wrote the first and final drafts of the manuscript; SPG, PW, and BLR: had primary responsibility for the manuscript's final content; and all authors edited, read, and approved the final manuscript.

Author disclosures: MJM is Founder and Director of Project Peanut Butter, the RUSF supplier for the study. All other authors report no conflicts of interest.

Data Availability

Data described in the manuscript, code book, and analytic code will be made publicly and freely available without restriction at https://data.usaid.gov/.

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