The American Journal of Clinical Nutrition 118 (2023) 782–791

The American Journal of
CLINICAL NUTRITION

journal homepage: https://ajcn.nutrition.org/

Original Research Article

Effect of Peanut Paste-based Ready-to-use School Meals With and Without Milk on Fluid Cognition in Northern Ghana: A Randomized Controlled Trial

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A B S T R A C T

Background: Few studies have investigated the role of school feeding in low- and middle-income countries as a means of improving childhood cognition. Peanut/milk ready-to-use food (PM-RUF) or cowpea offers an affordable, scalable option that might improve cognition.
Objectives: To determine whether micronutrient-fortified PM-RUF or peanut/cowpea ready-to-use food (PC-RUF) would improve fluid cognition as assessed by 4 tests from the National Institutes of Health Toolbox Cognitive Battery when compared with a micronutrient-fortified millet porridge (FP) after a year of school feeding.
Methods: An individually randomly assigned, investigator-blinded, controlled clinical trial was conducted at 6 schools in Mion District in rural northern Ghana. Eight hundred seventy-one school children aged 5–12 y were randomly assigned and allocated to receive PM-RUF (n = 282), PC-RUF (n = 292), or FP (n = 297), each providing ~400 kcal/d. The primary outcomes were 4 fluid cognition test scores: Dimensional Change Card Sort test, Flanker Inhibitory Control and Attention test, Pattern Comparison Processing Speed test, and a modified List Sorting Working Memory test. Secondary outcomes included a composite median ranking of the 4 primary outcomes and anthropometry changes.
Results: Among the 871 participants (median age, 8.8 y; 47% female), 795 (91%) completed endline cognitive testing. Median attendance rates exceeded 87% in all groups. PM-RUF group demonstrated better fluid cognition on the Dimensional Change Card Sort test [odds ratio (OR): 1.5; 95% CI: 1.1, 2.0; P = 0.016] and Pattern Comparison Processing Speed test (OR: 1.4; 95% CI: 1.0, 1.9; P = 0.026) than FP, whereas there were no significant differences on Flanker Inhibitory Control and Attention or List Sorting Working Memory tests. PC-RUF group demonstrated no improvement over FP on any cognitive tests. PM-RUF group had superior fluid cognition composite median rankings (OR: 1.5; 95% CI: 1.1, 2.0; P = 0.007).
Conclusions: Among rural Ghanaian children aged 5–12 y, PM-RUF compared with FP resulted in superior fluid cognition.
This trial was registered at clinicaltrials.gov as NCT04349007.

Keywords: school feeding, cognition, ready-to-use foods, peanut paste, milk, Ghana, low- and middle-income countries

Introduction

A burgeoning population and economic globalization will shape the immediate future of humanity. Enhancing education is essential for meeting challenges and seizing opportunities in this dynamic. School feeding is increasingly recognized as a lever for improving educational achievement, particularly in low- and middle-income countries (LMICs). This is reflected by growth in governmental programs and investments [1,2]. It is estimated that 305 million children in LMICs receive some form of school feeding daily [3]. Only 20% of children in low-income countries are served by a school feeding program; however, ~73 million children living in extreme poverty lack coverage [2, 4]. There are no global recommendations as to what constitutes an adequate school meal; unfortified grain porridges are common in low-income settings.

Abbreviations: DCCS, Dimensional Change Card Sort test; FICA, Flanker Inhibitory Control and Attention test; FP, fortified millet porridge; LMIC, low- and middle-income countries; LSWM, List Sorting Working Memory test; NIHTB-CB, NIH Toolbox Cognitive Battery; PCPS, Pattern Comparison Processing Speed test; PC-RUF, peanut/cowpea ready-to-use food; PM-RUF, peanut/milk ready-to-use food.

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https://doi.org/10.1016/j.ajcnut.2023.08.001
Received 13 January 2023; Received in revised form 24 May 2023; Accepted 7 August 2023; Available online 9 August 2023
0002-9165/

Often, school meals are regarded as a potent social safety net and have been shown to improve attendance in LMICs, particularly for girls; results are mixed on their impacts on growth and educational achievement [5–7]. There is limited evidence on the potential impact of school feeding on cognition [8]. Fluid cognition refers to the ability to process and integrate information and solve novel problems. It is less reliant on prior learning than crystallized cognition [9,10]. Fluid cognitive skills are essential for youth in academic settings, social interactions, and daily life tasks [11–13]. In Kenya, school snacks containing meat, milk, or corn/legume were compared in a cluster-randomized trial [14]. Using Raven's Progressive Matrices, it was shown that fluid cognition improved among those consuming meat. In Ghana, an individually randomly assigned trial compared the fortification of a cereal porridge with 3 quantities of milk or vegetable protein to control and found that 8.8 g of milk protein improved cognition more than an isonitrogenous vegetable porridge or 4.4 g of milk protein, as measured by the Cambridge Neuropsychologic Test Automated Battery [15]. These studies suggest that some school foods may augment fluid cognition.

Ready-to-use, low-moisture peanut pastes have revolutionized therapeutic and supplementary feeding of malnourished children over the previous 2 decades, increasing recovery rates several fold. Key to their success is that the foods are prepared under hygienic conditions remote to the site of feeding and require no cooking by the consumer. Peanut pastes provide a food matrix into which a multiplicity of nutrients can be incorporated because their robust flavor makes them organoleptically acceptable. The shelf life of such peanut pastes extends beyond 12 mo. The low water activity of peanut paste, <0.3, prevents the growth of microorganisms [16].

This study tested the hypotheses that Ghanaian children who consumed a peanut/milk ready-to-use food (PM-RUF) paste and those that consumed a peanut/cowpea ready-to-use food (PC-RUF) paste over the course of a school year would exhibit improved fluid cognition when compared to children consuming a micronutrient-fortified millet porridge (FP).

Methods

Trial design and oversight

This was an investigator-blinded, individually randomly assigned, parallel-group clinical trial conducted at 6 Mion District, Ghana schools. The trial was implemented in accordance with the Declaration of Helsinki. A parent or guardian of every participant gave oral and written informed consent. The study was approved by the Ghana Health Service Ethics Review Committee and the Human Research Protection Office of Washington University. The full protocol and Statistical Analysis Plan are available in Supplementary Materials 1 and 2, respectively.

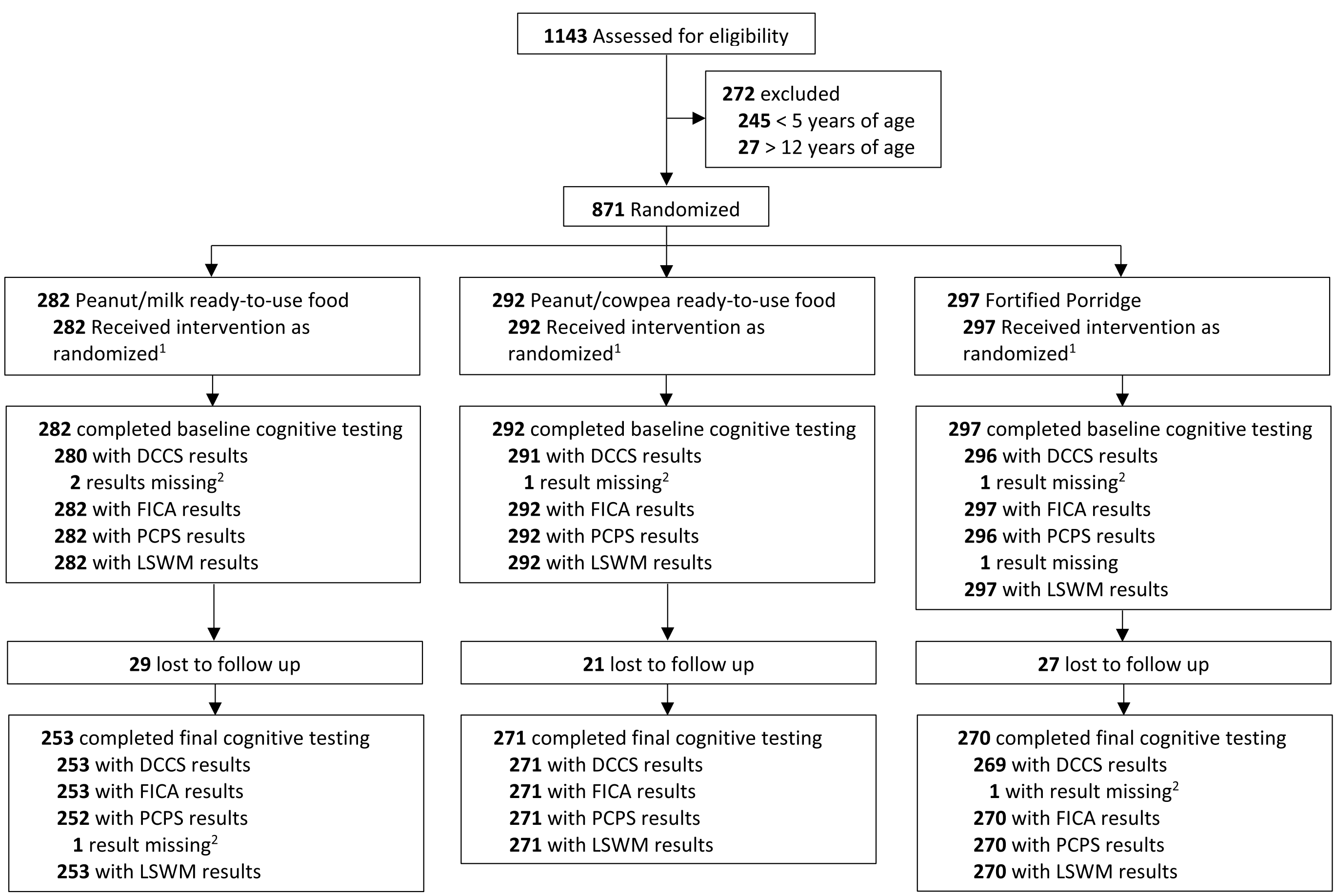


FIGURE 1. Participant flow in a trial comparing cognitive effects of 3 school foods in northern Ghanaian children. DCCS, Dimensional Change Card Sort test; FICA, Flanker Inhibitory Control and Attention test; LSWM, List Sorting Working Memory test; PCPS, Pattern Comparison Processing Speed test. [1]All participants received the correct study food according to randomization when they attended school. [2]Upon evaluation of data uploads in the cloud-based repository, several results were missing and could not be retrieved.

Participants and setting

Eligible participants were children aged 5.0–12.0 y attending 1 of 6 schools in Mion District in the Northern Region of Ghana who came to school between September 13, 2021, and October 27, 2021. Exclusion criteria were a diagnosis of severe acute malnutrition, presence of chronic debilitating disease, peanut or milk allergy, or caregiver intention to move out of the district in the following year.

Mion District is a rural, traditional, Islamic area east of Tamale where most families are engaged in subsistence farming as a primary occupation. Although most children attend primary school, only ~1 third completes it. The diet largely consists of millet, tubers, and rice, without animal-source foods.

Randomization and masking

Participants were randomly assigned 1:1:1 to PM-RUF, PC-RUF, or FP. At enrollment, each participant's parent or guardian selected a small opaque envelope enclosing a colored piece of paper from a larger opaque envelope. This larger envelope contained 24 identical small envelopes, 8/study group, in which 1 color corresponded to each study group. There was no stratification.

Participants were not masked. A study coordinator responsible for study food delivery to participating schools was unmasked but did not take part in outcomes assessment or data analysis. Two employees at each school were trained as feeding supervisors and were responsible for the disbursement of study foods and tracking their receipt, and thus were not masked. All outcome assessors were masked. The allocation key linking colors to food groups was kept locked and inaccessible to outcome assessors and the investigator responsible for statistical analysis (KBS) until after the analyses were completed.

Interventions

PM-RUF and PC-RUF were developed in the food laboratory of Dr Manary at Washington University and were produced by Project Peanut Butter, a not-for-profit in Kumasi, Ghana. Both were light-brown-colored, peanut-based pastes packaged in foil sachets containing an 80 g daily dose. They were tested and approved for school use by the Ghana FDA. FP was the preferred local millet porridge in Mion District. FP was cooked onsite daily by hired staff and distributed in uniform bowls up to a marked level of ~300 mL daily dose. Further details are provided in Supplementary Materials 1. The 3 meals were iso-energetic, providing ~410 kcal and ≥11.9 g of protein (Supplementary Table 1 in **Supplementary Materials 3**). PM-RUF contained 23 g of skimmed milk powder. A multiple micronutrient powder consisting of 14 vitamins and minerals was added in equal amounts to each food (Supplementary Table 2 in Supplementary Materials 3). Prior to trial initiation, acceptability testing of each food was conducted in Mion District among school-age children and demonstrated their acceptability (Supplementary Table 3 in Supplementary Materials 3).

Outcomes

The primary outcomes were 4 standardized tests of fluid cognition from the NIH Toolbox Cognitive Battery (NIHTB-CB) given at the end

TABLE 1
Baseline characteristics of children in rural Ghana who received 1 of 3 school foods[1,2]

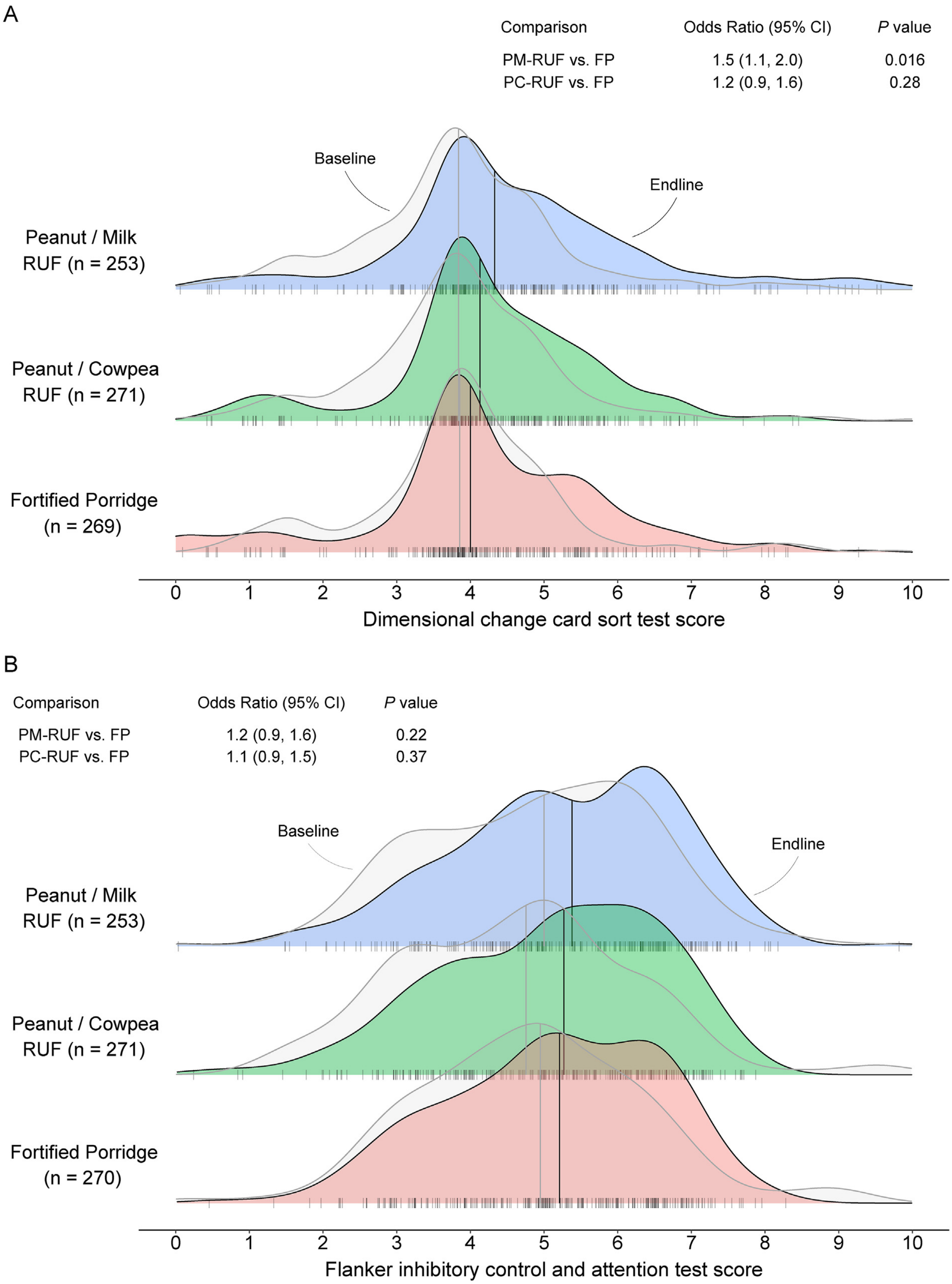
	Peanut/milk ready-to-use food (*n* = 282)	Peanut/cowpea ready-to-use food (*n* = 292)	Fortified porridge (*n* = 297)
Age, median (IQR), y	8.9 (7.1, 10.3)	8.7 (6.8, 10.0)	8.7 (7.3, 10.1)
Female sex, no. (%)	138 (49)	131 (45)	141 (47)
Mother alive, no./total (%)	231/235 (98)	242/249 (97)	218/223 (98)
Household owns, no./total (%)			
Radio	100/235 (43)	102/249 (41)	94/223 (42)
Computer	2/235 (0.9)	3/249 (1.2)	1/222 (0.5)
Access to private motorized transport	46/235 (20)	48/249 (19)	38/223 (17)
Clean water source, no./total (%)	182/234 (78)	197/249 (79)	168/223 (75)
Household food insecurity, no./total (%)[3]			
Food secure	15/233 (6)	29/249 (12)	21/223 (9)
Mildly food insecure	24/233 (10)	10/249 (4)	17/223 (8)
Moderately food insecure	87/233 (37)	97/249 (39)	74/223 (33)
Severely food insecure	107/233 (46)	113/249 (45)	111/223 (50)
School, no. (%)			
St. Anthony	85 (30)	90 (31)	83 (28)
Gumah	33 (12)	35 (12)	40 (13)
Kpiligine	35 (12)	45 (15)	51 (17)
Mbatinga	38 (13)	37 (13)	34 (11)
Salankpang	45 (16)	35 (12)	42 (14)
Afayili	46 (16)	50 (17)	47 (16)
Anthropometry			
Weight, kg	24.0 ± 5.5	23.6 ± 5.6	23.7 ± 5.2
MUAC, cm	17.6 ± 1.8	17.7 ± 3.8	17. 5 ± 1.7
Height-for-age *z*-score	–1.0 ± 1.3	–0.7 ± 2.0	–0.9 ± 1.8
BMI *z*-score	–0.6 ± 1.2	–0.8 ± 1.8	–0.8 ± 1.6
Fat-free body mass, kg	20.9 ± 4.9	20.5 ± 5.5	20.8 ± 5.2

IQR, Interquartile range; MUAC, midupper arm circumference.

1 Values are mean ± SD unless otherwise specified. Multiple children in the same household led to smaller numbers for some characteristics, as detailed by "no./total" where pertinent. The household data collected are reported for the oldest child in the study.

2 Data were not available for 1 household's water source in the peanut/milk ready-to-use food group. For household food insecurity, data were not available for 2 households in peanut/milk ready-to-use food group.

3 Food insecurity categories determined as per official guidance [38].



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of the school year, July 2022. These were the Dimensional Change Card Sort test (DCCS), the Flanker Inhibitory Control and Attention (FICA) test, the Pattern Comparison Processing Speed (PCPS) test, and a modified version of the List Sorting Working Memory (LSWM) test (see Supplementary Materials 1). Tests of fluid cognition were chosen because they are less culturally dependent, more sensitive to biologic processes, and less influenced by past exposures than alternatives [9, 17]. DCCS and FICA are measures of executive function, and both test cognitive flexibility, whereas FICA also tests inhibitory control, sustained attention, and attention allocation. PCPS is primarily a test of processing speed, whereas LSWM is a test of working memory.

Secondary outcomes were a composite median ranking of the 4 primary outcomes, subscores for speed and accuracy for DCCS and FICA, changes in height-for-age *z*-score, BMI (kg/m^2)-for-age *z*-score, FFM, and midupper arm circumference, and attendance rates. The composite median ranking was generated by ranking each participant's score within each test, calculating the median of each participant's ranks, and ranking these medians. Attendance was recorded as a measure of adherence.

Trial procedures

Following enrollment, caregivers were queried on demographics and household food insecurity. Participant height, weight, midupper arm circumference, and FFM were measured at baseline and at the end of the school year with scales, height boards, measurement tapes, and a bioelectrical impedance analyzer, respectively.

Participants underwent cognitive testing at baseline and at the end of the school year. Testing required ~40 min and was performed in quiet areas near the schools. The cognitive testers were 5 graduate students studying childhood education in northern Ghana. The testers were instructed in Dagbani, their local language, and each practiced testing with ≥25 children before the trial began. Dagbani was used for all instructions, practice sessions, and prompts. As per NIHTB-CB administration guidelines, cognitive testing was conducted with a tablet. DCCS, FICA, and PCPS responses and scores were recorded automatically, whereas for LSWM, several of the program's pictures were replaced by images of foods and animals that were easily recognizable to children in Ghana, as has been done in other settings, and scores were recorded manually on paper [18]. Further details of cognitive testing are available in Supplementary Materials 1.

Participants received their assigned food each school day they attended during the trial. Two feeding supervisors per school were responsible for confirming and documenting each participant's daily attendance, study group designation, and food receipt. The unmasked study coordinator made unplanned visits to each school 1–2 times/wk to assess the integrity of the feeding process by evaluating classroom feeding lists and comparing the assigned study group compared with the food received.

Cognitive test scoring

DCCS and FICA are composed of accuracy and speed subscores, each scaled to 5 points, which are then combined into a total score. For DCCS, the NIHTB-CB program skips the first 10 prompts and provides 1.25 accuracy points automatically for all children aged ≥8 y based on scoring patterns observed in the United States, where children would consistently score at the ceiling. In a prespecified, blinded, descriptive data evaluation step in which results were not separated by study group, the validity of this assumption was assessed and deemed unsupported by test results in this rural Ghanaian cohort, which were much lower than age-based expectations. Thus, instead of using the aforementioned procedure, the DCCS accuracy subscore was computed as the proportion of correct answers, scaled to 5, for all participants. The NIHTB-CB program undertakes a similar procedure for FICA, which was also not supported in this cohort, and so FICA accuracy subscores were computed as the proportion of correct answers, scaled to 5, for all participants. DCCS and FICA speed subscores are generated automatically by the tablet and were used without alteration. Further details are available in Supplementary Materials 1 and 2.

In the NIHTB-CB program, PCPS is scored as the sum of correct responses. In the descriptive, blinded data evaluation step, it was noted that multiple individuals had high scores despite the appearance of guessing, with ~50% accuracy, because they were able to respond to more of the 130 prompts within the 85-second test. Thus, an individual with 35/70 correct responses/total prompts would score higher than an individual with 34/35; this was judged to be an inaccurate reflection of test performance. Instead, PCPS scores were computed as the number of correct answers minus the number of incorrect answers, with a floor score of 0.

No changes were made to LSWM scoring, which is computed as the number of correctly ordered foods or animals.

Sample size

The study was planned to enroll 880 participants, anticipating that 15% would drop out during the school year, which would have provided >80% power to detect an odds ratio (OR) for a higher score of 1.6 at a 2-sided α of 0.05. This calculation was based on the use of ordinal logistic regression applied to simulated datasets because data were not available to estimate the primary outcome distributions in rural Ghanaian children, and the scores consisted of ordered numbers that were not interval-scaled. It was conservatively assumed that there would be ≥20 unique scores within each test (alternatives were tested; Supplementary Materials 2). Using the Dirichlet distribution and a random vector generator, 50,000 distributions of scores were simulated that varied in degrees of skewness and kurtosis (Supplementary Materials 2) [19]. Knowing that potential between-group differences would vary based on the data's underlying distribution, median scores in the control and intervention groups were simulated using the same 50,000 score distributions at various ORs. An OR = 1.6 yielded a median of median differences of 7.5% (interquartile range: 6%, 9%), equivalent to 0.75 points along a 10-point scale, as in DCCS and FICA. This was chosen as a modest target effect for detection. Using an OR = 1.6, 250 participants/group yielded power ≥80% in 97.5% of 50,000 simulations and thus was considered sufficient (Supplementary Materials 2) [20,21].

FIGURE 2. Results of (A) Dimensional Change Card Sort test and (B) Flanker Inhibitory Control and Attention test. Shown are ridgeline plots containing kernel density-estimated smoothed histograms separated by testing time (baseline compared with endline) and randomization group. The taller vertical black line within each plot is the median of the endline results. The shorter vertical lines underlying each plot correspond to individual values on endline tests, with random horizontal jittering within 0.05 points. Ordinal logistic regression was used to compare food groups, with endline score as the dependent variable, food group as the independent variable of interest, and baseline score and participant age as covariates. *P* values were computed using the Wald test. Several participants did not undergo baseline testing with dimensional change card sort (PM-RUF $n = 2$, PC-RUF $n = 1$) and thus were not included in statistical analysis. CI, confidence interval; FP, fortified millet porridge; PC-RUF, peanut/cowpea ready-to-use food; PM-RUF, peanut/milk ready-to-use food.

Statistical analyses

All analyses were performed according to a modified intention-to-treat principle, wherein only participants with final cognitive testing were included in the primary outcomes analysis. No missing data were imputed. Analyses were conducted on all outcome measures at the end of the school year. The effects of PM-RUF and PC-RUF compared with FP for the 4 primary outcomes were performed using ordinal logistic regression adjusted for baseline test score and participant age [22]. These adjustments were prespecified based on their a priori likelihood of predicting outcome cognitive scores [23–26]. Ordinal logistic regression was also used to compare composite median ranking, adjusted for baseline ranking and participant age. Food group effects were expressed with the use of ORs, with an OR >1 favoring PM-RUF or PC-RUF compared with FP. The results are presented visually using ridgeline plots, which are kernel density-estimated, smoothed histograms separated by food group, where the y-axis is the probability density of each score, the range of which is displayed along the x-axis. The proportional odds assumption was assessed and deemed not violated, as detailed in the Statistical Analysis Plan (Supplementary Materials 2) [20,27,28]. For DCCS and FICA, speed and accuracy subscores were analyzed using ordinal logistic regression with the same covariates.

Secondary analyses of heterogeneity of study food effects on the 4 primary outcomes and their composite median ranking were performed in prespecified subgroups based on age and sex using ordinal logistic regression adjusted for baseline score and age, with the addition of a subgroup-by-food group interaction. After confirming the normality of residuals and homoscedasticity, changes in anthropometry were compared using linear regression, adjusted for baseline anthropometric measurements. Attendance rates were compared using the Wilcoxon rank-sum test, with a continuity correction used to generate medians of differences with 95% CIs. The primary outcomes and median composite ranking were also compared between PM-RUF and PC-RUF, with OR >1 favoring PM-RUF. In a sensitivity analysis, results generated using the NIHTB-CB algorithm for DCCS and FICA accuracy scores were compared with those generated in this trial's primary analysis.

In a post hoc analysis, we assessed for heterogeneity of food group effects on the 4 primary outcomes and their composite median ranking by school attendance over the final 10 wk of the school year; this was considered an imperfect estimate of adherence. To do this analysis, an interaction term between attendance and food group was introduced into the regressions, and forest plots were produced showing between-group ORs with 95% CIs at different attendance levels. Greater attendance was a possible mechanism via which intervention foods might have improved fluid cognition.

Significance was set at a 2-sided $P < 0.05$. P values were computed for the 4 primary outcomes and key secondary outcomes median composite cognition ranking and effect heterogeneity analyses; otherwise, 95% CIs alone are presented. Because the widths of the 95% CIs and P values were not adjusted for multiplicity, the inferences drawn may not be reproducible. Data were analyzed using R version 4.1.2 (R Foundation for Statistical Computing).

Results

Study participants

Of the 871 participants who were enrolled and randomly assigned, 282 received PM-RUF, 292 received PC-RUF, and 297 received FP (Figure 1). The characteristics of participants at enrollment were similar between the 3 groups (Table 1). The median age of the participants was 8.8 y, the mean BMI-for-age z-score was –0.7, and >80% of participant households were classified as moderately or severely food insecure.

Baseline fluid cognition test results were similar between groups (Supplementary Table 4 in Supplementary Materials 3). School attendance rates over the last 10 wk of the study were high in all 3 groups: the medians (interquartile ranges) of attendance for PM-RUF, PC-RUF, and FP were 90% (79%–95%), 88% (79%–94%), and 92% (82%–96%), respectively (Supplementary Figure 1 in Supplementary Materials 3). On average, for participants receiving PM-RUF, PC-RUF, or FP, there were 175, 176, and 176 d of possible school feeding between enrollment and endline testing, respectively. There were no errors with participant receipt of correct study food identified during unscheduled school visits. Of enrolled participants, 76 (9%) stopped attending school, whereas the remaining 795 (91%) completed endline testing.

Primary outcomes

At the school year's end, children who had been randomly assigned to PM-RUF demonstrated better cognition on the DCCS (OR: 1.5; 95% CI: 1.1, 2.0; $P = 0.016$) and PCPS (OR: 1.4; 95% CI: 1.0, 1.9; $P = 0.026$) tests than those randomly assigned to FP, whereas there were no significant differences in the FICA or LSWM tests (Figures 2 and 3). Children randomly assigned to PC-RUF demonstrated no improvement over FP on any cognitive tests.

Secondary outcomes

PM-RUF participants had superior cognition composite median rankings compared with FP (OR: 1.5; 95% CI: 1.1, 2.0; $P = 0.007$; Supplementary Table 5 in Supplementary Materials 3), whereas PC-RUF participants did not. There were no differences in anthropometric change between study groups (Supplementary Table 6 in Supplementary Materials 3). PM-RUF improved both speed and accuracy subscores on DCCS compared with FP (Supplementary Table S5 in Supplementary Materials 3). In a sensitivity analysis, adhering to the NIHTB-CB scoring guideline for accuracy did not alter DCCS or FICA results (Supplementary Table 7 in Supplementary Materials 3).

Subgroup analyses

Subgroup analyses for the primary outcomes and composite median ranking demonstrated consistent results, except for the greater relative benefit of PM-RUF compared with FP among children aged <9 y compared with those ≥9 y (interaction $P = 0.01$) (Figure 4). There was no significant effect heterogeneity for PC-RUF compared with FP by age or sex (Supplementary Figure 2 in Supplementary Materials 3).

Post hoc analyses

Attendance, as assessed over the trial's final 10 wk, was not a significant effect modifier across the 4 primary outcomes or median composite ranking, although the study was not powered to detect this (Supplementary Figures 3 and 4 in Supplementary Materials 3). Children with the highest attendance derived the greatest relative benefit from PM-RUF compared with FP for DCCS, PCPS, and the composite median ranking but not for FICA or LSWM (Supplementary Figure 3 in Supplementary Materials 3). Similarly, higher attendance yielded greater ORs (95% CIs) for DCCS, PCPS, and composite rank for PC-RUF compared with FP, although the interaction between the

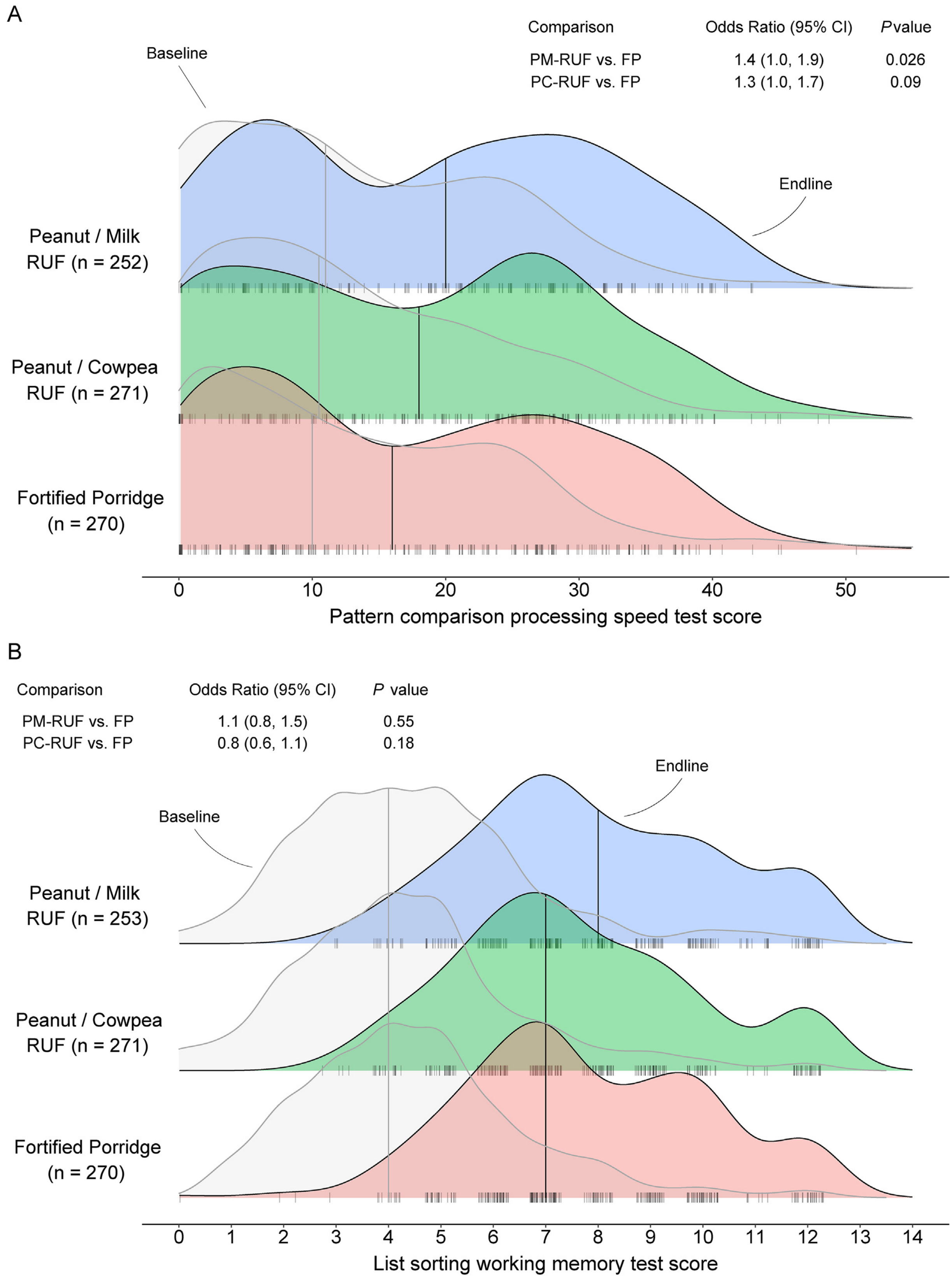

FIGURE 3. Results of (A) Pattern Comparison Processing Speed test and (B) List Sorting Working Memory test. Shown are ridgeline plots containing kernel density-estimated smoothed histograms separated by testing time (baseline compared with endline) and randomization group. The taller vertical black line within each plot is the median of the endline results. The shorter vertical lines underlying each plot correspond to individual values on endline tests, with random horizontal jittering within 0.3 points. Ordinal logistic regression was used to compare food groups, with endline score as the dependent variable, food group as the independent variable of interest, and baseline score and participant age as covariates. *P* values were computed using the Wald test. CI, confidence interval, FP, fortified porridge; PC-RUF, peanut/cowpea ready-to-use food; PM-RUF, peanut/milk ready-to-use food.

Test	Group		Fortified Porridge	Peanut/Milk RUF	Odds Ratio (95% CI)	Interaction *P* value
			No of participants			
DCCS						
	Overall		269	251	1.5 (1.1, 2.0)	
	Age, y					0.01
		< 9	151	128	2.0 (1.3, 3.1)	
		≥ 9	118	123	1.1 (0.7, 1.7)	
	Sex					0.46
		Male	138	129	1.6 (1.1, 2.5)	
		Female	131	122	1.3 (0.8, 2.0)	
FICA						
	Overall		270	253	1.2 (0.9, 1.6)	
	Age, y					0.55
		< 9	152	129	1.2 (0.8, 1.8)	
		≥ 9	118	124	1.2 (0.8, 1.9)	
	Sex					0.35
		Male	139	129	1.4 (0.9, 2.1)	
		Female	131	124	1.0 (0.7, 1.6)	
PCPS						
	Overall		270	252	1.4 (1.0, 1.9)	
	Age, y					0.52
		< 9	152	128	1.5 (1.0, 2.2)	
		≥ 9	118	124	1.4 (0.9, 2.2)	
	Sex					0.69
		Male	139	128	1.3 (0.9, 2.0)	
		Female	131	124	1.5 (1.0, 2.3)	
LSWM						
	Overall		270	253	1.1 (0.8, 1.5)	
	Age, y					0.82
		< 9	152	129	1.3 (0.9, 2.0)	
		≥ 9	118	124	0.9 (0.6, 1.4)	
	Sex					0.58
		Male	139	129	1.0 (0.7, 1.5)	
		Female	131	124	1.3 (0.8, 2.0)	
Composite[1]						
	Overall		270	253	1.5 (1.1, 2.0)	
	Age, y					0.20
		< 9	152	129	1.8 (1.2, 2.7)	
		≥ 9	118	124	1.2 (0.8, 1.9)	
	Sex					0.87
		Male	139	129	1.6 (1.0, 2.4)	
		Female	131	124	1.4 (0.9 to 2.2)	

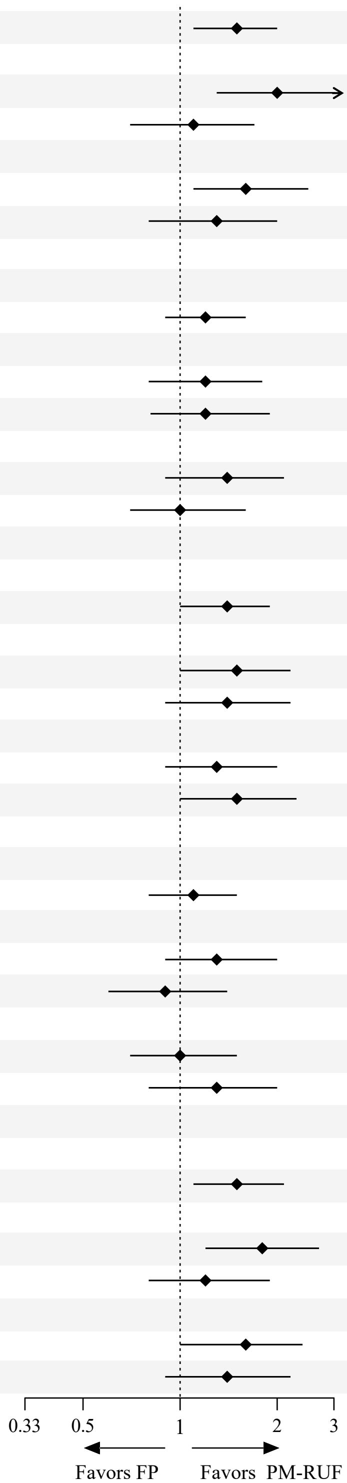

FIGURE 4. Subgroup analyses of cognitive test and composite median rank results comparing peanut/milk RUF and fortified porridge. Ordinal logistic regression was used to compare food groups, with endline score as the dependent variable, food group, baseline score, participant age, and an interaction term between a food group and age (as a continuous variable) or sex as independent variables. *P* values were computed using the Wald test and are shown for the interaction between food group and age or sex. CI, confidence interval; DCCS, Dimensional Change Card Sort test; FICA, Flanker Inhibitory Control and Attention test; LSWM, List Sorting Working Memory test; PCPS, Pattern Comparison Processing Speed test; RUF, ready-to-use food. [1]Composite median rank was obtained by first ranking all scores within each test, then computing the median of each participant's test ranks, and then ranking those median ranks.

study group and attendance was not statistically significant (Supplementary Figure 4 in Supplementary Materials 3).

Adverse events

There were no adverse events noted among the 574 participants receiving a daily ration of peanuts, including no eczematous rashes, hives, or signs or symptoms of anaphylaxis.

Costs

The cost of ingredients and mixing of the ready-to-use foods averaged $0.16/daily ration. Currently, the Ghanaian government estimates costs of $0.25/d for a school meal prepared onsite.

Discussion

Among schoolchildren aged 5–12 y in Mion District of northern Ghana, this trial demonstrated that a peanut-based ready-to-use school food made with milk resulted in improved fluid cognition on 2 of 4 NIHTB-CB tests as well as a fluid cognition composite median ranking after a year of feeding compared with FP.

Benefits were seen in executive function (DCCS) and processing speed (PCPS), 2 important aspects of fluid cognition. Executive function is regarded as key to academic success in children via its roles in self-motivation and self-regulation of learning and emotions [29]. In DCCS, PM-RUF demonstrated superiority in both speed and accuracy subscores, suggesting broad benefits in executive function. Greater processing speed is associated with age-related improvements in performance on tasks, including memory, reading, arithmetic, and reasoning [30,31]. Processing speed is also a component of working memory, which is a predictor of school achievement and later cognitive development [32,33]. Finally, the superior composite median ranking for PM-RUF compared with FP suggests wide-ranging benefits across the dimensions of fluid cognition tested.

There are several limitations of this study. First, it was conducted among a population whose habitual diet was primarily millet and rice with cowpea, little milk, or meat. The relative benefit of a ready-to-use food containing milk on fluid cognition may not be seen in different contexts. This diet, however, is typical for hundreds of millions of rural West Africans. Second, the cognitive benefits seen in children aged 5–12 y may not extrapolate to older children. Third, we did not correct for multiple comparisons, accepting an increased risk for type I error to avoid inflating the type II error in this trial of a low-risk intervention with 4 highly correlated outcome measures [34,35]. In place of *P* value corrections, 95% CIs are reported throughout, and a composite cognition metric chosen to minimize underlying assumptions (median of ranks) was used to compare food groups [36]. Fourth and fifth, we only tracked attendance over the final 10 wk of the study, and potential sharing was not formally monitored. These issues would be expected to bias effect estimates toward the null. Sixth, the duration of the benefit of PM-RUF is unknown.

PM-RUF was not superior to FP in FICA or LSWM. Despite the significant differences seen in the overall composite score, there were variable effects when analyzing the 4 tests individually. These differences may be attributable to the psychometric properties of the tasks in this population. For example, the LSWM task proved difficult for the participants, potentially making it more challenging to detect change. In addition, LSWM had a large practice effect, which may have diluted meal effects. Alternatively, it is possible that the cognitive constructs that each task taps into were differentially sensitive to the effects of PM-RUF.

This is the second school feeding study in which the addition of milk has been shown to improve fluid cognition [15,37]. In the previous analysis, serum concentrations of IGF-1 were associated with fluid cognition test scores, and greater IGF-1 was seen with milk consumption [37]. We speculate that there is a similar mechanism of action in this study. In prior studies, school foods have been shown to slightly improve attendance, which might be expected to promote cognitive development; PM-RUF had slightly lower attendance than FP, ruling out this mechanism of action.

Ready-to-use foods have several potential benefits. First, they do not require contribution on the part of students for food preparation. Second, they provide a food-safe product, avoiding the complications inherent in storing ingredients at ambient temperatures typical in sub-Saharan Africa. Third, although employment of local individuals in cooking and distribution is seen as a benefit of home-grown school feeding programs, such are also prone to inconsistent implementation when financing is limited. Cooks may not receive payment for upward of a year [8]. Additionally, the ingredients available in locally implemented programs often reflect the habitual diet, which, in areas, such as rural Ghana, does not provide sufficient nutrient intake. Indeed, this trial demonstrated cognitive benefit compared with an improved version of the local standard. We anecdotally observed many children tearing open the foil packets of ready-to-use food and licking the package surfaces clean. Additionally, there may be some cost savings associated with the use of ready-to-use food.

This clinical trial provides a road map for a successful, operational school feeding program that confers a cognition benefit. The peanut/milk combination in a ready-to-use food matrix makes this possible. If the benefit is lasting, it could promote higher educational and occupational performance.

Acknowledgments

We thank the participants and their families.

Author contributions

The authors' responsibilities were as follows – MJM, DRW, TGH, and TD: concept and design; KBS, DRW, TGH, TD, ED, MS-A, FKS, IS, and MJM: acquisition, analysis, or interpretation of the data; KBS and MJM: statistical analysis; KBS and MJM: drafting of the manuscript; KBS, DRW, TGH, TD, ED, MS-A, FKS, IS, and MJM: critical revision of the manuscript for important intellectual content; KBS, DRW, and MJM: supervision. KBS and MJM had full access to all the data in the study, and they took responsibility for the integrity of the data and the accuracy of the data analysis, and all authors: read and approved the final manuscript.

Conflict of interest

MJM is an associate editor of The American Journal of Clinical Nutrition and played no role in the Journal's evaluation of the manuscript. All other authors report no conflicts of interest.

Funding

This study was funded as part of the research of the Feed the Future Innovation Laboratory for Peanut, supported by funding from the United States Agency for International Development (USAID). This publication was made possible through support provided by USAID under the terms of Cooperative Agreement No. 7200AA18CA00003. The opinions expressed herein are those of the authors and do not necessarily reflect the views of USAID. The funders had no role in the study design or conduct, data collection, analysis, interpretation, manuscript preparation, review, approval, or decision to submit the manuscript for publication.

Data availability

Data described in the manuscript, code book, and analytic code will be made available within 6 mo of publication at data.gov.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajcnut.2023.08.001.

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