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RESEARCH ARTICLE

Effect of egg powder-fortified Tom Brown on nutritional and academic performance among school-aged children in Wa Municipality, Ghana: a parallel-group randomised controlled trial

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Objective: This study investigated the impact of egg powder-fortified Tom Brown on classroom scores among resource-poor school-aged children aged between 5 and 12 years in the Wa Municipality, Ghana.
Design: A 24-week parallel-group randomised controlled trial was conducted with 136 primary school children from low-income communities. Participants were individually randomised within schools into intervention ($n = 68$) and control ($n = 68$) arms.
Setting: Wa Municipality, Ghana.
Participants: School-aged children in primary four in public primary schools in Wa Municipality.
Intervention and outcome measures: The intervention group received egg powder-fortified Tom Brown three times per week, while controls received the standard porridge. Academic performance was assessed pre/post-intervention using Ghana Education Service validated standardised tests in English and mathematics using linear mixed-effects models (LMM) to analyse scores, controlling for time, treatment, their interaction (fixed effects) and school-level clustering (random effects).
Results: The intervention group demonstrated significant improvement in test scores. English scores increased by 19.3 points at endline (vs. 3.8-point gain in controls; Time × Treatment interaction: $b = 15.46$, $p < 0.001$). Mathematics scores also improved by 18.8 points (41.5% improvement; interaction: $b = 19.91$, $p < 0.001$), while controls declined marginally. Baseline equivalence confirmed successful randomisation (English: $p = 0.935$ and mathematics: $p = 0.715$). Between-school heterogeneity was moderate with a variance partition coefficient of 9.6–10.7%.
Conclusion: Fortifying Tom Brown with egg powder is an effective and potentially scalable intervention to boost academic scores among Ghanaian schoolchildren. Integrating it into national programmes could help combat malnutrition and advance educational achievement in children.
Trial design: Parallel-group randomised controlled trial (allocation ratio 1:1)
Trial registration: Pan African Clinical Trial Registry, pactr.samrc.ac.za, identifier: PACTR202408897182810.

Keywords: school feeding, egg fortification, academic performance, malnutrition, Ghana, linear mixed-effects model

Introduction

Malnutrition remains a major public health concern in sub-Saharan Africa, including Ghana, where undernutrition, micronutrient deficiencies and emerging overnutrition coexist.[1] Among school-aged children, inadequate dietary intake and household food insecurity continue to negatively affect growth, health and academic performance. In Ghana, approximately 1.5 million individuals experience food insecurity, contributing to poor dietary diversity and insufficient nutrient intake.[2] Factors such as poverty, geographical disparities and limited access to safe drinking water further exacerbate the risk of malnutrition among children.[1] Addressing these challenges will require context-specific, nutrition-sensitive interventions that improve both dietary quality and accessibility.

Tom Brown is a locally prepared roasted cereal-based flour, commonly made from maize and sometimes combined with legumes such as groundnuts or soybeans to enhance its nutritional value. Tom Brown is widely consumed in Ghana as a porridge across different age groups due to its affordability and ease of preparation.[3] Due to financial constraints experienced by families, poor households sometimes prepare roasted corn flour without adding legumes and consume it as Tom Brown, especially in the northern part of Ghana. However, traditional cereal-legume formulations may not adequately meet all macronutrient and micronutrient requirements without appropriate fortification.[4,5] In this study, Tom Brown refers to roasted corn flour fortified with egg powder to improve its protein quality and micronutrient content, making it more suitable for addressing nutritional gaps among school-aged children.

To improve child nutrition and educational outcomes, the Government of Ghana introduced the Ghana School Feeding Programme (GSFP) in 2005. Although the programme has contributed to increased school enrolment, attendance and retention, concerns persist regarding the nutritional quality of meals provided and their impact on children's health and cognitive development.[6,7] Undernutrition and anaemia remain prevalent among schoolchildren in many communities in Ghana, indicating gaps in the effectiveness of current interventions.[8] The use of nutrient-dense, locally sourced foods has been suggested as a sustainable strategy to improve both the nutritional quality and cost-effectiveness of school meals.[6,7]

There is substantial evidence linking nutrition to cognitive development and academic performance in school-aged children. Adequate intake of protein and essential micronutrients such as iron, zinc, iodine and folate is critical for brain development, neurotransmitter synthesis and overall cognitive functioning.[8] Conversely, nutrient deficiencies, as well as parasitic infections that impair nutrient absorption, can lead to poor concentration, reduced school attendance and diminished academic achievement.[7] School-based interventions, including deworming and micronutrient supplementation, have demonstrated improvements in educational outcomes in similar settings.[7]

Recent research has explored the role of nutrient-rich foods such as eggs in improving child nutrition. Eggs are a rich source of high-quality protein and essential nutrients, including choline and lutein, which are important for brain development and function.[9] Studies have shown that egg supplementation can improve nutritional status, including serum zinc and ferritin levels among school-aged children in Ghana, although effects on cognitive outcomes have been inconsistent.[10,11] Similarly, while multi-micronutrient fortification has been shown to improve micronutrient status and reduce anaemia, its impact on cognitive performance varies depending on the population and type of intervention.[12,13]

Given these mixed findings, there is a need for further research to evaluate context-specific, food-based interventions that utilise locally available and culturally accepted foods to improve both nutritional status and cognitive outcomes among school-aged children. We hypothesised that children who consume egg powder-fortified Tom Brown would demonstrate significantly greater improvements in English and mathematics scores compared with those receiving the unfortified control. Therefore, this study aimed to evaluate the effect of regular consumption of egg powder-fortified Tom Brown on English and mathematics scores among school-aged children in the Wa Municipality of Ghana.

Materials and methods

Study design

This study was a 24-week, parallel-group randomised controlled trial in which participants were individually randomised within schools with a 1:1 allocation ratio (Figure 1). Participants were randomly assigned to the intervention group, which received egg powder-fortified Tom Brown, or the control group which, received the unfortified Tom Brown using a computer-generated random sequence generated by an independent statistician. Stratified randomisation was employed based on key baseline characteristics, including school, academic performance quintiles and school size to ensure a balance between groups. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes prepared by an independent research assistant who was not involved in participant recruitment, intervention administration or outcome assessment. This process minimised selection bias and ensured comparable groups at baseline for valid assessment of the effects of the intervention. The primary outcomes of the study were changes in standardised English and mathematics test scores from baseline to endline. There were no predefined secondary outcomes in this study. The study intervention was also duly registered with the Pan African Clinical Trials Registry (PACTR202408897182810).

Study area

The study was conducted in the Wa Municipality of the Upper West region of Ghana.

Study population

School-aged children aged between 5 and 12 years living within the Wa Municipality were the target population for the study.

Sample size determination

The sample size for this study was calculated to detect a clinically meaningful difference in mean class score between the intervention and control groups. Pilot data among school-aged children under similar environment conditions revealed a baseline mean English class score of 37.46. For this study, the standard deviation (SD) of class scores was assumed to be 1.04 based on preliminary data. A clinically relevant absolute difference (Δ) of 0.5 points was selected as a conservative estimate to ensure adequate statistical power to detect even small but meaningful improvements in academic performance. The minimum sample size per group was calculated using the formula for comparing two independent means.[14]

$$n = \frac{2\left(Z_{\frac{\alpha}{2}} + Z_{\beta}\right).\mathrm{SD}^2}{\Delta^2}$$

Where:

$Z_{\alpha/2} = 1.96$ (5% significance level)

$Z_{\beta} = 0.84$ (80% power)

$\mathrm{SD} = 1.04$

$\Delta = 0.5$ (absolute difference)

Substituting these values yielded a minimum sample size of approximately 58 participants per group.

$$n = \frac{2(1.96 + 0.84)^2 \times 0.96^2}{0.5^2} = \frac{2 \times 7.84 \times 0.9216}{0.25} \gg 57.8$$

The required sample size was adjusted to allow for a 15% attrition rate, resulting in a required sample size of 68 per group (136 participants in total).

The relatively small standard deviation reflects variability in standardised class scores derived from averaged assessments across multiple evaluation points rather than raw individual test scores. A total of 136 school-aged children were thus recruited for the study, of whom 15 were lost to follow-up, and 121 participants completed the study and were included in the final analysis. Given that participants were recruited from school settings, potential clustering effects were addressed during analysis using appropriate statistical models.

A multistage sampling approach was used in this study. The Wa Municipality was initially divided into circuits (clusters), from which urban circuits were excluded, leaving nine eligible circuits. Four circuits (Kpongu, Busa, Nakore, and Charia) were randomly selected. One primary school was then randomly selected from each circuit and Primary four pupils were purposively chosen to ensure uniformity in assessment. All eligible pupils underwent anaemia screening, and those who met the inclusion criteria formed the sampling frame. Proportional

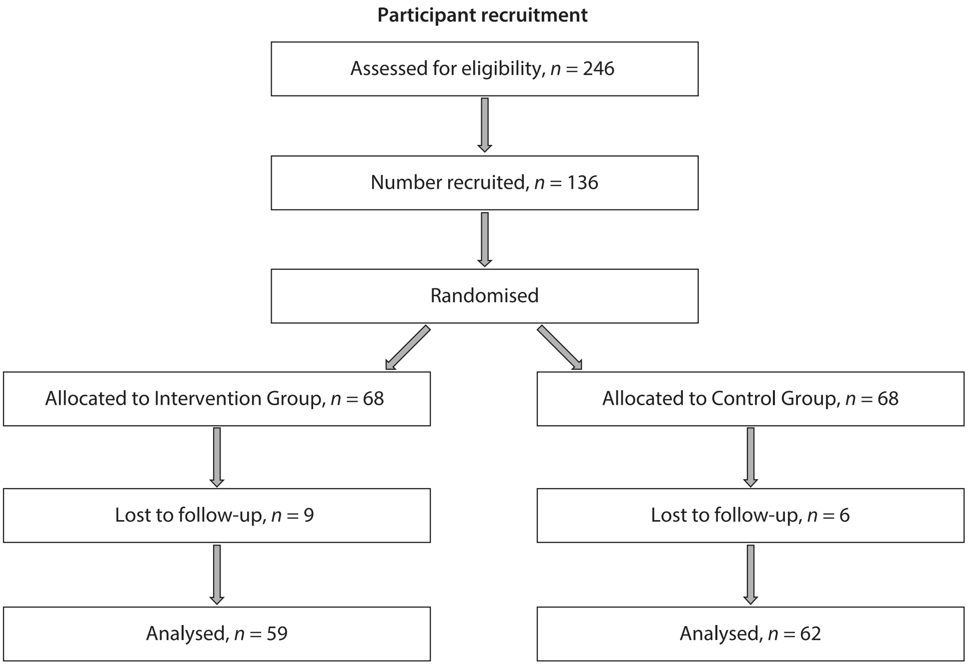

Figure 1: CONSORT Flow diagram of participant recruitment and follow-up.

allocation was used to determine the number of participants selected from each school, followed by simple random sampling. Finally, selected participants were randomly assigned to either the intervention or control group.

Inclusion and exclusion criteria and control of confounding factors

All school children aged 5–12 years old in public government primary schools in the Wa Municipality were eligible to participate in the study. Children of the same age group in private primary schools were excluded from the study. Besides children with special conditions, those with known allergy to egg and egg products, those on special medications, children receiving special extra teaching outside the normal school hours, children with special disabilities that may interfere with their physical and mental activity levels or whose parents/guardians declined to consent to their participation were excluded from the study.

Baseline nutritional status was assessed using anthropometric measurements (weight, height and BMI-for-age Z-scores). Inflammation was evaluated using C-reactive protein (CRP) and ferritin values were measured to ensure that both groups were comparable at baseline. Participant screening was employed to gather information on recent illness, medication use and dietary supplement intake and children taking iron supplements or medications that could give added advantage or confound our outcomes were excluded. Participants were individually randomised within each school to reduce the impact of unmeasured variables.

Tom Brown preparation

The Tom Brown used in this study was roasted corn flour alone, made from locally produced corn. Yellow corn was purchased from the Wa market, any bad cobs were carefully removed and the remainder was roasted using dry heat in a gas-operated oven at about 150–200°C. During the roasting, the corn was turned or stirred to ensure even roasting and prevent it from burning. The roasting process was deemed completed when the corn turned brown in colour. The roasted corn was then allowed to cool and milled into flour.[15] The Tom Brown was then prepared by mixing the roasted corn flour with egg powder to enhance its nutritional content using the formulation ratio of 100 g of corn flour to 20 g of egg powder. A predefined amount of sugar was added to the cooked Tom Brown to enhance the taste.

Description and nutrient composition of the intervention product

The intervention in this study was consumption of egg powder-fortified Tom Brown (roasted corn flour) porridge. The school children were fed with the prepared Tom Brown porridge 3 times a week for 24 weeks continuously without a break to assess its impact on their classroom performance. Participant recruitment and baseline assessments were conducted from January 2024 and the intervention, follow-up and endline assessments were conducted from 12 May 2024 and completed by 29 October 2024. The intervention group received egg powder-fortified Tom Brown porridge while the control group received the standard (the unfortified) roasted corn flour porridge. Each pupil consumed 250 ml of Tom Brown per serving, administered 3 times per week for the 24 weeks. From the proximate and mineral analysis conducted on the egg powder-fortified composite flour, which was used to prepare the Tom Brown, the nutrient content estimation of the prepared Tom Brown using the formulation ratio and average RDA for the age bracket, consuming 250 ml of the Tom Brown, provided a 573 kcal per day serving, 17.34 g of protein per day and 6.66 mg of iron per day respectively, the details of which are presented in another article.[16] The concentration of zinc, magnesium, folate and riboflavin, which influence cognitive performance, was also investigated in the fortified Tom Brown.[16] To control for the impact of confounding factors, participants were randomly assigned to the intervention and control groups to evenly distribute known and unknown confounders while stratification employed during randomisation was based on critical baseline variables such as academic performance quintiles, school size and location, to ensure balance. Again, covariate data on potential confounders such as household income, parental education, feeding practices and nutritional status, parasitic infection history and access to clean water were collected through parent/guardian questionnaires and school records. Research assistants administering and marking tests items as well as all other outcome assessors and data analysts were blinded to group allocation and treatment while teacher quality, attendance and classroom learning environment were adjusted for using standardised observation tools and statistics as fixed effects in the linear mixed-effects model alongside time and treatment. Also, participants and their caregivers were largely blinded to the groups as much as possible by ensuring similar appearance, texture and taste of the Tom Brown as complete blinding of participants and caregivers was impossible due to the nature of the food-based intervention. The intervention was closely monitored for compliance throughout the study period. The research team prepared the Tom Brown porridge daily, delivered it to the participating schools and directly supervised its consumption by the pupils to ensure intake. The porridges for both the intervention and control groups were prepared and served in a similar manner, with efforts made to ensure comparable appearance, texture and taste to minimise the likelihood of participants distinguishing between the two groups. Daily attendance and consumption were recorded using a monitoring checklist. For pupils who were absent from school, home follow-ups were made on the same day, where the intervention was administered and consumption supervised. This approach ensured that participants consistently received the intervention and minimised missed doses. The intervention was also closely monitored for any adverse effects, with a stand-by health team. No changes to the study design, methods or outcome measures were made after commencement of the trial. Also, no interim analyses or stopping guidelines were planned or conducted and the trial ended as planned after completion of follow-up. The nutrient composition of the egg powder-fortified Tom Brown used in the intervention was analysed and its contribution to the Recommended Dietary Allowance (RDA) for children aged 5–12 years was estimated and presented (Table 1).

Study participants

The participants were 136 Primary four pupils aged between 5 and 12 years selected from public primary schools in low-income suburbs of Wa Municipality of the Upper West region of Ghana. Children with special conditions or requiring special needs were excluded. Written assent was obtained from the students while written consent was obtained from the parents on behalf of the students before engaging them in the study. Ethical approval was granted for the study protocols by the Committee on Human Research, Publication and Ethics, Kwame Nkrumah University of Science and Technology, with approval number CHRPE/AP/998/23.

Table 1: Nutrient composition and percentage contribution of egg powder-fortified Tom Brown to RDA

Nutrient	Amount per 100g	Average RDA (for ages 5–12 years)	% contribution to RDA
Minerals (mg)			
Iron (Fe)	6.66	9 mg/day	74.0
Zinc (Zn)	3.91	7 mg/day	55.8
Magnesium (Mg)	94.97	185 mg/day	50.8
Vitamins (µg)			
Vitamin A	158.7	500 µg/day	31.7
Folate	141.1	250 µg/day	56.4
Riboflavin	313.6 (0.31 mg)	0.7 mg/day	41.9

Source: (d). RDA = Recommended Dietary Allowance. Values represent nutrient content per 100 g of the composite product. RDA values are based on averages for children aged 5–12 years as provided by the Institute of Medicine (IOM).

Cognitive test administration

Standardised assessment tests in numeracy and literacy were administered to the study participants before and after the Tom Brown meal intervention. The test items were obtained from the Ghana Education Service Standardised Assessment Test items. The test was conducted, supervised, marked and the test scores recorded by trained research assistants. The baseline test was conducted in all four schools on the same day before the intervention, and the question papers were retrieved from the pupils and kept by the lead researcher. After the 24-week Tom Brown intervention, the test was repeated on the same topics, concepts and very similar test items and the scores were recorded. The endline assessments were conducted immediately after the completion of the intervention period. Both baseline and endline tests were administered during regular school hours in the classroom setting under standardised conditions. Efforts were made to ensure consistency across assessments, including conducting tests at similar times of the day, in the same classroom environments and under comparable supervision. This approach minimised the potential influence of external factors such as temperature, time of day and environmental variations on test performance.

The baseline and endpoint tests were marked by the same trained markers, who were responsible for scoring both the baseline and endpoint tests but at different times. A standardised marking scheme was used to ensure consistency and all scripts were marked following the same criteria to minimise variability and bias. The markers were blinded to group allocation and time point. Additionally, random cross-checking of marked scripts was conducted by the lead researcher to ensure scoring consistency. The two test scores were compared to determine the impact of the intervention on cognitive performance.

Data processing and analysis

Data quality was ensured through careful data entry and validation procedures. Data were double-entered into SPSS (IBM Corp, Armonk, NY, USA) and R data analysis software (R Foundation for Statistical Computing, Vienna, Austria) and cross-checked for consistency. Any discrepancies identified were resolved by referring to the original data recording forms. Data cleaning was performed to check for missing values, outliers and logical inconsistencies prior to analysis. Apart from participants who were lost to follow-up, all remaining 121 individuals completed the intervention with full adherence to the study protocols, hence data were analysed using a modified intention-to-treat approach by including all participants with available outcome data in the groups to which they were originally assigned. To ensure the groups were comparable at enrolment, baseline participant characteristics were compared between the intervention and control groups. Pearson's chi-square test was used to evaluate categorical data (age and gender), and the independent samples t-test was used to compare continuous variables (baseline English and mathematics scores). The data were analysed

Table 2: Baseline characteristics of study participants

Variable	Intervention (n = 68)	Control (n = 68)	p-value
Age distribution (years)			
7–8	12 (17.6%)	10 (14.7%)	
9–10	35 (51.5%)	36 (52.9%)	0.093
11–12	21 (30.9%)	22 (32.4%)	
Gender distribution	Male: 34 (50.0%)	Male: 36 (52.9%)	0.073
	Female: 34 (50.0%)	Female: 32 (47.1%)	
Baseline English score	39.26 ± 10.13	40.01 ± 11.72	0.094
Baseline mathematics score	42.65 ± 7.64	44.85 ± 8.91	0.072

Note: P-values were derived using Pearson's chi-square test for categorical variables (age and gender) and independent samples t-test for continuous variables (baseline English and mathematics scores). $P < 0.05$ indicates statistical significance: $P < 0.05$ indicates significant difference.

using linear mixed-effects models to assess the impact of the intervention on English and mathematics scores. Effect sizes with 95% confidence intervals were reported to provide estimates of the magnitude and precision of the intervention effects. The models included time (baseline vs. endline), treatment group (intervention vs. control) and their interaction (time × treatment) as fixed effects. Although randomisation was performed at the individual level, a random intercept for school was included in the analysis to account for intra-cluster correlation among participants within the same school. No additional covariates were included in the model, as baseline equivalence between groups was confirmed. Model assumptions were assessed by examining residual plots and the distribution of scaled residuals. The residuals were approximately normally distributed, and no major violations of normality or homoscedasticity were observed. Therefore, no data transformation was required. All analyses were performed using SPSS and R data analysis software and statistical significance was set at $p < 0.05$.

Results

A total of 15 participants were lost to follow-up during the study period, 9 from the intervention group and 6 from the control group for reasons such as absenteeism and withdrawal from school. The remaining participants were included in the final analysis and no adverse effects or unintended harms related to the intervention were observed or reported during the study period. The results show that the study participants did not differ significantly in their baseline characteristics ($p >$ 0.05). There was no statistically significant difference in age, gender, mean English and mathematics scores at baseline between the intervention and control groups ($p > 0.05$), indicating that the groups were comparable at baseline (Table 2).

Model fit and diagnostics for scores

Linear mixed-effects models showed that they worked well for both English and mathematics outcomes, and there were no major problems with the assumptions of the model. For both models, the residuals were roughly normally distributed and centred on zero. Random intercepts showed that there was some variation between schools, accounting for 9.6% and 10.7% of the total variance in English and mathematics scores, respectively. Most of the variation was due to individual-level factors. These results validate the suitability of the modelling approach and the incorporation of school-level clustering. Details of the full model diagnostics and estimates of the parameters are presented in the Supplementary tables (S1–S8).

Effect of the intervention on English scores

There was no significant difference between the intervention and control groups at baseline ($p = 0.935$), confirming successful randomisation and comparability of groups. Over time, the intervention group demonstrated a substantial improvement in English scores compared with the control group. The control group showed a modest increase of 3.8 points from baseline to endline, whereas the intervention group improved markedly by 19.3 points. The between-group difference in change (interaction effect) was 15.46 points, which was statistically significant ($p < 0.001$), indicating a strong positive effect of the intervention on English performance. These findings are summarised in Table 3 with further details in Supplementary Table S1 for full model estimates.

Effect of the intervention on mathematics scores

Similarly, the results in mathematics scores showed that the groups were comparable at baseline ($p = 0.715$), reflecting a balanced group allocation. The control group showed no meaningful change in mathematics scores over time, with a slight decrease of 1.2 points. In contrast, the intervention group demonstrated a substantial improvement of 18.8 points from baseline to endline. The between-group difference in change (interaction effect) was 19.91 points and was highly significant ($p < 0.001$), indicating a strong effect of the intervention on mathematics performance. A summary of these results is presented in Table 4 and the details may be found in Supplementary Table S2.

Comparison of intervention effects across subjects

Overall, the intervention effect was greater in mathematics (19.91-point improvement) compared with English (15.46-point improvement). This suggests that the intervention may have had a stronger influence on mathematics performance, although it was effective in improving outcomes in both subjects.

Discussion

The study demonstrates that consumption of egg powder-fortified Tom Brown led to meaningful improvements in both English and mathematics performance among school-aged

Table 3: Effect of the intervention on English test scores

Group	Baseline mean (95% CI)	Endline mean (95% CI)	Mean change within group	Between-group difference (interaction effect)	p-value
Control	38.6 (32.8–44.3)	42.4 (36.4–48.3)	+ 3.8	–	–
Intervention	40.0 (34.0–46.0)	59.3 (53.3–65.2)	+ 19.3	15.46	< 0.001

Note: Values are estimated marginal means from linear mixed-effects models with random intercepts for school to account for clustering at the school level. The interaction effect represents the difference in change between intervention and control groups over time: "–" indicates not applicable at baseline, as no within-group change or interaction effect is defined prior to follow-up.

Table 4: Effect of the intervention on mathematics test scores

Group	Baseline mean (95% CI)	Endline mean (95% CI)	Mean change within group	Between-group difference (interaction effect)	*p*-value
Control	43.5 (38.7–48.2)	42.3 (37.5–47.1)	−1.2	–	–
Intervention	45.2 (40.3–50.1)	64.0 (59.1–68.8)	+ 18.8	19.91	< 0.001

Note: Values are estimated marginal means from linear mixed-effects models with random intercepts for school to account for clustering at the school level. The interaction effect represents the difference in change between intervention and control groups over time: "–" indicates not applicable at baseline, as no within-group change or interaction effect is defined prior to follow-up.

children compared with the control group. These findings suggest that improving the nutritional quality of commonly consumed school meals can enhance cognitive function and translate into better academic outcomes. Importantly, the magnitude of improvement observed in the intervention group suggests an additional benefit beyond expected learning progression, highlighting the role of nutrition as a key determinant of learning in resource-constrained settings. Beyond statistical validity, the findings suggest that the observed improvements are unlikely to be attributable to analytical bias or variations at the school level. Instead, they reflect a true intervention effect at the individual level. This distinction is important, as it reinforces the credibility of the findings and supports their relevance for real-world application in school-based settings.

Effect of the intervention on English and mathematics scores

Improved nutrition may have a positive impact on cognitive areas linked to language comprehension and memory, as shown by the improvement in English performance among children exposed to the intervention. The amount of change seen in the intervention group suggests an additional benefit beyond standard learning progression, even though some degree of academic gain over time is often expected in educational settings. The results of this study support the findings of another study, which reported that nutrition is critical in brain development and function, as verbal understanding, attention span and memory retention, which are all vital for language learning and acquisition in children, are substantially modulated by nutritional intakes.[17] This is because such nutrition interventions provide critical nutrients such as vitamin B complex and omega-3 fatty acids, which are vital for academic learning.[2]

Critically, this finding highlights that nutritional interventions can extend their impact beyond physical health to influence educational outcomes. Human memory and attention span are influenced by dopamine and serotonin as neurotransmitters whose synthesis largely depends on the intake of essential amino acids.[18] Therefore, egg being a complete protein source with high levels of essential amino acids was able to significantly impact positively on the English scores among the intervention group at the end of the intervention. The findings of this study are thus grounded in literature regarding the cognitive development and enhanced ability of eggs. A study which supplemented Indonesian children with eggs found that cognitive and linear development scores significantly improved among the intervention group after the egg intervention.[19] Similarly, a study in Burkina Faso revealed that kids who took protein supplements from milk source performed better in numeracy and language than the control group.[20] However, the relatively smaller effect observed in English compared with mathematics suggests that language-related skills may be influenced by a broader range of environmental and pedagogical factors, including teaching quality and home literacy environment. This underscores the need to view nutrition as a complementary, rather than standalone driver of academic performance in language-based subjects.

The difference in how the intervention affected mathematics and English scores can be attributed to the specific cognitive demands of each subject and how these are differently influenced by nutritional status. Mathematical problem-solving depends heavily on working memory, attention control and executive function, which are highly energy-intensive and especially susceptible to shortages of nutrients like iron, zinc and protein.[19,21] On the other hand, English (literacy) skills also require verbal fluency, a broad vocabulary and the support of a rich home literacy environment, making them more influenced by a wide array of social and environmental factors beyond just short-term nutrition.[22] Neuroimaging research indicates that solving arithmetic problems involves the prefrontal cortex and parietal lobes, aspects of the human brain that need efficient dopamine production, itself dependent on sufficient iron and amino acids from dietary protein.[23] Eggs, as a rich source of protein, choline and essential amino acids, help synthesise crucial neurotransmitters (like acetylcholine and dopamine) and support memory development in the hippocampus, which may give a particular advantage to mathematical reasoning over language tasks.[12,24] This view is supported by intervention studies that have found larger improvements in mathematics skills than in literacy after micronutrient and protein supplementation in similar low-resource settings.[24] Therefore, the observed differences likely reflect true differences in how each cognitive domain responds to nutrition, rather than being a result of how the outcomes were measured. This finding is in line with the World Food Programme's fortified biscuit intervention, which raised mathematics scores in Ghanaian schools by 0.3 standard deviations.[25] The significant improvement in mathematics implies that the intervention may have improved cognitive efficiency in ways that are especially advantageous for tasks involving analysis and reasoning.

From a critical standpoint, the control group's lack of improvement supports the claim that the intervention, rather than outside academic or environmental factors, was responsible for the observed benefits. This result emphasises how crucial it is to address dietary restrictions as a means of enhancing learning outcomes, especially in learning areas with high cognitive demands.

Relevance of findings to the field of nutrition and education

The findings of this study add to the increasing understanding of the fundamental role diet plays in determining academic achievements. Inadequate nutrition continues to be a major obstacle to the best possible cognitive development and academic achievement in many resource-constrained environments. The choline content of eggs, which promotes hippocampal formation and memory, while iron lessens weariness and improves attention, are probably responsible for the intervention's positive results.[12,13] The larger demand for working memory and problem-solving in mathematical activities, which are more sensitive to micronutrient status, may be the reason for the stronger positive effect in mathematics scores compared with English.[26,27] School-based nutritional treatments may thus be a useful approach to close this gap, as seen by the improvements in mathematics and English scores. The different effects on arithmetic and English scores produced by the intervention suggests subject-specific cognitive responses to nutritional intakes, indicating that learning task design should be taken into account in nutrition-sensitive academic policy.

Crucially, the study's practical value is increased by using a food product that is both culturally appropriate and geographically accepted. This approach shows that context-specific solutions can produce significant benefits rather than relying on highly specialised or externally directed initiatives. This has consequences for expanding interventions inside current school feeding programmes, especially in comparable socioeconomic settings.

Implications of the findings for stakeholders

These findings have significant implications for multiple actors. They offer compelling justification for policymakers to integrate nutrition-focused strategies into educational policies and school feeding programmes, as such integration has the potential to produce the dual benefits of improving health and academic performance simultaneously. For educators, the results pointed out the significance of considering nutritional status as a factor influencing learning ability, capacity and classroom engagement, highlighting that addressing nutritional needs may enhance the effectiveness of teaching efforts. Finally, the study underscores the value of designing interventions that are not only nutritionally beneficial but also contextually appropriate and scalable. The success of the intervention suggests that relatively simple, locally adapted solutions can produce meaningful improvements in child outcomes.

Limitations and future directions

Haemoglobin and serum choline were not measured as biochemical indications to authenticate nutrient absorption. Also, teacher quality and family involvement, which could modulate the outcome, may have accounted for the 9.6–10.7% between-school variance. Future research should evaluate long-term effects and contrast fortified eggs with other protein sources. The cost of producing eggs should also be considered because it may have a greater impact on the adoption and sustainability of the intervention among households with limited resources.

Conclusion

The study provided compelling evidence that targeted nutrition interventions such as serving egg powder-fortified Tom Brown as a school breakfast intervention significantly improved academic performance in English and mathematics scores. This approach has the potential to contribute to improving educational outcomes and nutritional status among school-aged children in low-resource settings by addressing the negative impact of insufficient protein and micronutrients on learning ability in children. Incorporating fortified school meals into education policy could have long-term benefits for human capital and health as global food poverty increases. These findings therefore have significant implications for future research, nutritional programming and educational policy, pointing to a clear direction for integrative school-based health and education initiatives. However, the findings may be most generalizable to similar low-resource, school-based settings with comparable dietary patterns and socioeconomic conditions.

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Ethics statement — The study was approved by the Committee on Human Research, Publication and Ethics at the Kwame Nkrumah University of Science and Technology, Ghana.

Consent — Consent and assent of guardians and participants was duly obtained before recruitment. The confidentiality and privacy of participants were ensured throughout the study.

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