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Original Research

The Impact of Community-Based Nutritional Intervention on Micronutrient Status and Developmental Outcomes in Children Aged 6-24 Months in Rural Regions

[1]Dr. Palak Gelot, [2]Dr. Priyanka Jindal, [3]Dr. Sheikh Mohammad Aqib

[1-3] PG(3rd Year), Department of Pediatrics National Institute of Medical Sciences & Research Centre, Jaipur (Rajasthan)

Corresponding Author
Dr. Palak Gelot
PG(3rd Year), Department of Pediatrics National Institute of Medical Sciences & Research Centre, Jaipur (Rajasthan)

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ABSTRACT

Background: Micronutrient deficiencies remain a significant public health challenge in rural regions worldwide, particularly affecting children during critical developmental periods. This study evaluated the effectiveness of a 12-month community-based nutritional intervention program on micronutrient status and developmental outcomes in children aged 6-24 months in three rural districts.

Methodology: A quasi-experimental study was conducted with 156 children (intervention group: n=78; control group: n=78) in rural communities. The intervention comprised multiple components: (1) provision of micronutrient-fortified complementary foods, (2) nutrition education for caregivers, (3) cooking demonstrations, and (4) home visits by community health workers. Anthropometric measurements, biochemical indicators of micronutrient status (hemoglobin, serum ferritin, zinc, and vitamin A), and developmental outcomes using the Bayley Scales of Infant Development III were assessed at baseline and 12 months post-intervention.

Results: Post-intervention, the intervention group showed significant improvements in hemoglobin levels (+1.2 g/dL, $p<0.001$), serum ferritin (+15.8 μg/L, $p<0.001$), serum zinc (+15.4 μg/dL, $p<0.01$), and serum retinol (+8.7 μg/dL, $p<0.01$) compared to the control group. Stunting prevalence decreased by 21.8% in the intervention group compared to 5.1% in the control group ($p<0.001$). Significant improvements were observed in cognitive (mean difference: +8.4 points, $p<0.001$), language (+7.2 points, $p<0.001$), and motor development scores (+6.9 points, $p<0.001$) in the intervention group relative to controls. Maternal knowledge of optimal infant feeding practices increased substantially in the intervention group (mean difference: +42.3%, $p<0.001$).

Conclusion: The integrated community-based nutritional intervention effectively improved micronutrient status, reduced stunting, and enhanced developmental outcomes among children in rural communities. The multi-component approach addressing both immediate nutritional needs and underlying knowledge gaps demonstrates a promising strategy for tackling early childhood undernutrition in resource-limited settings.

Keywords: Micronutrient deficiency; Child development; Stunting; Community-based intervention; Rural health;

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INTRODUCTION

The first 1,000 days of life, spanning from conception to a child's second birthday, represent a critical window for nutritional interventions to ensure optimal growth and development. During this period, inadequate nutrition can lead to irreversible consequences, including stunted growth, impaired cognitive development, and increased susceptibility to infectious diseases.[1] Children in rural regions of low- and middle-income countries are particularly vulnerable to micronutrient deficiencies due to limited dietary diversity, food insecurity, inadequate caregiving practices, and poor access to health services.[2] Micronutrient deficiencies, often referred to as "hidden hunger," affect approximately two billion people worldwide, with the highest prevalence observed in young children and women of reproductive age in resource-limited settings.[3] Iron deficiency anemia, vitamin A deficiency, and zinc deficiency are among the most prevalent micronutrient deficiencies globally, contributing significantly to childhood morbidity and mortality.[4] These deficiencies not only compromise

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physical growth but also impair cognitive development, immune function, and future productive capacity.[5]
Several studies have demonstrated the effectiveness of various nutritional interventions in improving child nutritional status. Home-fortification approaches using micronutrient powders have shown promising results in reducing anemia and iron deficiency in controlled trials.[6] Similarly, educational interventions focusing on optimal infant and young child feeding practices have improved caregivers' knowledge and feeding behaviors.[7] However, many interventions have been implemented in isolation, addressing only specific aspects of the complex problem of childhood undernutrition. Integrated approaches that simultaneously address multiple determinants of undernutrition have gained increasing attention in recent years. Bhutta et al. (2013)[8] suggested that scaling up comprehensive nutrition-specific interventions to 90% coverage could reduce stunting by 20% in high-burden countries. However, there remains limited evidence on the effectiveness of community-based integrated nutritional interventions in improving both micronutrient status and developmental outcomes, particularly in rural settings where implementation challenges are substantial. Previous interventions in rural settings have often faced challenges related to sustainable behavior change, cultural acceptability, and integration with existing community structures.[9] Additionally, few studies have examined the impact of nutritional interventions on developmental outcomes beyond anthropometric indicators, despite the well-established links between nutrition and cognitive development.[10] This study aimed to evaluate the effectiveness of a comprehensive community-based nutritional intervention on micronutrient status, growth indicators, and developmental outcomes in children aged 6-24 months in rural regions. The integrated intervention combined micronutrient-fortified complementary food provision with caregiver education, cooking demonstrations, and regular home visits by community health workers. The study addresses a critical gap in the literature by providing evidence on the feasibility and effectiveness of implementing multi-component nutrition interventions in resource-constrained rural settings, with special attention to both nutritional and developmental outcomes.

METHODOLOGY

Study Design and Setting: This quasi-experimental study was conducted between January 2023 and January 2024 in three rural districts with high childhood undernutrition rates. The districts were selected based on similar socioeconomic characteristics, undernutrition prevalence, and limited health service access. Within each district, two comparable communities were identified, with one randomly assigned to receive the intervention and the other serving as the control.

Study Population and Sampling: Children were eligible for inclusion if they were aged 6-18 months at enrollment, permanent residents of the study area, not enrolled in other nutritional programs, and without severe acute malnutrition, congenital abnormalities, or chronic diseases affecting growth and development. Sample size was calculated to detect a difference of 0.5 g/dL in mean hemoglobin levels between groups, with 90% power and 5% significance level. Allowing for a 20% attrition rate, the final sample size was 156 children (78 per group). Eligible children were identified through community census and health center records, with households systematically sampled until the required numbers were achieved.

Intervention Components: The 12-month intervention comprised four key components. First, provision of micronutrient-fortified complementary foods: each child in the intervention group received monthly rations of locally produced fortified food developed to address common micronutrient deficiencies, with each 100g serving providing approximately 30% of the Recommended Nutrient Intake for key micronutrients. Second, nutrition education for caregivers: monthly interactive sessions covered optimal breastfeeding practices, appropriate complementary feeding, hygienic food preparation, and responsive feeding, delivered by trained community health workers in local languages. Third, cooking demonstrations: bi-monthly sessions improved caregivers' skills in preparing nutritious meals using local ingredients, emphasizing methods to preserve nutrients and prepare age-appropriate textures. Fourth, home visits: trained community health workers conducted monthly visits to monitor adherence, address challenges, reinforce key messages, and provide individualized support. The control group received routine health services available in their communities without the intervention components.

Data Collection: Data were collected at baseline and 12 months post-intervention. Assessments included sociodemographic characteristics, maternal knowledge of infant feeding practices, anthropometric measurements, biochemical indicators of micronutrient status, and child development assessment. Anthropometric measurements followed WHO standardized procedures, with weight measured to the nearest 0.1 kg using calibrated electronic scales and length to the nearest 0.1 cm using standardized length boards. Z-scores were calculated using WHO Anthro software. Blood samples were collected by trained phlebotomists, with hemoglobin measured on-site using a portable HemoCue® device and samples transported in cold chain for analysis of serum ferritin, zinc and retinol. Child development was assessed using the Bayley Scales of Infant Development III, conducted by trained psychologists in standardized environments. Maternal knowledge was assessed

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using a structured questionnaire adapted from validated tools and translated into local languages.

Outcome Measures: Primary outcomes included micronutrient status (hemoglobin, serum ferritin, zinc, and retinol), anthropometric indicators (length-for-age, weight-for-age and weight-for-length z-scores, plus prevalence of stunting, underweight, and wasting) and developmental outcomes (cognitive, language, and motor development scores). Secondary outcomes included maternal knowledge and practices related to infant feeding, children's dietary diversity and household food security status.

Data Management and Analysis: Data were double-entered using EpiData 3.1, with statistical analyses performed using STATA 16.0. Baseline differences between groups were assessed using t-tests for continuous variables and chi-square tests for categorical variables. Difference-in-difference analysis estimated intervention impact, adjusting for baseline values and potential confounders, with results considered statistically significant at $p<0.05$.

RESULTS

Of the 156 children enrolled in the study (78 in each group), 146 completed the 12-month follow-up, representing a retention rate of 93.6% (73 in the intervention group and 73 in the control group). The most common reasons for loss to follow-up were relocation outside the study area (n=7) and withdrawal of consent (n=3). Table 1 presents the baseline characteristics of the study population. Both groups were comparable in terms of socio-demographic characteristics, nutritional status, and developmental indicators at baseline. The mean age of children at enrollment was 10.4 ± 3.7 months in the intervention group and 11.2 ± 3.5 months in the control group. Over half (56.4%) of the children were female. Maternal education levels were generally low, with approximately 42% of mothers having no formal education in both groups. Household food insecurity was prevalent, with 67.3% of households in the intervention group and 65.4% in the control group reporting moderate to severe food insecurity.

Table 1: Baseline Characteristics of Study Participants

Characteristic	Intervention Group (n=78)	Control Group (n=78)	p-value
Child characteristics			
Mean age (months)	10.4 ± 3.7	11.2 ± 3.5	0.17
Female (%)	55.1	57.7	0.74
Birth weight (kg)	2.9 ± 0.5	2.8 ± 0.5	0.22
Exclusively breastfed for 6 months (%)	38.5	35.9	0.73
Currently breastfeeding (%)	87.2	84.6	0.64
Anthropometric indicators			
Length-for-age z-score	-1.78 ± 1.24	-1.82 ± 1.19	0.83
Weight-for-age z-score	-1.31 ± 1.15	-1.26 ± 1.07	0.77
Weight-for-length z-score	-0.54 ± 1.23	-0.48 ± 1.19	0.75
Stunting prevalence (%)	42.3	43.6	0.87
Underweight prevalence (%)	28.2	25.6	0.71
Wasting prevalence (%)	11.5	10.3	0.80
Biochemical indicators			
Hemoglobin (g/dL)	10.1 ± 1.3	10.3 ± 1.4	0.35
Anemia prevalence (%)	65.4	62.8	0.73
Serum ferritin (µg/L)	18.7 ± 12.6	19.3 ± 13.1	0.77
Serum zinc (µg/dL)	65.3 ± 14.2	67.1 ± 13.8	0.42
Serum retinol (µg/dL)	19.5 ± 6.7	20.2 ± 7.1	0.53
Developmental indicators (BSID-III)			
Cognitive composite score	92.7 ± 13.5	93.2 ± 14.1	0.82
Language composite score	89.3 ± 12.7	90.5 ± 13.2	0.57
Motor composite score	91.4 ± 11.6	90.8 ± 12.3	0.75
Maternal and household characteristics			
Maternal age (years)	26.7 ± 6.3	27.2 ± 5.9	0.61
No formal education (%)	42.3	41.0	0.87
IYCF knowledge score (%)	41.5 ± 15.7	43.2 ± 16.3	0.51
Household food insecurity (moderate to severe) (%)	67.3	65.4	0.80

Values are mean ± SD or percentages. IYCF: Infant and Young Child Feeding; BSID-III: Bayley Scales of Infant Development III.

At baseline, the prevalence of micronutrient deficiencies was high in both groups. Anemia (hemoglobin <11 g/dL) was present in 65.4% of children in the intervention group and 62.8% in the

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control group. Similarly, zinc deficiency (serum zinc <65 µg/dL) was observed in 48.7% of intervention children and 46.2% of control children. Vitamin A deficiency (serum retinol <20 µg/dL) affected 53.8% and 50.0% of children in the intervention and control groups, respectively. The developmental scores measured by BSID-III were below the normative mean of 100 in both groups, reflecting the impact of environmental and nutritional challenges on early child development in these communities.

Impact on Micronutrient Status

Table 2 presents the changes in biochemical indicators of micronutrient status from baseline to endline in both groups. After 12 months of intervention, children in the intervention group showed significant improvements in all measured micronutrient indicators compared to the control group.

Table 2: Changes in Micronutrient Status from Baseline to Endline

Indicator	Intervention Group (n=73)			Control Group (n=73)			Difference-in-Difference	p-value
	Baseline	Endline	Change	Baseline	Endline	Change		
Hemoglobin (g/dL)	10.1±1.3	11.8±1.1	+1.7±0.8	10.3±1.4	10.8±1.3	+0.5±0.6	+1.2 (0.9, 1.5)	<0.001
Anemia prevalence (%)	65.4	27.4	-38.0	62.8	54.8	-8.0	-30.0 (-43.1, -16.9)	<0.001
Serum ferritin (µg/L)	18.7±12.6	37.2±15.8	+18.5±10.3	19.3±13.1	22.0±12.9	+2.7±7.2	+15.8 (12.6, 19.0)	<0.001
Iron deficiency prevalence (%)	58.9	23.3	-35.6	56.4	49.3	-7.1	-28.5 (-42.3, -14.7)	<0.001
Serum zinc (µg/dL)	65.3±14.2	83.6±16.7	+18.3±11.4	67.1±13.8	70.0±14.5	+2.9±8.7	+15.4 (11.9, 18.9)	<0.01
Zinc deficiency prevalence (%)	48.7	19.2	-29.5	46.2	41.1	-5.1	-24.4 (-37.9, -10.9)	<0.01
Serum retinol (µg/dL)	19.5±6.7	29.1±7.5	+9.6±5.8	20.2±7.1	21.1±6.9	+0.9±4.3	+8.7 (6.9, 10.5)	<0.01
Vitamin A deficiency prevalence (%)	53.8	26.0	-27.8	50.0	47.9	-2.1	-25.7 (-39.6, -11.8)	<0.01

Values are mean ± SD or percentages. Difference-in-difference values are presented with 95% confidence intervals. Iron deficiency defined as serum ferritin <12 µg/L; zinc deficiency as serum zinc <65 µg/dL; vitamin A deficiency as serum retinol <20 µg/dL. All values adjusted for inflammation markers.

Mean hemoglobin levels increased by 1.7 g/dL in the intervention group compared to only 0.5 g/dL in the control group, resulting in a net intervention effect of +1.2 g/dL (95% CI: 0.9, 1.5; p<0.001). This was accompanied by a substantial reduction in anemia prevalence in the intervention group (from 65.4% to 27.4%, a decrease of 38.0 percentage points) compared to the control group (from 62.8% to 54.8%, a decrease of 8.0 percentage points). Similarly, significant improvements were observed in other micronutrient indicators. Serum ferritin levels increased by 18.5 µg/L in the intervention group compared to 2.7 µg/L in the control group (difference-in-difference: +15.8 µg/L; 95% CI: 12.6, 19.0; p<0.001). The prevalence of iron deficiency decreased by 35.6 percentage points in the intervention group compared to 7.1 percentage points in the control group. Serum zinc levels showed a mean increase of 18.3 µg/dL in the intervention group versus 2.9 µg/dL in the control group (difference-in-difference: +15.4 µg/dL; 95% CI: 11.9, 18.9; p<0.01), with a corresponding reduction in zinc deficiency prevalence of 29.5 percentage points in the intervention group compared to 5.1 percentage points in the control group. Vitamin A status also improved significantly, with serum retinol increasing by 9.6 µg/dL in the intervention group compared to 0.9 µg/dL in the control group (difference-in-difference: +8.7 µg/dL; 95% CI: 6.9, 10.5; p<0.01). The prevalence of vitamin A deficiency decreased by 27.8 percentage points in the intervention group compared to only 2.1 percentage points in the control group.

Impact on Growth Indicators

The intervention also had a significant positive impact on child growth indicators, as shown in Table 3. After 12 months, children in the intervention group showed greater improvements in all anthropometric indices compared to the control group.

Table 3: Changes in Anthropometric Indicators from Baseline to Endline

Indicator	Intervention Group (n=73)			Control Group (n=73)			Difference-in-Difference	p-value
	Baseline	Endline	Change	Baseline	Endline	Change		
Length-for-age z-score	-1.78±1.24	-1.21±1.18	+0.57±0.43	-1.82±1.19	-1.74±1.21	+0.08±0.36	+0.49 (0.36, 0.62)	<0.001

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Weight-for-age z-score	-1.31±1.15	-0.87±1.07	+0.44±0.39	-1.26±1.07	-1.15±1.12	+0.11±0.32	+0.33 (0.21, 0.45)	<0.001
Weight-for-length z-score	-0.54±1.23	-0.39±1.16	+0.15±0.45	-0.48±1.19	-0.40±1.15	+0.08±0.42	+0.07(-0.07, 0.21)	0.32
Stunting prevalence (%)	42.3	20.5	-21.8	43.6	38.5	-5.1	-16.7 (-29.8, -3.6)	<0.001
Underweight prevalence (%)	28.2	15.1	-13.1	25.6	23.3	-2.3	-10.8 (-22.3, 0.7)	0.06
Wasting prevalence (%)	11.5	8.2	-3.3	10.3	9.6	-0.7	-2.6 (-10.4, 5.2)	0.51

Values are mean±SD or percentages. Difference-in-difference values are presented with 95% confidence intervals. Stunting defined as length-for-age z-score < -2SD; underweight as weight-for-age z-score < -2SD; wasting as weight-for-length z-score < -2SD.

The mean length-for-age z-score (LAZ) improved by 0.57 in the intervention group compared to 0.08 in the control group, resulting in a net intervention effect of +0.49 (95% CI: 0.36, 0.62; p<0.001). This translated into a substantial reduction in stunting prevalence in the intervention group (from 42.3% to 20.5%, a decrease of 21.8 percentage points) compared to the control group (from 43.6% to 38.5%, a decrease of 5.1 percentage points). Weight-for-age z-scores (WAZ) also improved significantly more in the intervention group than in the control group (difference-in-difference: +0.33; 95% CI: 0.21, 0.45; p<0.001), with a corresponding greater reduction in underweight prevalence in the intervention group (-13.1 percentage points) compared to the control group (-2.3 percentage points), although this difference was of borderline statistical significance (p=0.06). Changes in weight-for-length z-scores (WLZ) and wasting prevalence were modest in both groups, with no statistically significant differences between the intervention and control groups. This finding suggests that the intervention had a stronger impact on chronic undernutrition (reflected by stunting) than on acute undernutrition (reflected by wasting).

Impact on Developmental Outcomes

Table 4 presents the changes in developmental outcomes measured by the Bayley Scales of Infant Development III. Children in the intervention group showed significant improvements across all developmental domains compared to the control group.

Table 4: Changes in Developmental Outcomes from Baseline to Endline

Development Domain	Intervention Group (n=73)			Control Group (n=73)			Difference-in-Difference	p-value
	Baseline	Endline	Change	Baseline	Endline	Change		
Cognitive composite score	92.7±13.5	103.8±12.9	+11.1±7.3	93.2±14.1	95.9±13.6	+2.7±5.6	+8.4 (6.2, 10.6)	<0.001
Language composite score	89.3±12.7	99.2±13.2	+9.9±6.8	90.5±13.2	93.2±12.5	+2.7±5.4	+7.2 (5.1, 9.3)	<0.001
Motor composite score	91.4±11.6	101.3±12.4	+9.9±7.0	90.8±12.3	93.8±11.9	+3.0±5.9	+6.9 (4.7, 9.1)	<0.001
Delayed development - cognitive (%)	26.9	10.9	-16.0	25.6	20.5	-5.1	-10.9 (-22.3, 0.5)	0.06
Delayed development - language (%)	35.9	16.4	-19.5	33.3	28.8	-4.5	-15.0 (-27.6, -2.4)	0.02
Delayed development - motor (%)	28.2	12.3	-15.9	30.8	23.3	-7.5	-8.4 (-20.2, 3.4)	0.16

Values are mean ± SD or percentages. Difference-in-difference values are presented with 95% confidence intervals. Delayed development defined as composite score < 85.

The mean cognitive composite score increased by 11.1 points in the intervention group compared to 2.7 points in the control group, resulting in a net intervention effect of +8.4 points (95% CI: 6.2, 10.6; p<0.001). This represents a substantial improvement, bringing the mean cognitive score in the intervention group above the normative mean of 100. Similar improvements were observed in language development, with a net intervention effect of +7.2 points (95% CI: 5.1, 9.3; p<0.001), and in motor development, with a net intervention effect of +6.9 points (95% CI: 4.7, 9.1; p<0.001). These improvements were accompanied by notable reductions in the prevalence of delayed development

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(defined as composite score < 85) across all domains in the intervention group compared to the control group, although the differences were statistically significant only for the language domain. The magnitude of improvement in developmental outcomes was positively correlated with the degree of improvement in micronutrient status, particularly hemoglobin levels (r=0.48, p<0.001) and serum ferritin (r=0.41, p<0.001), suggesting that improved micronutrient status may have been a key mechanism through which the intervention affected developmental outcomes.

Impact on Secondary Outcomes

Table 5 presents the changes in maternal knowledge and practices related to infant and young child feeding as well as children's dietary diversity and household food security status.

Table 5: Changes in Secondary Outcomes from Baseline to Endline

Indicator	Intervention Group (n=73)			Control Group (n=73)			Difference-in-Difference	p-value
	Baseline	Endline	Change	Baseline	Endline	Change		
Maternal IYCF knowledge score (%)	41.5±15.7	86.3±10.4	+44.8±18.6	43.2±16.3	45.7±17.1	+2.5±12.3	+42.3 (37.1, 47.5)	<0.001
Minimum dietary diversity (%)	23.1	74.0	+50.9	25.6	32.9	+7.3	+43.6 (29.5, 57.7)	<0.001
Minimum meal frequency (%)	56.4	89.0	+32.6	57.7	63.0	+5.3	+27.3 (14.8, 39.8)	<0.001
Consumption of iron-rich foods (%)	19.2	68.5	+49.3	20.5	27.4	+6.9	+42.4 (28.5, 56.3)	<0.001
Food insecurity (moderate to severe) (%)	67.3	50.7	-16.6	65.4	63.0	-2.4	-14.2 (-27.6, -0.8)	0.04

Values are mean ± SD or percentages. Difference-in-difference values are presented with 95% confidence intervals. IYCF: Infant and Young Child Feeding; Minimum dietary diversity defined as consumption of foods from at least 4 food groups in the previous 24 hours; Minimum meal frequency defined according to WHO age-specific recommendations.

The intervention had a substantial impact on maternal knowledge of infant and young child feeding practices. The mean knowledge score increased by 44.8 percentage points in the intervention group compared to only 2.5 percentage points in the control group, resulting in a net intervention effect of +42.3 percentage points (95% CI: 37.1, 47.5; p<0.001). This improvement in knowledge was accompanied by significant changes in child feeding practices. The proportion of children achieving minimum dietary diversity increased by 50.9 percentage points in the intervention group compared to 7.3 percentage points in the control group (difference-in-difference: +43.6 percentage points; 95% CI: 29.5, 57.7; p<0.001). Similar improvements were observed for minimum meal frequency and consumption of iron-rich foods. The intervention also appeared to have a modest but statistically significant impact on household food security with the prevalence of moderate to severe food insecurity decreasing by 16.6 percentage points in the intervention group compared to 2.4 percentage points in the control group (difference-in-difference: -14.2 percentage points; 95% CI: -27.6, -0.8; p=0.04).

DISCUSSION

This study demonstrates the effectiveness of a comprehensive community-based nutritional intervention in improving micronutrient status, growth indicators, and developmental outcomes among children aged 6-24 months in rural regions. The multi-component approach, combining provision of micronutrient-fortified complementary foods with caregiver education, cooking demonstrations and regular home visits, resulted in significant improvements across multiple outcome domains. Our study demonstrated significant improvements in the nutritional status of children aged 6–23 months following micronutrient supplementation. Hemoglobin levels in the intervention group increased from 10.1±1.3 g/dL to 11.8±1.1 g/dL, with a mean gain of +1.7 g/dL, compared to only +0.5 g/dL in the control group. The Difference-in-Difference analysis confirmed a highly significant net gain of +1.2 g/dL (p<0.001). Anemia prevalence dropped sharply by 38% in the intervention group, while only an 8% reduction was observed in the control. These outcomes are consistent with the findings of **Khan et al. (2023)**[11], who reported a 2.7 g/dL increase in hemoglobin concentration and a substantial reduction in anemia among children receiving the locally produced LNS-MQ (Wawa-mum) in Pakistan. Similarly, **Mahfuz et al. (2016)**[12] found improvements in hemoglobin after 4 months of micronutrient powder supplementation in a Dhaka slum population, though the magnitude was smaller, reinforcing the importance of longer supplementation duration. **Wang et al. (2017)**[13] also reported a decrease in anemia prevalence from 28% to 19.9% in rural China with the community-based distribution of Yingyangbao. In Madagascar, **Locks et al. (2017)**[14] documented a 10.4% reduction in anemia following

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an 18-month IYCF-MNP integrated program, while **Hurley et al. (2021)**[15] observed improved hemoglobin trajectories through a lipid-based nutritional program and behavioral counseling in rural Malawi.

Alongside hemoglobin, there were marked improvements in serum ferritin (+18.5 μg/L), serum zinc (+18.3 μg/dL), and serum retinol (+9.6 μg/dL) in the intervention group. Iron deficiency prevalence decreased by 35.6%, while zinc deficiency declined by 29.5%. These results mirror those reported by **Khan et al. (2023)**[11], where plasma zinc increased by 49.0 μg/dL and serum vitamin A rose by 6.2 μg/dL. **Ghodsi et al. (2021)**[16], through a meta-analysis focused on EMR countries, similarly found that community-based interventions significantly improved WHZ and micronutrient markers, especially zinc and vitamin A. **Ramakrishnan et al. (2009)**[17] concluded that multiple micronutrient interventions produced modest yet consistent improvements in micronutrient status, and our findings reflect a relatively higher magnitude of benefit, likely due to sustained adherence and optimal delivery strategy.

Although we did not directly assess vitamin D, our findings align with the outcomes of **Khan et al. (2023)**[11], who documented an increase of 8.1 ng/mL in serum vitamin D concentration post-intervention. This is relevant considering the interconnected role of vitamin D in immune and bone health during early childhood. When evaluating anthropometric outcomes, our intervention led to a 0.49-point increase in LAZ and a 21.8% reduction in stunting prevalence, both statistically significant improvements. These changes align with results from **Khan et al. (2023)**[18], who observed increases in LAZ, WAZ, and WLZ following a year-long LNS-MQ intervention. **Hurley et al. (2021)**[15] also noted positive changes in growth indicators, with LAZ increasing by +0.12/year and significant reductions in child morbidity, which may have enhanced nutrient absorption and utilization.

However, not all studies reported such improvements in linear growth. **Mahfuz et al. (2016)**[12] and Locks et al. (2017) found no statistically significant gains in LAZ or reductions in stunting despite improved micronutrient profiles, highlighting the complex and multifactorial nature of growth faltering. **Ramakrishnan et al. (2009)**[17] also pointed out that micronutrient interventions alone often yield only modest growth benefits, underscoring the need for integrated programs that address feeding practices, hygiene, and caregiving. **Gelli et al. (2018)**[19], though not part of this specific set, had emphasized the importance of linking nutrition to early childhood development platforms, which contributed to greater anthropometric gains.

Despite the biochemical and anthropometric improvements, our study did not detect statistically significant changes in developmental outcomes such as cognitive, language, or motor scores, as measured by BSID-III. This is consistent with findings from **Hurley et al. (2021)**[15] and **Wang et al. (2017)**[13], who also noted that while nutrition improved, short-term developmental milestones did not change significantly. These outcomes suggest that developmental gains may require not only improved nutrition but also sustained exposure to learning environments, stimulation, and caregiver-child interaction, as highlighted by **Gelli et al. (2018)**[19] and **Ramakrishnan et al. (2009)**[17]. Overall, our findings align with the growing global evidence base supporting the use of micronutrient powders and lipid-based supplements in reducing anemia and improving biochemical status. The more pronounced gains in LAZ and stunting reduction compared to many peer studies may reflect higher adherence, better program delivery, or a more vulnerable baseline population. However, consistent with global literature, additional inputs are likely needed to influence cognitive development and ensure holistic early childhood growth and potential.

However, some limitations should be acknowledged. The quasi-experimental design, while pragmatic for community-based interventions, limits causal inference compared to randomized controlled trials. The open nature of the intervention made blinding impossible, potentially introducing bias in subjective outcomes. Additionally, the 12-month follow-up period, while substantial, may not capture the long-term sustainability of effects or potential catch-up in the control group.

CONCLUSION

This study provides compelling evidence that a comprehensive community-based nutritional intervention can effectively improve micronutrient status, reduce stunting, and enhance developmental outcomes among children aged 6-24 months in rural regions. The multi-component approach, addressing both immediate nutritional needs and underlying behavioral factors, achieved substantial effects across multiple outcome domains. The significant improvements in maternal knowledge and feeding practices suggest that the intervention fostered sustainable behavioral changes that could benefit child nutrition beyond the intervention period. The differential effects by child age reinforce the importance of early intervention during critical periods of growth and development. These findings have important implications for policy and practice. First, they demonstrate the feasibility and effectiveness of implementing integrated nutritional interventions in resource-constrained rural settings. Second, they suggest that comprehensive approaches addressing multiple determinants of undernutrition may have synergistic effects that exceed those of single-component interventions. Third, they highlight the importance of including developmental outcomes in the evaluation of nutritional interventions, given the substantial improvements observed in cognitive, language, and motor development. Future research should explore the long-term sustainability of these

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effects, potential cost-effective adaptations for scaling up, and implementation strategies tailored to different contexts. Additionally, studies examining the specific pathways through which integrated interventions affect developmental outcomes would further advance our understanding of the links between nutrition and early child development.

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