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SUPPLEMENT ARTICLE

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Small-scale egg production centres increase children's egg consumption in rural Zambia

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Abstract

Animal source foods can efficiently enhance dietary quality, but they remain inaccessible and unaffordable for many women and young children in remote, low-income communities. We piloted an intervention in which 20 groups established egg production centres (EPCs) in their rural Zambian communities to increase the availability of eggs in the local food system. In a repeated cross-sectional design over 1 year (midline [4 months after the start of egg production] and endline [11 months]), we evaluated programme impact on household egg acquisition within those communities and on egg consumption and height-for-age *z* score (HAZ) among young children (6–36 months) using multilevel linear, logistic, and truncated negative binomial regression techniques. At midline, households in project areas were significantly more likely to consume eggs than those in control areas (OR 2.08, 95% CI [1.56, 2.78]), particularly those located within 250 m of the EPC. Similarly, children living in project communities were significantly more likely to consume eggs at midline than those in control areas (OR 5.53, 95% CI [2.90, 10.58]). Although increased over baseline, egg acquisition and consumption decreased by endline because of depressed egg production over time. There was no impact on children's HAZ, likely because of the short follow-up time and relatively modest "dose" of egg consumption. Although productivity can be improved, the EPC programme offers a novel approach to improving access to eggs in rural communities, and optimization of the production practices and marketing is needed to ensure that egg consumption translates to improved dietary quality, growth, and health.

KEYWORDS

animal source foods, child nutrition, eggs, food systems, nutrition-sensitive agriculture, stunting

1 | INTRODUCTION

Animal source foods (ASF) are an efficient mechanism for meeting children's dietary requirements, because relatively small amounts can make large contributions to their nutrient intake (Allen, 2003, 2012; Dror & Allen, 2011; Murphy & Allen, 2003; Neumann, Harris, & Rogers, 2002). There is strong evidence that the incorporation of ASF into the diets of young children can improve dietary quality, micronutrient intake, and nutrition outcomes (Allen, 1993; Allen, Backstrand, & Stanek, 1992; Darapheak, Takano, Kizuki, Nakamura, & Seino, 2013; Grillenberger et al., 2006; Herrador et al., 2014; Iannotti, Lutter, Stewart, et al., 2017a; Iannotti, Lutter, Waters, et al., 2017b; Krasevec, An, Kumapley, Bégin, & Frongillo, 2017; Krebs et al., 2011; Lien et al., 2009; Long et al., 2011; Neumann et al., 2013). However, the poorest families in low and lower middle income countries often rely on low-quality, plant-based diets consisting primarily of starchy staples (Allen, 1993, 2012; Arimond & Ruel, 2004; Black et al., 2008), and novel approaches are needed to improve ASF availability and consumption in these settings.

Small-scale livestock production is one approach to improving the physical and economic accessibility of ASF in rural, low-income communities, and poultry production is particularly promising for a number of reasons. First, village (or backyard) poultry production is already a familiar livelihood activity for more than 85% of rural families in sub-Saharan Africa (Gueye, 2000a). Second, it is estimated that more than 70% of chicken owners are women (Gueye, 2000a, 2000b; Wong et al., 2017), and women's empowerment and control over agricultural resources are important mediators of child nutrition outcomes (Ruel et al., 2013). Third, backyard poultry production has a low cost of entry and maintenance (Alders & Pym, 2009; Gueye, 2000a). Finally, eggs are an appropriate first complementary food (Iannotti, Lutter, Bunn, & Stewart, 2014), and feeding young children just one egg per day can have dramatic effects on their growth (Iannotti, Lutter, Stewart, et al., 2017a) and micronutrient status (Iannotti, Lutter, Waters, et al., 2017b).

Despite the great potential of village poultry, research evaluating the impact of poultry-based interventions has historically shown only modest impacts on child nutrition outcomes (Appendix S1). In rural Zambia, a package of interventions that effectively increased flock sizes had no effect on chicken or egg consumption. Instead, smallholders demonstrated a strong preference for leaving eggs from village chickens to hatch, increasing flock sizes, and allowing them to more readily sell birds as needed (Dumas et al., 2016). This phenomenon has been reported elsewhere (de Bruyn et al., 2017; Dumas et al., 2017; Gueye, 2000a; Olney, Vicheka, Kro, & Chakriya, 2013) and is a major limitation to the use of village poultry as a tool for increasing egg availability and consumption. Additionally, there is an emerging concern that free-ranging poultry can negatively affect child nutrition outcomes by exposing them to zoonotic pathogens that cause clinical disease (e.g., diarrhoea; Zambrano, Levy, Menezes, & Freeman, 2014) or environmental enteric dysfunction (Gelli et al., 2017; George, Oldja, Biswas, Perin, Lee, Ahmed, et al., 2015; George, Oldja, Biswas, Perin, Lee, Kosek, et al., 2015; Headey & Hirvonen, 2016; Marquis et al., 1990; Ngure et al., 2013).

As an alternative to village poultry, we designed and implemented a novel poultry intervention utilizing semi-intensive egg production practices to increase the availability of eggs in communities in rural Zambia. This pilot aimed to evaluate the impact of an egg production centre (EPC) programme over its first year on (a) household egg acquisition, (b) egg consumption among young children (6–36 months of age), and (c) child height-for-age *z* score (HAZ). We hypothesized that, compared with control areas, households and children in communities with an EPC would be more likely to acquire and consume eggs after implementation of the programme but that there would be little to no effect on HAZ in the short follow-up time.

> **Key messages**
>
> - Household acquisition of eggs increased significantly as a result of the programme, particularly among households located closest to the EPCs and when egg production was high.
> - Children were significantly more likely to eat eggs as a result of the programme but only when egg production within the EPCs was high.
> - There was no impact on child HAZ in the first year of the programme.
> - Semi-intensive egg production practices may be a viable approach to increasing egg availability in some rural food systems, but programme delivery and system productivity should be refined and optimized to maximize benefits from replication or scaling up.

2 | METHODS

2.1 | Study setting

This research was conducted in rural farming communities of the Luangwa Valley (Appendix S2), located in Zambia's Eastern Province. Four traditionally defined areas, or chiefdoms, were purposively selected, and 24 rural communities within those chiefdoms were purposively selected to receive the pilot egg production intervention. Participating communities were selected by the implementing organization, Community Markets for Conservation (COMACO, a local non-governmental organization; www.itswild.org), based on their location within the COMACO intervention area, subjective evaluation of community need, and resource availability. Due to time and resource constraints, 20 of these 24 communities ("project areas") were randomly selected to participate in this impact evaluation. Twenty additional communities were identified by our implementing partner as suitable matched controls based on their Chiefdom and a subjective assessment of their size, density, and proximity to major roads, schools, markets, and protected areas, criteria deemed likely to affect local markets and food availability. Control areas were a median of 5.2 km from their matched project areas (range 1.6–17.5 km) and approximately 1 hr walking (range 26–210 min) to minimize risk of spillover.

2.2 | Programme description

A complete description of the programme, including training materials and protocols, is available elsewhere (Dumas, 2017). Briefly, four to five smallholder farmers from each of the 24 project areas were recruited as "egg producers" and were trained in hen health, biosecurity, food safety, and business management. Individuals were eligible for selection if they were members of a COMACO Poultry Producer group (focused on improving village chicken production), had a history of successfully adopting recommended agricultural practices, and were vulnerable to food insecurity and poverty based on the assessment of COMACO evaluators, itself incorporating input suggested from consultation with chiefdom or village leaders.

The design of the EPC was adapted from a previous, smaller pilot project in the area (Dumas et al., 2016). Each of the EPCs was stocked with 40 layer hens—considered to be a manageable number of hens for first-time egg producers, that would fit within a reasonably small facility, and yet would produce a reasonable number of eggs for the local markets—and egg production began in September 2015. During egg production, COMACO extension staff monitored production records and intervened where necessary to address production concerns; however, each of the egg producer groups worked together as the owners and operators of their EPC and were ultimately responsible for their own businesses, including marketing eggs, purchasing feed, and maintaining records. Egg prices were determined by each egg producer group based on the local market, but the most common egg price was 1 ZMW (~US$ 0.096).

2.3 | Data collection

In a repeated cross-sectional study design, data were collected at four time points selected to represent the dry and rainy seasons in the years prior to and during the intervention: June 2014 (Baseline 1; dry season; n = 906 households), December 2014 (Baseline 2; rainy season; n = 886), December 2015 (midline; rainy season; n = 885), and June 2016 (endline; dry season; n = 869). Distinct dry and rainy season evaluations were important because of pervasive food and income scarcity during the "hungry season," which coincides with the rainy season, and which was expected to significantly modify food acquisition and consumption. Each field site was marked with a GPS point; for project areas, this global positioning system (GPS) location was at the site of the EPC. A sampling frame of eligible households in each field site was generated through in-home visits. Inclusion criteria were (a) there was a child 6–36 months residing in the household, and (b) the dwelling was located ≤1.5 km from the field site GPS location. The 20 eligible households nearest to each field site GPS location were recruited and enrolled in the study, and all eligible children 6–36 months of age in enrolled households were included. The sampling and enrolment procedures were repeated at each of the four time points.

At each enrolled household, the research staff administered questionnaires over approximately 45 min, assessing household characteristics (household composition, asset ownership, food security, etc.) and the child's diet, animal source food consumption, recent morbidities, and breastfeeding history (WHO, 2010). Anthropometric measurements were then taken on both the child and his or her mother (weight, height or length, and mid-upper arm circumference) following standard procedures (Cogill, 2003). Height and weight measures were taken using standardized seca 872 electronic scales with mother or child function and seca 213 portable stadiometers (seca GMbH & Co., Hamburg, Germany). For both height and weight, two measures were taken; a third measure was taken if there was a difference of at least 0.5 kg or 1.0 cm between the first two measures (Cogill, 2003). The mean of the two most similar measures was defined as the child's height and weight. Data were collected by pairs of trained research staff, and responses were recorded either on paper forms (June 2014) or in GPS-enabled tablets using ODK Collect (v.1.4.10, Open Data Kit, https://opendatakit.org; all other time points).

2.4 | Outcome measures

We assessed the impact of the EPC programme on three outcomes of interest following our programme impact pathway. *Household egg acquisition* (Outcome 1) was operationalized as a dichotomous variable indicating whether or not anyone in the household consumed any eggs in the 7 days prior to the survey, as recalled by the mother of the eligible child. Because meals, especially for women and children, are typically consumed from a communal dish, determining the exact number of eggs consumed by an individual is difficult. Therefore, *children's egg consumption* (Outcome 2) was operationalized in a two-step process: first, as a dichotomous variable indicating that he or she did or did not consume any eggs in the 7 days prior to the survey and second, as the number of times that he or she consumed eggs over the past 7 days. This does not attempt to quantify the number of eggs consumed by an individual. A 7-day recall period, rather than 24 hr, was determined a priori to be most appropriate for both household and child egg consumption given the low average egg consumption in Zambia as a whole (3.3 kg per capita/year = 59 eggs per capita/year = 1.13 eggs per capita/week; FAO, 2013), a country that is significantly wealthier on average than the study area. *Children's nutritional status* (Outcome 3) was measured by HAZ, where the reference population was based on the WHO Child Growth Standards (WHO Multicentre Growth Reference Study Group, 2006).

2.5 | Covariates and descriptive variables

Household economic welfare was assessed with an asset index generated using principal components analysis, which collapses a large number of observed variables into a single measure (Filmer & Pritchett, 2001; Sahn & Stifel, 2003). The first component was retained as both a continuous variable and a categorical variable (low, medium, and high) to create a measure of relative household wealth (Appendix S3). Household food security was assessed by the Household Food Insecurity Access Scale (Coates, Swindale, & Bilinsky, 2007), a nine-item questionnaire that captures the frequency of experiences of inadequate household food access over the past month, scored from 0 (food secure) to 27 (severely food insecure).

Child morbidities were operationalized as dichotomous variables and included having any fever, diarrhoea (>3 stools in a day or abnormally soft or watery stool), vomiting, or rapid or difficult breathing with coughing in the past 14 days, as recalled by the child's primary caregiver (CSO et al., 2015), or malaria diagnosed by a health professional in the past 14 days. Caregivers were also asked questions about the child's breastfeeding and complementary feeding history, with questions and indicators following WHO recommendations (WHO, 2010).

At baseline, the child's mother or primary caregiver was asked multiple-choice questions (with response categories informed by qualitative formative research) about the household's primary source of eggs, travel time to that source, and barriers to more frequent egg consumption. To understand prevailing attitudes and beliefs about the social acceptability of eggs for particular individuals, they were asked to indicate their level of agreement with a series of statements using a 5-point Likert-type scale with a visual aid. They were also asked if "there are any people who are not supposed to eat eggs because of traditional or cultural reasons," and if so, who.

2.6 | Statistical analyses

Data were cleaned and analysed in Stata (Stata/IC version 14.0, StataCorp, College Station, Texas). Bivariate analyses were performed to identify differences between the treatment and control groups at baseline (considered significant if $p < 0.05$).

2.6.1 | Household egg acquisition

To investigate programme impact on household acquisition of eggs, the probability that a household consumed any eggs over the past 7 days was modelled using four-level random-intercept logistic regression with random-effects for chiefdom, matched field site pairs, and field site (i.e., community; Appendix S4). Level 1 covariates controlled for differences in household characteristics (Appendix S5). The interaction of time point and group (project vs. control community) was the "treatment effect" and preintervention and postintervention data were compared across the same season.

2.6.2 | Children's egg consumption

Because the frequency of children's egg consumption was highly zero inflated and right skewed, two-stage models were used (Afifi, Kotlerman, Ettner, & Cowan, 2007; Hu, Pavlicova, & Nunes, 2011). In the first stage, we used multilevel random-intercept logistic regression to model the probability that a child consumed any eggs in the past 7 days. To account for the survey design, random effects were included for chiefdom, matched field site pairs, field site, and household (Appendix S4). In the second stage, we conducted zero-truncated negative binomial regression to model the number of times a child ate eggs in the past 7 days within the subsample of those individuals who consumed any eggs. Stata does not support multilevel truncated negative binomial regression, so standard errors were clustered at the field site level, which had the largest variance component in the model fit in the first stage. In addition to geographic random effects, models at both stages included covariates at the level of the household, woman, and child (Appendix S5).

2.6.3 | Children's HAZ

To examine the impact of the intervention on children's HAZ, we fit multilevel mixed effect models using the maximum likelihood estimation method. To account for the survey design, nested random effects were included for chiefdom, field site pairs, communities, and households, and fixed effects were included to control for differences in household and individual characteristics (Appendix S5).

2.6.4 | Sample size calculation

The sample size for the survey at each time point was estimated to examine the impact on HAZ in children 6–36 months of age. The desired effect size was set at 0.33 standard deviations, which is smaller than the magnitude of the effect of a recent dairy intervention (0.54 standard deviations; Rawlins, Pimkina, Barrett, Pedersen, & Wydick, 2014) and approximately half the effect of a recent egg feeding trial on child HAZ (0.63 standard deviations; Iannotti, Lutter, Stewart, et al., 2017a). The sample size calculation considered a power of 80% and alpha of 0.05, with an estimated HAZ variance of 1.69. To adjust for geographic clustering, a design effect (DE) was included, where DE = 1 + ICC (n−1) (Rutterford, Copas, & Eldridge, 2015), and ICC = the intraclass correlation for HAZ in rural areas of low-income countries, estimated to be 0.035 (Fenn, Morris, & Frost, 2007). The sample size per cluster, n, was set at 20 children aged 6–36 months, deemed a reasonable number of children likely to live within 1.5 km of the EPC. This resulted in a required sample size of 405 children at each time point in each group (project and control), or 810 total children per time point and 3,240 children across all four time points.

2.7 | Ethical standards

All procedures, protocols, and research materials underwent an internal review process at the implementing organization, COMACO, and were approved by the Institutional Review Board at Cornell University (Protocol ID#: 1402004456). The study is registered at ClinicalTrials.gov (ID#: NCT02516852). Approval was obtained from area chiefs prior to initiating research activities, and all participants provided individual written informed consent at the time of enrolment. For illiterate participants, the interviewer read the consent forms in full, took a thumbprint from the participant, and acquired a witness signature confirming that informed consent was appropriately obtained.

3 | RESULTS

3.1 | Baseline characteristics

With few exceptions, the characteristics of children, mothers, and households in project and control areas did not differ significantly at Baseline 1 (Table 1). The preintervention characteristics of households and women did not vary meaningfully by season. However, in the rainy season, children were overall less likely to eat a minimally diverse diet (37.8% vs. 51.4%, $p < 0.001$), experienced fewer morbidities (75.4% vs. 90.3%, $p < 0.001$), and had lower weight-for-height z scores (0.10 vs. 0.29, $p < 0.001$).

Egg acquisition by households and consumption by children did not vary by group at baseline (Table 1). Eggs were mostly commonly sourced from the family's own flock of village chickens (48.0%) or purchased from road-side stalls (31.0%). Despite high prevalence of village chicken ownership, per capita household egg consumption was very low, and women cited cost and physical availability as the primary barriers to routine consumption of eggs in their household (Hong, Martey, Dumas, Young, & Travis, 2016). The majority of women liked eating eggs (94.0%), and they valued eggs primarily for their nutritional value (57.4%) and taste (20.1%). Most women agreed or strongly agreed that eggs are good for infants (91.8%) and young children (93.8%); slightly fewer agreed or strongly agreed that eggs are good for pregnant (82.3%) or lactating women (89.9%). Only 7.8% of women responded that they believed in taboos restricting egg consumption by certain individuals, most commonly pregnant women ($n = 41$).

3.2 | Outcome 1: Did households access more eggs as a result of the programme?

In project communities, the odds that a household acquired any eggs in the 7 days prior to the survey increased dramatically after

TABLE 1 Characteristics of participating households, women, and children in project and control communities in the Luangwa Valley at Baseline 1

	Baseline 1 (dry season)	
	Control	Project
Household characteristics	*n* = 390	*n* = 409
Household size, mean (±*SD*)	5.7 (2.0)	5.8 (2.1)
Female headed (%)	13.1	13.9
Head of household completed primary school (%)	56.0	61.3
Socio-economic status (tertiles of asset index)		
Lowest (%)	36.2	34.4
Middle (%)	33.9	33.9
Highest (%)	29.9	31.7
COMACO membership (%)	**21.9**	**40.1**
Any livestock ownership (%)	68.0	62.4
Chicken (%)	**64.4**	**55.5**
HFIAS, mean (±*SD*)	10.4 (6.9)	9.9 (6.6)
Food secure (HFIAS = 0), %	8.0	9.6
Mildly FI (1 ≤ HFIAS ≤9), %	37.3	39.2
Moderately FI (10 ≤ HFIAS ≤18), %	41.7	39.5
Severely FI (19 ≤ HFIAS ≤27), %	13.1	11.8
Number of eggs eaten, per capita in the past 7 days, mean (±*SD*)	0.6 (1.1)	0.6 (1.1)
Travel time to access eggs, mean minutes (±*SD*)	12.1 (17.5)	14.4 (23.2)
Women's characteristics	*n* = 396	*n* = 413
Age (year), mean (±*SD*)	27.9 (8.6)	28.1 (7.9)
Completed primary school (%)	**32.1**	**39.5**
Dietary diversity,[a] mean (±*SD*)	4.1 (1.2)	4.2 (1.3)
Underweight (%)	8.7	5.8
Overweight (%)	12.0	11.7
Children's characteristics	*n* = 426	*n* = 434
Age (months), mean (±*SD*)	20.1 (8.7)	20.3 (8.9)
Gender, % female	52.8	51.8
Dietary diversity,[b] mean (±*SD*)	3.6 (1.3)	3.7 (1.3)
Minimum dietary diversity met (6–23 months), %	47.3	55.6
Any eggs in past 7 days (%)	40.1	37.3
Number of times eating eggs, past 7 days, mean (±*SD*)	0.8 (1.3)	0.8 (1.3)
Currently breastfeeding (%)	50.5	47.7
At least one morbidity in past 2 weeks (%)	91.6	89.1
Fever (%)	**77.4**	**71.1**
Diarrhoea (%)	**56.6**	**49.0**
Malaria diagnosis (%)	54.2	47.7
HAZ, mean (±*SD*)	−1.76 (1.18)	−1.72 (1.18)
WHZ, mean (±*SD*)	**0.21 (1.18)**	**0.37 (1.02)**
WAZ, mean (±*SD*)	−0.77 (1.17)	−0.67 (1.05)
Stunted (<2 *SD* below mean) %	41.8%	39.1%

Note. Bolded values indicate that the test statistic for the chi-squared or *t* test is significant at $p < 0.05$. COMACO: Community Markets for Conservation; HAZ: height-for-age *z* score; HFIAS: Household Food Insecurity Access Scale; SD: standard deviation; WAZ: weight-for-age *z* score; WHZ: weight-for-height *z* score.

[a]Ranging from 0–9 food groups, based on the Women's Dietary Diversity Score (WDDS; Arimond et al., 2010; Kennedy, Ballard, & Dop, 2011).

[b]Ranging from 0–7 food groups, dietary diversity was defined here as the number of food groups consumed in the 24 hr prior to the survey, where the food groups were (a) grains, roots, and tubers; (b) legumes and nuts; (c) dairy products; (d) flesh foods; (e) eggs; (f) vitamin A-rich fruits and vegetables; and (g) other fruits and vegetables (WHO, 2010).

production began in the EPCs (Figure 1a and Table 2). By endline, 10 months after egg production began, the odds of household egg acquisition had decreased (likely due to depressed egg production at the time of the endline survey; Figure 2), but remained significantly higher compared to Baseline 1. In contrast, in control communities, the only significant change in the probability of egg acquisition

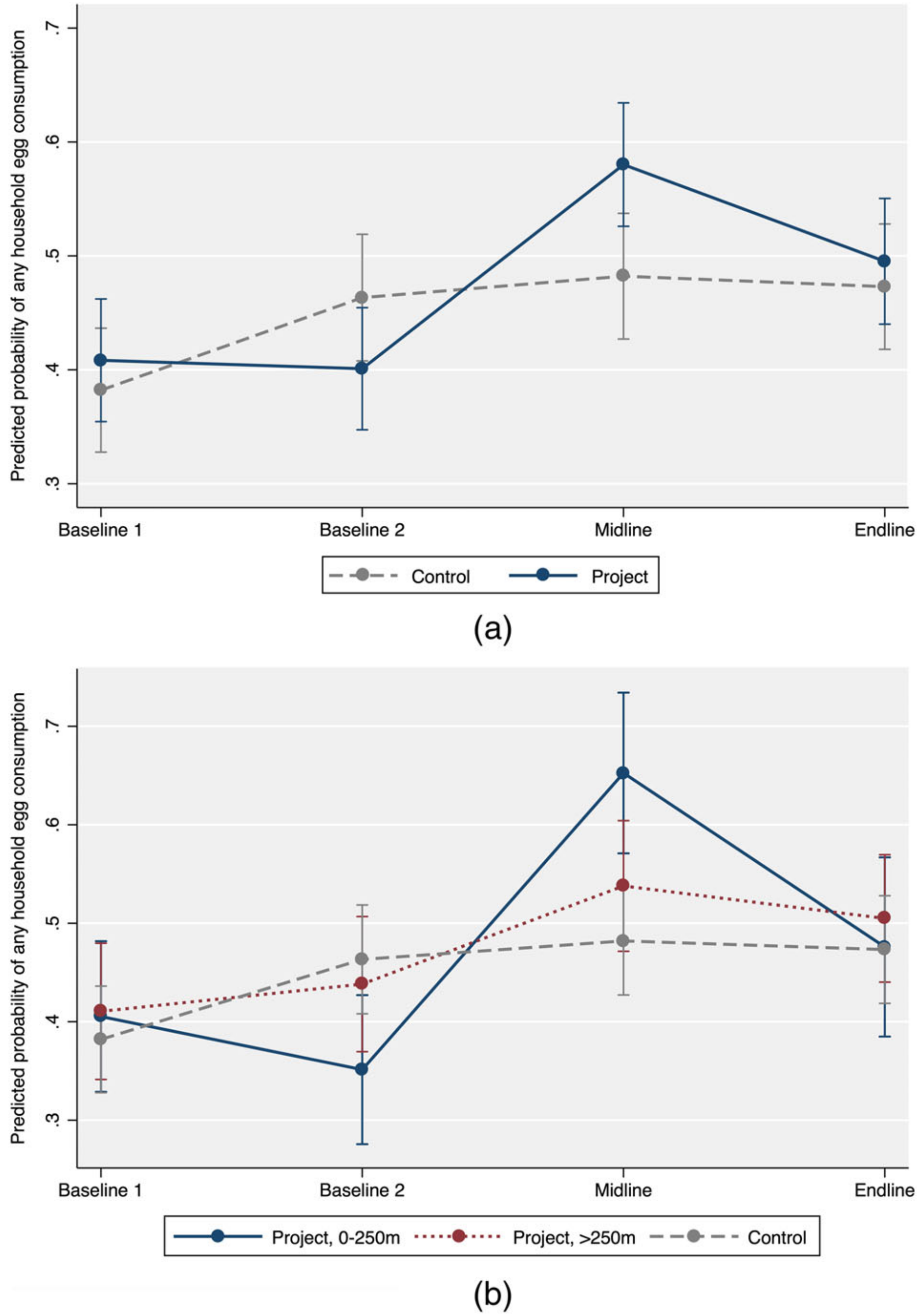

FIGURE 1 (a) Predicted probability and 95% confidence intervals of household egg acquisition in the 7 days prior to the survey in project (solid navy) and control (dashed grey) communities. (b) Predicted probability and 95% confidence intervals of household egg acquisition in the 7 days prior to the survey in households in project communities within 250 m of an egg production centre (EPC) (solid navy), in households in project communities greater than 250 m from an EPC (dotted maroon), and control (dashed grey) communities with no EPC

occurred between the two baseline time points and can therefore not be attributed to the programme.

Within project communities, there were significant differences in the impact of the intervention on household egg consumption based on their proximity to the EPC (Figure 1b). At midline, households located within 250 m of the EPC were significantly more likely to consume eggs than households in control communities (OR 2.03, 95% CI [1.03, 2.16]), whereas households located greater than 250 m from the EPC were not. By endline, however, there was no difference between either group and the control.

3.3 | Outcome 2: Did the programme increase children's egg consumption?

In project communities, but not control communities, the odds that a child consumed any eggs increased significantly from Baseline 2 to midline after the start of the EPC programme (Figure 3a and Table 2). There was no significant difference in the odds of children's egg consumption at endline relative to Baseline 1 in either group. In contrast to analyses at the household level, the odds of children's egg consumption within project areas did not significantly differ by

TABLE 2 Odds ratios and contrasts comparing the four outcomes of interest at each time point in project versus control areas ("project versus control") and within group over time ("project areas" and "control areas")

	Household egg acquisition		Children's egg consumption				Children's HAZ	
	OR	95% CI	OR	95% CI	β[b]	95% CI	β[c]	95% CI
Project versus control								
Baseline 1[a]	1.12	0.82, 1.53	0.66	0.35, 1.24	−0.04	−0.30, 0.22	0.01	−0.19, 0.21
Baseline 2[a]	0.77	0.57, 1.05	0.63	0.35, 1.18	−0.20	−0.50, 0.10	0.02	−0.18, 0.22
Midline	**1.49**	**1.10, 2.03**	**2.29**	**1.22, 4.29**	0.02	−0.27, 0.31	−0.06	−0.26, 0.14
Endline	1.09	0.81, 1.48	1.57	0.84, 2.90	−0.20	−0.49, 0.08	−0.12	−0.32, 0.08
Project areas								
Rainy season (midline vs. Baseline 2)	**2.08**	**1.56, 2.78**	**5.53**	**2.90, 10.58**	**0.59**	**0.31, 0.87**	−0.16	−0.33, 0.01
Dry season (endline vs. Baseline 1)	**1.41**	**1.06, 1.88**	1.42	0.79, 2.54	0.27	−0.09, 0.62	0.07	−0.11, 0.25
Control areas								
Rainy season (midline vs. Baseline 2)	1.07	0.80, 1.43	1.52	0.85, 2.72	**0.37**	**0.02, 0.71**	−0.08	−0.26, 0.10
Dry season (endline vs. Baseline 1)	**1.45**	**1.08, 1.94**	0.60	0.33, 1.09	**0.43**	**0.21, 0.66**	**0.20[d]**	**0.02, 0.38**

Note. HAZ: height-for-age *z* score; OR: odds ratio; CI: confidence interval.

[a]Two baseline evaluations were conducted to control for the effect of season of food acquisition and consumption in this region. "Baseline 1" is the preintervention survey conducted in the dry season (2–4 months after harvest). "Baseline 2" is the preintervention survey conducted in the rainy season (8–10 months after harvest), also commonly referred to as the "hungry season" because of food and resource scarcity.

[b]β is the estimated difference in the mean frequency of egg consumption in the past 7 days, among those children consuming any eggs, between the two groups being compared in the row.

[c]β is the estimated difference in mean children's HAZ between the two groups being compared in the row.

[d]Although significant, these changes are unlikely to be as a result of the egg production centre (EPC) programme.

[e]Bolded values indicate that the OR or beta is statistically significant at $p<0.05$.

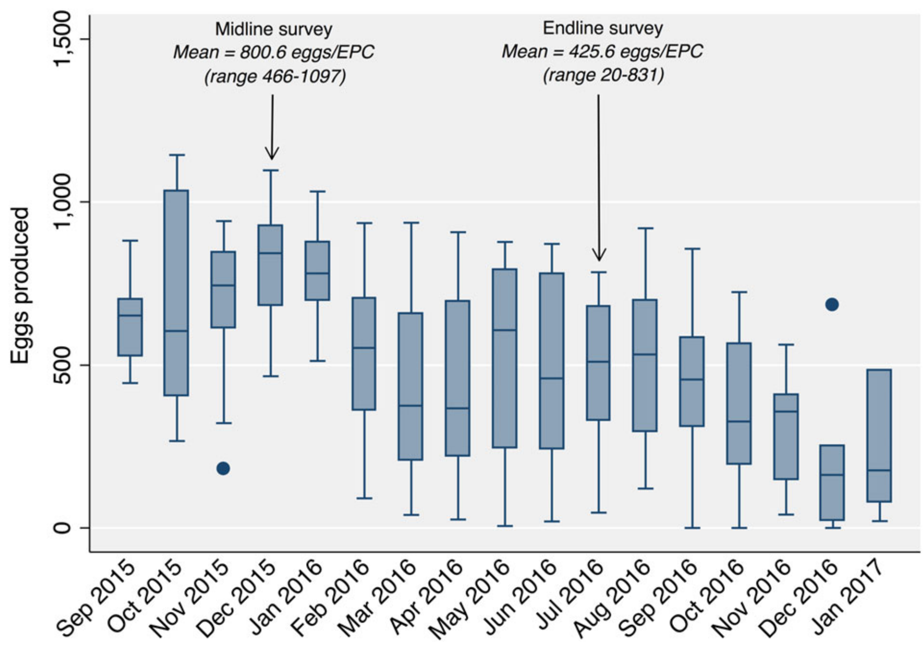

FIGURE 2 Total number of eggs produced per month in 16 egg production centres (EPCs). Production data excludes the four EPCs in Mwanya, for which insufficient records were available. Anecdotally, three of these four EPCs had very low production throughout the year. Arrows indicate the months that midline and endline surveys were conducted

proximity of the household to the EPC. Among children consuming any eggs, the *frequency* of egg consumption in the past 7 days increased from Baseline 2 to midline in both project and control communities (Figure 3b and Table 2), before returning to approximately baseline levels at endline, as egg production declined.

3.4 | Outcome 3: Did the programme affect children's HAZ?

Mean children's HAZ did not differ between those living in project and control communities at any of the four time points (Table 2), and there

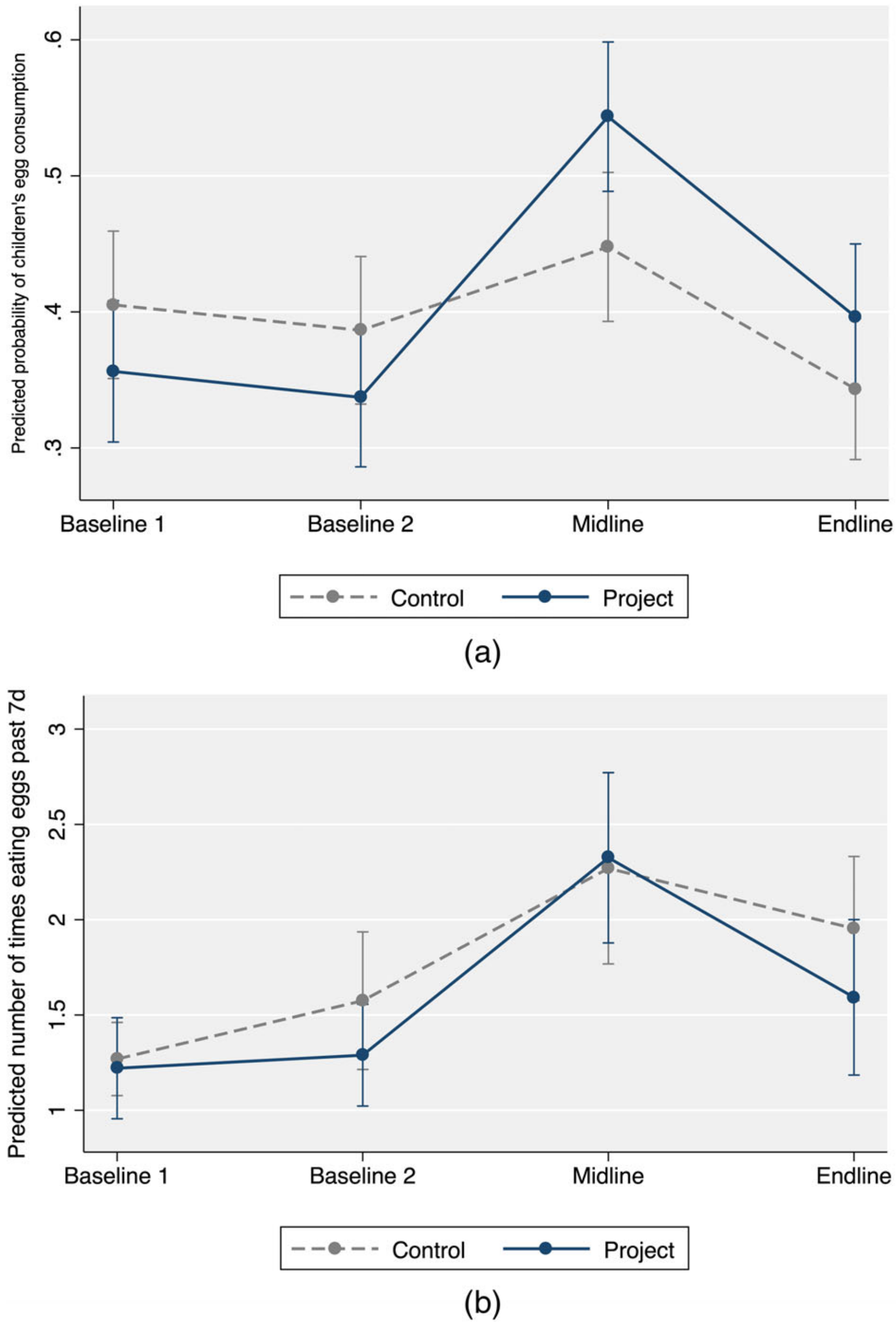

FIGURE 3 (a) Predicted probability and 95% confidence intervals of any child egg consumption in the 7 days prior to the survey in project (solid navy) and control (dashed grey) communities. (b) Among those consuming any eggs, predicted number of times children consumed eggs in the 7 days prior to the survey, in project and control communities

was no significant change in HAZ over time that could be attributed to the project.

4 | DISCUSSION

In summary, the EPC pilot programme in rural Zambia successfully increased household acquisition of eggs and their consumption by young children in participating communities. However, programme impact was significantly attenuated by endline due to declining egg production in EPCs. The greatest impact on household egg acquisition was among households located within 250 m of an EPC, but distance did not modify the impact of the programme on children's egg consumption. Interestingly, although the programme successfully increased the *odds* of egg consumption among children living in project versus control communities, there was no difference in their *frequency* of egg consumption. There was no evidence for programme impact on child HAZ.

Existing research on the use of small-scale egg production to improve diets in rural, low-income communities has focused entirely on village chickens (Iannotti et al., 2014). Unfortunately, village chickens are unlikely to effectively and sustainably deliver eggs to children in rural, low-income households because of a combination of factors. First, village chickens experience high flock mortality because of disease, poor management, or predation (Gueye, 2000a). Second, among those that survive to maturity, indigenous chickens have limited genetic potential for egg production, with hens laying 20 to 80 eggs per year compared with over 300 eggs per year for layer hens (Gueye, 2000a; Wong et al., 2017).

Third—perhaps most importantly—as a means of offsetting high flock mortality, smallholders have repeatedly demonstrated a preference for allowing eggs from village chickens to hatch rather than consuming them at home (de Bruyn et al., 2017; Dumas et al., 2016; Dumas et al., 2017; Gueye, 2000a; Olney et al., 2013). The multipurpose utility of poultry (as a source of food, income, and resilience in the face of shocks) requires a daily cost–benefit analysis on the part of the smallholder, who must weight the many demands of their household in the face of limited resources (Pell & Kristjanson, 2017). Thus, although appropriate interventions in the village chicken system can increase productivity and profitability, there is limited evidence to date that they have successfully increased child ASF consumption, dietary quality, and/or growth and development (Appendix S1). At the other end of the production spectrum, commercial egg production is largely found in peri-urban areas to serve the larger (and wealthier) urban markets, with limited penetration of fresh, quality eggs to poorer, rural areas. The limitations of these two most common poultry systems therefore demand a novel approach for delivering eggs to the children most likely to benefit.

In response to this, the EPC model uniquely aims to improve the local food environment in rural, low-income communities. Additionally, previous research in similar settings has focused exclusively on the impact of poultry programmes on consumption of ASF *by the programme beneficiaries*. To our knowledge, the current study is the first to examine the effect of a poultry intervention on the diets and nutrition outcomes of the potential customers—families living in the surrounding community who were not direct beneficiaries of the programme. Because the intervention is market driven and the primary consumers are those living around the EPC, this model may be an economically sustainable approach to changing the local food environment to the benefit of the entire community while providing inputs (training, technology) to relatively few individuals.

Due to resource and time constraints, the follow-up time for the impact evaluation was just 1 year. This short time frame does not match the lengthy pathway from programme implementation to improved nutritional status and growth expected for nutrition sensitive programmes, which likely requires at least 1,000 days of programme exposure to achieve *full* impact (Leroy et al., 2016). Nonetheless, an egg feeding trial in Ecuador recorded significant effects on child length-for-age *z* scores after just 9 months of follow-up (Iannotti, Lutter, Stewart, et al., 2017a), suggesting that a larger "dose" of egg consumption (one egg per day, in the case of the Ecuador trial) is required to affect child growth and that the relatively modest increase in egg consumption as a result of the EPC programme was insufficient.

This may in part be because the evaluation was conducted in the first year of the pilot programme, during which time only 40 hens were placed in each EPC, and egg production was suboptimal, particularly at endline. Decreased egg production over time is expected as hens age, but in many EPCs, production was below expectations throughout the year because of production challenges (Dumas, 2017). These included difficulty in consistently accessing layer feed, suboptimal husbandry and management practices in some EPCs, excessive ambient temperatures, and an inability to increase egg prices in response to rising feed costs (Dumas, 2017). As a result, there were fewer eggs available in project communities than initially expected and demand often exceeded supply. Nonetheless, some EPCs met performance benchmarks (Dumas, 2017), indicating that the programme can be successful in this setting with appropriate management. Prior to replication, the lessons learned from this project, detailed at length elsewhere, need to be integrated into training and monitoring protocols to maximize productivity of the EPCs (Dumas, 2017). Additionally, market research is needed to analyse demand, market size, and buyer behaviours (e.g., distance people will travel to buy eggs at an EPC, frequency of egg consumption) such that EPCs can be built and stocked appropriately to meet market demand. A repeated evaluation after the programme has reached its highest level of quality or production that the system can support is warranted.

Although this study has many strengths in its design, including controlling for season and analysing intermediate outcomes, a cluster randomized controlled trial was not possible due to COMACO's internal programme goals and resource availability. Project areas were purposively selected, and matched control areas were selected based on a subjective assessment of their characteristics, a process that produced adequate but not ideal counterfactuals based on observed characteristics. We attempted to control for these differences in our models; however, there are also likely differences between the groups that were not observed or controlled, resulting in biased estimates.

These limitations notwithstanding, the EPC programme investigated here adds to the empirical evidence for a link between livestock development programmes and child nutrition outcomes. Although not measured in this paper, the model may also address some of the drawbacks and pitfalls of previous livestock interventions: (a) by distributing inputs to groups of farmers rather than households, it may avoid contributing to women's time poverty; (b) it can limit children's exposure to zoonotic pathogens by operating within a confined poultry system and training EPC members in proper hygiene practices; and (c) it was integrated with extension support that provided programme beneficiaries with access to feed, vaccination and veterinary services, and ongoing support to limit catastrophic losses. Improvements to the programme should consider the "lessons learned" in this pilot (Dumas, 2017) to optimize productivity of the EPCs and ensure the local market demand is met. Integration with a nutrition education programme should also be considered, an approach that the literature suggests may maximize the impact of livestock interventions on nutrition outcomes (Leroy & Frongillo, 2007; Randolph et al., 2007). Given the positive short-term impact of the programme on egg consumption among children when egg production was high, we encourage continued evaluation of the programme to investigate the model's long-term potential to improve dietary quality, micronutrient adequacy, women's empowerment, and child growth and development after the model has been optimized.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

S.E.D. was responsible for research design, project administration, research methodology, data collection, database management, data analysis and data visualization, funding acquisition, and initial drafting of the manuscript. D.L. contributed to project administration, study design, and critical reviewing and editing of the manuscript. A.J.T. contributed to research design, project administration, research methodology, funding acquisition, supervision of all research activities, and critical reviewing and editing of the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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