EVALUATING THE IMPACT OF POULTRY INTERVENTIONS ON MATERNAL AND CHILD NUTRITION OUTCOMES IN THE LUANGWA VALLEY, ZAMBIA

A Dissertation

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

by

Sarah Elise Dumas

December 2017

EVALUATING THE IMPACT OF POULTRY INTERVENTIONS ON MATERNAL AND CHILD NUTRITION OUTCOMES IN THE LUANGWA VALLEY, ZAMBIA

Sarah Elise Dumas, Ph.D.

Cornell University 2017

Worldwide, approximately 156 million children under five are stunted because of chronic undernutrition. Animal source foods (ASF) can improve children's dietary quality, micronutrient intake, and nutrition outcomes, but ASF are often inaccessible and unaffordable for the most vulnerable children. Livestock interventions can increase the accessibility of ASF in remote, low-income communities, but evidence that they effectively improve child nutrition remains inconclusive. We therefore aimed to examine the association between household livestock ownership and child nutrition outcomes and evaluate the impact of two targeted poultry interventions in rural communities in the Luangwa Valley, Zambia.

First, we utilized multiple data sources to assess the impact of interventions addressing health and management constraints in the existing "village chicken" production system. Our analyses revealed that the interventions resulted in improved flock sizes and profits, but had no impact on household consumption of chickens or eggs, because farmers preferred to sell chickens. Then, in a large cross-sectional survey, we similarly found that owning livestock managed in traditional systems was not associated with improved dietary or nutrition outcomes among children. Building off these studies, we implemented a novel, market-based intervention supporting egg production centers (EPCs) in 24 communities. Using mixed methods, we found that, despite programmatic challenges, the EPCs could be adequately productive and profitable,

widely acceptable to participants, and practical to implement in most rural communities in the Luangwa Valley. Finally, in an impact evaluation, we found that the EPC program successfully increased the acquisition and consumption of eggs by households, women, and young children in participating communities.

In this dissertation, we took a comprehensive and stepwise approach, utilizing conceptual frameworks and program impact pathways to identify and test underlying assumptions and intermediate outcomes on the hypothesized pathway from livestock to child nutrition. We suggest that the novel EPC program could function as one component of an integrated nutrition intervention to enhance access to, and consumption of, high-quality ASF in vulnerable households. Our results contribute to the growing evidence that livestock can enhance child nutrition and point to a new approach for livestock interventions and evaluations that focuses on impact at the community-level.

BIOGRAPHICAL SKETCH

Originally from Portland, Oregon, Sarah Elise Dumas completed her undergraduate degree in biology (pre-medical track) at Pomona College in Claremont, California where she received distinction for her senior thesis on the role of the FoxO transcription factor in controlling lifespan in the *Hydra vulgaris*. Through extensive coursework in political science, Sarah became interested in the important roles of public policy and food systems in ensuring human health, and, with the aim of dedicating herself to achieving optimal health and wellbeing for the greatest number of people, she decided to pursue a career in public health.

Sarah studied mixed animal medicine at Cornell University College of Veterinary Medicine, where she was introduced to the concept of "One Health" – the framework that recognizes that human health is intricately linked to the health of the environment and the animals around them. During veterinary school, she worked extensively in Kenya and Zambia (with International Livestock Research Institute and Community Markets for Conservation, respectively) on projects that aimed to improve rural livelihoods and reduce natural resource degradation through the sustainable development of smallholder livestock systems. Sarah was awarded the Leonard Pearson Veterinary Prize for academic and professional leadership upon her graduation from Cornell in 2012 and practiced farm animal medicine and surgery for a year in the University of Illinois' Rural Animal Health Management program.

Sarah returned to Cornell University in Fall 2013 to pursue her PhD in Comparative Biomedical Sciences, with a focus on epidemiology and nutrition, to develop research and practices skills relevant to public health, including design, implementation, and evaluation of nutrition-sensitive strategies to support livestock development in vulnerable communities.

For Sarrah

ACKNOWLEDGEMENTS

I am grateful to the members of my special committee for their support and guidance. Alex Travis has served as my mentor since the fall of 2008, my first year in veterinary school, when he took me on as a summer research student and sent me to Zambia through Cornell's Expanding Horizons program. Whereas most Expanding Horizons projects are completed in a single 2-3 month trip, Alex encouraged me to continue my research in Zambia throughout veterinary school, and his dedication and enthusiasm to the project inspired me to return to Cornell for my doctoral studies to continue working on it. As an adviser and mentor, Dr. Travis has been patient and supportive, challenging me to improve myself, develop my strengths, and explore new opportunities. I have no doubt that he is truly committed to the advancement of my career and development of my knowledge and skills, and I am truly indebted to him for his vision, encouragement, and advice throughout the years.

Becky Stoltzfus and Sera Young generously invited me into their respective research groups, and the relationships I built and knowledge I gained in those meetings were instrumental to my development as a researcher. I sincerely value the time I spent in those meetings, learning, sharing, and getting insightful feedback from Becky, Sera, and the amazing group of graduate students, staff, and colleagues they work with. Sera also challenged me to develop qualitative research skills, then gave me the perfect balance of independence and support to design a small substudy within her project in Kenya exploring the perceived role of gender on livestock ownership, investments, and benefits among female smallholder livestock keepers. Yrjö Gröhn was generous with his time and was always willing to share his deep knowledge of epidemiological methods and provide guidance and feedback on my work.

This research would not have been possible without the incredible support of my friends and colleagues in Zambia, including: Luke Lungu, Nathan Mulmabya, Kelvin Kasongo, Smith Kapeya, Whiteson Daka, Joel Ngumayo, Mary Tembo, Moses Njobvu, Major Lungu, and Isaac Mbuzi at COMACO; Joseph Mumba and Peter Ng'ona at CARE Zambia; and the doctors, nurses, and staff of the Masumba Rural Health Centre. I am especially indebted to Dale Lewis, founder and President of COMACO, for believing in this project and dedicating the time, staff, and resources to help make it a reality. Thank you also to my field research staff: Ruth Ngoma, Chiefundo Jere, Matthews Mwanza, Margaret Zulu, Jannet Mwanza, Lucky Ulaya, Jonathan Jumbe Mwale, Obed Mulambya, Riston Mbewe, Vidah Phiri, Anderson Chulu, Mostafa Makawa, Samuel Kasaro, Suwilo Mulambya, Zagwa Zulu, Noah Tembo, Janet Ndashe, Brenda Tembo, Zondwase Ziba, and Augustine "Tobias" Banda. I am fortunate to have worked with such an enthusiastic, dedicated, and thoughtful team of young researchers. Thank you to Senior Chief Nsefu, late Chief Jumbe, Chief Mnkhanya, and Chief Mwanya for graciously allowing me to work within their communities. Of course, I am incredibly grateful for the members of the egg producer groups and our research participants for their time, patience, and interest in this project.

I have relied heavily on the resources at Cornell. I am very grateful to Benjamin Lucio-Martinez, Jarra Jagne, Karel "Ton" Schat, and Ricardo de Matos for their many lessons on poultry medicine and production. The amazing statisticians at the Cornell Statistical Consulting Unit, in particular Françoise Vermeylen, Kevin Packard, and Stephen Parry guided me through the complex statistical analyses presented here and answered my many questions with patience. I am grateful for the administrative support at the College of Veterinary Medicine and the Baker Institute, who helped me to navigate the logistics of conducting research across continents, including: Arla Hourigan and Cindy Grey at the Office of Graduate Education at the College of

Veterinary Medicine; Grants and Contracts Officers Kimberly Hayes, Teresa Griffin, and Bonnie Coffin; Cathy Lee and Vonda Royce at the Accounting Service Center at the College of Veterinary Medicine; and Jacque Nelson-Harrington of the Travis Lab. Thank you also to Dave Lin, Director of Graduate Studies in the field of Comparative Biomedical Sciences, for his support and patience as I explored research questions far outside of what is "typical" for the field. Undergraduate researchers Abena Maranga, Emily Martey, Josephine Hong, Lea Kassa, Paige Killelea, Lauren Blacker, and Elise Pajak all directly or indirectly contributed to this work. Special thanks to Roseanne Schuster, Stephanie Martin, Marianne "Vicky" Santoso, and all the Department of Nutritional Sciences students and faculty who made me feel so welcome at DNS.

This research was supported by the Atkinson Center for a Sustainable Future, with supplementary funding from the Mario Einaudi Center for International Studies, the Cornell University Graduate School, and the College of Veterinary Medicine. The research reported in this publication was additionally supported by the Office of the Director, National Institutes of Health of the National Institutes of Health (NIH) under Award Number T32 OD011000 (Graduate Program in Comparative Medicine training grant, PI: John Parker) and the NIH Loan Repayment Program. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Center for Research Resources or the National Institutes of Health. I would never have made it here if it were not for the opportunities afforded me by the College of Veterinary Medicine's Expanding Horizons Program, which is made possible by the generosity of the Lincoln Ellsworth Foundation, Ton Schat, the John F. Whitefield '65 Memorial Fund, the Alumni Association, and other charitable donors.

Finally and most importantly, I would like to express my love and gratitude to my family for their encouragement, support, and perspective over the past four and a half years – and in all

the years leading up to today. Thank you especially to my wife, Sarrah, who endured my extended absences, served as a confidant and much needed outlet, and provided me strength and steadiness. I could not have done this without you.

TABLE OF CONTENTS

Biographical Sketch iii

Acknowledgements v

List of Appendices x

List of Abbreviations xi

Chapter 1: Introduction and literature review 1

Chapter 2: Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia 58

Chapter 3: Examining the association between livestock ownership typologies and child nutrition in the Luangwa Valley, Zambia 89

Chapter 4: Assessing the productivity, profitability, producer satisfaction, and programmatic challenges of small-scale egg production centers in rural Zambia 125

Chapter 5: Do small-scale egg production centers in rural Zambia enhance maternal and child egg consumption and dietary diversity? 167

Chapter 6: Conclusion 225

LIST OF APPENDICES

Appendix 1: Regional vulnerabilities in the Luangwa Valley, Zambia.................................... 246

Appendix 2: Details of the various sources of data for assessing the impact of improvements in extensive village poultry production and semi-intensive egg production pilot..... 249

Appendix 3: Summary of previous observational research on the link between livestock ownership and child nutrition outcomes in sub-Saharan Africa. 251

Appendix 4: Data collection instruments – Example 255

Appendix 5: Variances and model diagnostics from null and adjusted models for the four outcomes of interest. 270

Appendix 6: Multilevel mixed-effects linear and logistic regression models assessing the relationship between child nutrition outcomes and livestock ownership 271

Appendix 7: Egg Production Center: Building Plan and Budget 273

Appendix 8: Monthly Egg Production and Sales Record 275

Appendix 9: Missing production and sales records 276

Appendix 10: Level-2 variables considered as covariates in a polynomial random-coefficient model of egg productivity 277

Appendix 11: Luangwa Valley Annual Egg Producer Interview Guide (Form 6) 279

Appendix 12: Average temperatures and precipitation in Mfuwe, 1961 - 1990 281

Appendix 13: Variables included in the computation of the asset index, derived from the first principal component arising from principal components analysis (PCA). 282

Appendix 14: Descriptions of the Level-1 and Level-2 covariates included in models for each outcome of interest. 283

Appendix 15: Total number of eggs produced per month in 16 EPCs 286

Appendix 16: Predicted probability of children's consumption of each food group................. 287

Appendix 17: Proportion of children aged 6-36 months who consumed animal source foods .. 289

LIST OF ABBREVIATIONS

ASF	animal source foods
BMI	body mass index
CDDS	children's dietary diversity score
CI	confidence interval
COMACO	Community Markets for Conservation
DDS	dietary diversity score
DHS	Demographic and Health Surveys
EPC	egg production center
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
HAZ	height-for-age z-score
HCZ	head circumference z-score
HFIAS	Household Food Insecurity Access Scale
HH	household
HHS	Household Hunger Scale
HKI	Helen Keller International
ICC	intraclass correlation
K	Zambian kwacha (1 K = US$ 0.096, on average)
LAZ	length-for-age z-score
MUAC	mid-upper arm circumference
ND	Newcastle disease
NM	not measured
ODK	Open Data Kit
OR	odds ratio
PCA	principal components analysis
p.p.	percentage points
RCT	randomized controlled trial
RDA	recommended dietary allowance
SD	standard deviation
SES	socioeconomic status
TLU	Tropical Livestock Unit
UNICEF	United Nations Children’s Fund
USAID	United States Agency for International Development
WASH	water, sanitation and hygiene
WAZ	weight-for-age z-score
WDDS	Women’s Dietary Diversity Score
WHO	World Health Organization
WHZ	weight-for-height z-score

CHAPTER 1

Introduction and literature review

Worldwide, approximately 156 million children under the age of five are stunted as a result of chronic undernutrition (de Onis & Branca, 2016; UNICEF, WHO, World Bank, 2016), and most of these children live in low- and lower-middle-income countries in Africa and Asia (UNICEF et al., 2016). Stunting, defined as having a length/height-for-age z-score (HAZ) more than 2 standard deviations below the WHO Child Growth Standard median (WHO Multicentre Growth Reference Study Group, 2006), is a well documented risk factor for poor child development. It is associated with poor motor development, poor cognitive function and school performance, poor immune function, increased hazard of death from infectious disease, and decreased economic productivity in adulthood (Adair et al., 2013; Black et al., 2013; de Onis & Branca, 2016; Victora et al., 2008). Almost all stunting occurs in the “First 1000 Days” from conception to two years of age, and its long-term effects on cognitive and physical development are considered to be largely irreversible (Black et al., 2013; de Onis & Branca, 2016).

As described by the UNICEF framework of child malnutrition, the causes of stunting are complex and multifactorial, including basic (e.g. national economic development, political leadership), underlying (e.g. household food security, caregiver capacity, maternal education, household water source), and immediate causes (e.g. dietary intake and disease) (Black et al., 2013; 2008; UNICEF, 1990). A recent WHO conceptual framework entitled “Childhood Stunting: Context, Causes and Consequences” builds on the UNICEF framework to emphasize inadequate complementary feeding of infants and young children as a particularly important cause of stunted growth and development (Stewart et al., 2013). Dietary quality is highly predictive of adequate micronutrient intake (Kennedy et al., 2007; Steyn et al., 2007) and growth

(Arimond & Ruel, 2004; Steyn et al., 2007), and it is especially important for young children, for whom both the demand for nutrients to support growth and the burden of infectious diseases are high (Arimond & Ruel, 2004; Black et al., 2008).

Importance of animal source foods in child nutrition outcomes

Animal source foods (ASF), including meat, milk, eggs, and fish, are energy- and lipid-dense foods that provide highly bioavailable amino acids, minerals, and vitamins. Compared to a plant-based diet, a diet including ASF will generally contain more calcium, zinc, choline, vitamins A, D, and E, and riboflavin; additionally, heme iron and vitamin B12 are found only in ASF (Allen, 2012; Murphy & Allen, 2003). As such, ASF are a more efficient mechanism for meeting children's micro- and macronutrient requirements than are plant source foods, as relatively small amounts of ASF can make large contributions to a child's micronutrient intake (Table 1.1; (Allen, 2003; 2012; Dror & Allen, 2011; Murphy & Allen, 2003; Neumann et al., 2002)). Indeed, there is strong evidence that the incorporation ASF into the regular diets of young children can improve dietary quality, micronutrient intake, and nutrition outcomes (Table 1.2).

Table 1.1. Nutrient content of a single serving of various animal source foods (ASF) compared to the recommended dietary allowances (RDAs) for children aged 12 – 36 months.

Nutrient	RDAs per day [a]	Milk, whole, unfortified (1 cup or 244 g) [b]	Egg, cooked, hardboiled (1 large or 50 g) [b]	Beef, medium fat (3 oz or 85 g) [b]	Fish, tilapia (3 oz or 87 g) [b]
Energy (kcal)	865 – 1129 [c]	149	78	212	109
Protein (g)	13	7.69	6.29	22.04	22.30
Total lipid (g)	ND [d]	7.93	5.30	13.10	2.26
Carbohydrates (g)	130	11.71	0.56	0.0	0.0
Vitamins					
Vitamin A, RAE (µg)	300	112	74	3	0
Thiamin (mg)	0.5	0.11	0.03	0.04	0.08
Riboflavin (mg)	0.5	0.41	0.56	0.15	0.06
Niacin (mg)	6	0.22	0.03	4.57	4.05
Vitamin B6 (mg)	0.5	0.09	0.06	0.33	0.11
Vitamin B12 (µg)	0.9	1.10	0.56	2.24	1.59
Folate (µg)	150	12	22	8	5
Choline (mg)	200 [e]	34.9 [f]	113 [f]	70.5 [f]	35.7 [f]
Vitamin D (D2 + D3, µg)	15	3.2	1.1	0.0	3.2
Vitamin E (mg)	6	0.17	0.52	0.10	0.67
Minerals					
Calcium (mg)	700	276	25	15	12
Iron (mg)	7	0.07	0.59	2.21	0.59
Magnesium (mg)	80	24	5	18	29
Phosphorus (mg)	460	205	86	168	174
Selenium (µg)	20	9.0 [f]	15.4 [f]	17.9 [f]	45.6 [f]
Zinc (mg)	3	0.90	0.53	5.36	0.35

Notes: [a] Source: Institute of Medicine Dietary Reference Intakes Tables, available at www.nationalacademies.org/hmd/Activities/Nutrition/SummaryDRIs/DRI-Tables.aspx [b] Source: USDA Food Composition Database, except where otherwise noted. [c] Estimated for healthy, well-nourished children (Torun, 2005). [d] ND = Not determined. [e] Adequate intake (AI) is presented. This is the amount believed to cover the needs of all healthy children in this age group, but insufficient data prevent calculation of an RDA. [f] Source: Nutrition Data, accessible at www.nutritiondata.com.

Table 1.2. Evidence linking animal source food (ASF) consumption and child nutrition outcomes in low- and lower-middle-income countries

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Observational studies, by year				
Graham et al., 1981 (Peru)	Cross-sectional; sampling strategy not described	2 – 19 yr (n=123)	Height, weight	Percentage of protein from ASF and fat were significantly associated with height and weight, especially in males
Sigman et al., 1991 (Kenya)	Longitudinal study; non-random sample (NCRSP)	18 – 30 mo at enrollment (n=83)	Cognition at 5 yr	ASF intake at 18-30 mo was associated with higher cognitive scores at 5 yr
Walker et al., 1990 (Jamaica)	Case-control; non-random sampling from purposively selected (poor) communities	Stunted (n=129) and non-stunted children (n=62), 9 – 24 mo	Stunting	• Stunted children ate significantly fewer dairy products (1.5 vs. 2.0; p<0.01) • Stunted children ate fewer meat, fish, and eggs (1.0 vs. 1.5) but difference was not significant
Allen et al., 1992 (Mexico)	Longitudinal study; non-random sample (NCRSP)	18 mo at enrollment (n=67)	Weight, length	Total energy and protein intakes were not correlated with height or weight, but energy and protein from ASF were positively associated with both
Allen, 1993 (Egypt, Kenya, and Mexico)	Longitudinal study; non-random sample of all eligible HHs from purposively selected cluster of communities (NCRSP)	Initially: • Pregnant women (n~300); • 18 mo (n~300); or • 7 – 8 yr (n~300)	Numerous, including growth, psychological development, birth outcomes, child behavior, and morbidity	• ASF intake was associated with higher dietary quality and micronutrient intake among children • Maternal intake of ASF during pregnancy and lactation positively predicted birth weight, birth length, and infant growth from 0 to 6 mo • Total ASF intake in Kenya and meat intake in Mexico positively predicted growth of pre-school aged children • ASF intake was positively associated with cognitive function at various ages in young children
Marquis et al., 1997 (Peru)	Longitudinal surveillance study; two-stage random sample	12 mo at enrollment (n=107)	Linear growth between 12 and 15 months of age	Higher ASF intake was associated with improved growth in children who were weaned, infrequently breastfed, or had low intakes of complementary food

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Gittelsohn et al., 1997 (Nepal)	Case-control study; cases identified by community-based screening	Previously xerophthalmic (n=78) and non-xerophthalmic (n=78) children; 1 – 6 yr	Xerophthalmia due to vit A deficiency	• Consumption of any meat (OR= 0.09, 95% CI= 0.01 – 0.70), any fish (OR= 0.41, 95% CI= 0.17 – 0.99), or occasional eggs (OR= 0.11, 95% CI = 0.01 – 0.88) in the first 2 years of life was protective from xerophthalmia • Consuming an "animal flesh" diet pattern in the second year of life was protective from xerophthalmia (OR = 0.43, 95% CI= 0.20 – 0.94)
Leonard et al., 2000 (Ecuador)	Cross-sectional; simple random sampling of 2 communities; 6 mo follow-up	Children < 60 mo living in highlands (n=61) or coastal (n=58) communities	HAZ	• Among infants living in coastal community, but not among those living in the highlands, linear growth was positively associated with ASF energy and protein intake • Coastal children consume 4x as many calories and 6x as much protein from ASF as highland children
Grillenberger et al., 2006 (Kenya)	Longitudinal study; 2 yr follow-up; post-hoc analysis of a supplementation trial (RASF-DGD), here additionally considering home dietary intake	5 – 14 yr (n=554)	Height, weight, mid-upper-arm muscle and fat area, skinfold thickness	• Total energy intake from ASF over 12 months positively predicted gain in height, weight, mid-upper-arm muscle area, and mid-upper-arm fat • Total intake of specific nutrients in ASF (heme Fe, retinol, Ca, and vit B12) also positively predicted height and weight gain
Sari et al., 2009 (Indonesia)	Cross-sectional surveillance study (over 4 years); multi-stage cluster sampling	Children 0 – 59 mo in rural (n=446,473) or poor urban areas (n=143,807)	Stunting	Higher HH expenditure on ASF is associated with a lower odds of child stunting (OR= 0.87 for highest vs. lowest quintile in rural areas, 95% CI= 0.85 – 0.90; OR= 0.78, 95% CI= 0.74 – 0.81 in urban areas)

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Krebs et al., 2011 (Guatemala, Democratic Republic of Congo, Zambia, Pakistan)	Cross-sectional; convenience sample of children attending health clinics	5 – 9 mo (n=1500); 12 – 24 mo (n=1658)	Stunting and wasting	Consumption of meat was associated with decreased likelihood of stunting (OR= 0.64; 95% CI= 0.46 – 0.90) and wasting (OR= 0.50; 95% CI= 0.26 – 0.94)
Darapheak et al., 2013 (Cambodia)	Cross-sectional; two-stage random sampling	12 – 59 mo (n=6209)	Stunting, wasting, underweight, and diarrhea in past 2 wks	• ASF consumption in the past 24 hours was associated with a lower odds of stunting (OR= 0.69, 95% CI= 0.54 – 0.89) and underweight (OR= 0.74, 95% CI= 0.57-0.96) • Consumption of milk in the past 24 hours was associated with an increased risk of diarrhea in the poorest, poor, and middle-income HHs (OR= 1.85, 95% CI= 1.17-2.93)
Turyashemererwa et al., 2013 (Uganda)	Cross-sectional; sampling not described	5 – 11 yr (n=122)	Anemia	Compared to those consuming fish at least 4 times/week, children who did not consume any fish were significantly more likely to be anemic (OR= 9.0, 95% CI 1.6 – 50.7)
Herrador et al., 2014 (Ethiopia)	Cross-sectional; multi-stage cluster sampling	4 – 15 yr (n=886)	Stunting and thinness (BMI-for-age z-score < -2)	• In rural communities, consumption of any ASF in the past 24 hours was negatively associated with stunting (OR= 0.51, 95% CI= 0.29 – 0.91), but not thinness • In urban communities, consumption of any ASF in the past 24 hours was negatively associated with thinness (OR= 0.26, 95% CI= 0.10 – 0.67), but not stunting

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Widodo et al., 2016 (Indonesia)	Cross-sectional; multi-stage cluster sampling	0.5 – 12 yr (n=3600)	Micro- and macronutrient intakes	Higher frequency of dairy intake was associated with a greater proportion of the sample achieving the RDA for all nutrients examined
Muslimatun and Wiradnyani, 2016 (Indonesia)	Longitudinal; inclusion of all eligible children from 11 purposively selected health posts; 12 mo follow-up	12 – 59 mo (n=227)	Micro- and macronutrient adequacy, HAZ	• Adequate intakes of vit A, Ca, and Zn were associated with frequency of dairy consumption • Adequate protein intake was associated with frequency of egg consumption • Meat consumption was not associated with nutrient adequacy • Neither dietary diversity nor ASF consumption were associated with HAZ at endline
Miller et al., 2016 (Nepal)	Longitudinal study nested within a cluster RCT of community livestock development; 48 mo follow-up	0.5 – 8 yr at enrollment (n=689)	Head circumference z-score (HCZ)	HCZ was significantly higher among children eating ≥2 ASFs in the previous 24 hr (+0.39, $p<0.01$)
Krasevec et al., 2017	Cross-sectional, nationally representative surveys from 39 countries (2010-2014)	Children 6-23 mo (n= 74,548) from 39 Demographic and Health Surveys	Stunting	Compared to children consuming all 3 types of ASF (egg, meat, dairy) the day prior, children consuming no ASF had 1.44 greater stunting odds, those who consumed 1 type had 1.28 greater stunting odds, and those consuming 2 had 1.16 higher odds

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Experimental feeding trials, by year				
Malcolm, 1970 (New Guinea)	1) 2-arm milk-based supplementation trial; 10 wk follow-up 2) 4-arm supplementation trial of milk powder, margarine, taro/sweet potato, or normal diet; 13 wk follow-up	Children 5 – 15 years at a boarding school (n=43 for first experiment; n=110 for second experiment)	Length, weight, skinfold thickness, Hb, and serum proteins	1) Any supplementation resulted in increased height (+1.24 cm, $p<0.001$) and weight (+0.86 kg, $p<0.01$) gain compared to negative controls; Hb and serum protein did not differ 2) Milk-supplementation resulted in the greatest height (+2.32 cm; $p<0.001$) and weight (+1.21 kg; $p<0.001$) gains compared to control (+1.10 cm; +0.50 kg), margarine (+0.96 cm; +1.05 kg), or taro/sweet potato (+1.54 cm; +0.47 kg)
Lampl et al., 1978 (New Guinea)	3-arm milk-based supplementation trial (control, 10g protein/d, 20g protein/d); 8 mo follow-up	Children 7.7 – 13.0 yr at a boarding school (n=86)	Height, weight, skeletal development, skinfold thickness	• Supplementation resulted in significantly greater linear growth, weight gain, and skeletal development • Supplementation with 20g of protein resulted in significantly greater weight gain than with 10g of protein
Walker et al., 1991 (Jamaica)	4-arm RCT with milk supplementation and psychosocial stimulation; 12 mo follow-up	Stunted children 9 – 24 mo (n=129)	Length, weight, MUAC, head circumference, skinfold thickness	Supplementation resulted in significant increases in length (β= 0.94 cm, $p<0.01$), weight (β = 0.38 kg, $p<0.01$), and head circumference (β = 0.29 cm, $p<0.01$) after 12 months, with greater gains among the youngest children
Bhandari et al., 2001 (India)	4-arm RCT with milk supplementation and nutritional counseling; 8 mo follow-up	4 mo (n=418)	Length and weight	Supplementation and counseling resulted in a 0.25 kg greater weight gain than in control (95% CI= 0.02 – 0.48 kg) but had no effect on length
Siekmann et al., 2003 (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 12 mo follow-up	5 – 14 yr (n=555)	Micronutrient status	Supplementation with either meat or milk improved vit B12 status compared to energy or control, but had no effect on Fe, Hb, Zn, copper, folate, retinol or riboflavin status

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Grillenberger et al., 2003 (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 23 mo follow-up	5 – 14 yr (n=554)	Weight, height, MUAC, skinfold thickness, mid-upper-arm muscle and fat	• Supplementation did not affect height, HAZ, WHZ, or body fat • Any supplementation significantly increased weight gain and MUAC compared to negative control (+0.4 kg and +0.26 cm, respectively), but neither meat nor milk performed better than energy alone • Among children with very low baseline HAZ, milk supplemented children gained 1.3cm more height than children in control group ($p=0.05$) • Meat supplementation resulted in greater gain in lean body mass than milk ($p=0.04$), energy ($p=0.03$), or no supplementation ($p<0.01$)
Whaley et al., 2003 (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 21 mo follow-up	5 – 14 yr (n=555)	Reasoning and problem-solving (Raven's), verbal comprehension, and arithmetic performance	• Children supplemented with meat performed significantly better on the Raven's test than other groups; children in the milk and energy groups did not perform differently than those in controls • The four groups did not differ in verbal comprehension • Children supplemented with meat or energy outperformed children in the control and milk groups
Sigman et al., 2005 (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 21 mo follow-up	5 – 14 yr (n=540)	Activity, affect, initiative, and leadership	• All supplemented children were more active, showed more leadership, and showed more initiative than did non-supplemented controls • Children in the meat group were more active and maintained greater social initiative and leadership over time compared to the other groups

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Walker et al., 20095 (Jamaica)	4-arm RCT with milk supplementation and psychosocial stimulation; follow-up to 1991 study, 16 yr follow-up	Stunted (n=103) and non-stunted (n=129) children, now 17 – 18 yr	Cognitive and educational test scores	• There was no significant effect of nutritional supplementation • Psychosocial stimulation had broad, positive effects on cognitive performance, especially among stunted children
McLean et al., 2007 (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 21 mo follow-up	5 – 14 yr (n=503)	Vit B12 status	• At baseline, plasma vit B12 was predicted by portion of energy from ASF (r=0.3, p<0.01); milk was the strongest individual dietary predictor of B12 status (r=0.27, p<0.01) • At baseline, B12 deficiency was predicted by ASF intake (OR= 6.28 for lowest vs. highest ASF consumption) • Supplementation with meat or milk greatly reduced B12 deficiency vs. energy and negative control groups
Hall et al., 2007 (Vietnam)	Longitudinal trial of biscuit and milk snacks in schools, compared to those without; 18 mo follow-up (only 143 days of discontinuous feeding)	Children enrolled in Grade 1, mean age 6.9 yr (n=1080)	Weight, height	• Children in program schools gained significantly more weight than those in controls (beta= 0.187, p=0.02) • There was no difference in height gain between program and control schools (p= 0.44)
Dalton et al., 2009 (South Africa)	RCT of fish-flour or placebo; 6 mo follow-up	7 – 9 yr (n=183)	Cognition	There were significant treatment effects of the fish-flour supplementation on verbal learning, spelling, and memory
Lien Do et al., 2009 (Vietnam)	3-arm milk based supplementation trial (regular milk, fortified milk, control); 6 mo follow-up	7 – 8 yr (n=454)	HAZ, WAZ, WHZ, anemia	• Supplementation had no significant effect on weight or height, but resulted in significantly lower prevalence of underweight (10-13 p.p. reduction) • Supplementation resulted in significantly lower prevalence of anemia, vit A deficiency, and Zn deficiency

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Long et al., 2011 (Kenya)	3-arm cluster RCT of supplementation with millet, millet +milk, or millet +meat; 5 mo follow-up	11 – 40 mo (n=303)	Height, weight, MUAC, mid-upper-arm muscle and fat area	• Linear growth was greater for children in milk vs. meat group (p=0.01) • Change in MUAC was greater for the milk group compared to the meat (p=0.04) and plain (p=0.05) groups • Weight gain and change in fat mass did not vary among groups • Arm muscle area increased most among children supplemented with plain millet compared to meat (p<0.01)
Krebs et al., 2012 (Guatemala, Democratic Republic of Congo, Zambia, Pakistan)	Cluster RCT of daily meat vs. micronutrient- fortified cereal supplementation; 12 mo follow-up	6 mo (n=1062)	Linear growth, stunting, anemia, micronutrient status, morbidity, psychomotor development	• Linear growth velocity (1.00 vs. 1.02 cm/mo, p=0.39) and stunting prevalence (50% vs. 45%, p=0.08) did not differ • Hb, Zn, and vit B12 did not differ • There was no treatment effect on morbidity or development • Anemia prevalence was greater in the meat group (23.7% vs. 15.7%, p<0.01)
Neumann et al., 2013a (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 21 mo follow-up	5 – 14 yr in two cohorts from the same schools (n= 902)	Morbidities	• For nearly all morbidities examined, the control group had the highest probability of morbidity and least decline over time • Meat and energy groups had greatest declines in probabilities of severe illness, malaria, poor appetite, reduced activity, and fever • The milk group showed the greatest decline in probability of upper respiratory infections
Neumann et al., 2013b (Kenya)	4-arm cluster RCT (RASF-DGD[a]); 21 mo follow-up	5 – 14 yr in two cohorts from the same schools (n= 910)	Arm muscle area, MUAC	Meat and milk groups had significantly greater increase in MUAC and arm muscle area compared to the energy and control groups

Table 1.2 (Continued)

Citation (Location)	Study design	Sample age (size)	Outcomes examined	Key findings
Bauserman et al., 2015 (Democratic Republic of Congo)	Cluster RCT of daily caterpillar cereal supplementation vs. usual diet; 12 mo follow-up	6 mo (n=175)	Stunting, Hb, anemia, Fe stores, infectious morbidity	• Supplementation had no effect on stunting prevalence at 18 mo (p=0.38) • At 18 mo, supplementation group had higher Hb concentrations (10.7 vs. 10.1, p=0.03) and lower prevalence of anemia (26% vs. 50%, p=0.006), but no difference in body Fe stores or morbidities
Iannotti et al., 2017 (Ecuador)	RCT of egg supplementation vs. usual diet; 9mo follow-up	6 – 9 mo (n=163)	LAZ, stunting, underweight	• Supplementation increased LAZ by 0.63 (95% CI= 0.38 – 0.88) and reduced stunting prevalence by 47% • Supplementation increased WAZ by 0.61 (95% CI= 0.45 – 0.77) and reduced underweight by 74%

Notes: [a] RASF-DGD= "Role of Animal Source Food to Improved Diet Quality and Growth and Development in Kenyan School Children" feeding trial study, a 4-arm cluster randomized control school-feeding trial testing the impact of daily feeding of a local plant-based dish, *githeri*, with 1) meat, 2) milk, or 3) oil compared to 4) usual diet (no feeding). Two cohorts were enrolled from the same schools, one year apart, and some published papers examine only one cohort (inconsistently reported as n=555, n=554, n=540, n=525, n=518 or n=503), while others examine data from both (reported at n=910, n=902, or n=900)

Abbreviations: ASF, animal source foods; BMI, body mass index; Ca, calcium; CI, confidence interval; Fe, iron; HAZ, height-for-age z-score; Hb, hemoglobin; HCZ, head circumference z-score; LAZ, length-for-age z-score (identical to HAZ, but used for recumbent length in children under 24 months, rather than standing height); MUAC, mid-upper-arm circumference; NCRSP= Nutrition Collaborative Research Support Program study in Egypt, Kenya, and Mexico; OR, odds ratio; p.p., percentage point; RCT, randomized controlled trial; RDA, recommended dietary allowance; vit, vitamin; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score; Zn, zinc

A large longitudinal observational study of young children in Egypt, Kenya, and Mexico in the 1980s provided some of the strongest early evidence of the link between ASF intake and child nutrition outcomes, finding that ASF consumption among children or their pregnant/lactating mothers positively predicted linear growth, weight gain, and cognitive performance (Allen, 1993; Allen et al., 1992; Sigman et al., 1991). Later observational research similarly found a positive association between ASF consumption and child nutrition outcomes in Peru (Marquis et al., 1997), Nepal (Gittelsohn et al., 1997), Ecuador (Leonard et al., 2000), Kenya (Grillenberger et al., 2006), Indonesia (Sari et al., 2009; Widodo et al., 2016), Guatemala, Democratic Republic of Congo, Zambia, and Pakistan (Krebs et al., 2011), Cambodia (Darapheak et al., 2013), Uganda (Turyashemererwa et al., 2013), and Ethiopia (Herrador et al., 2014) (Table 1.2). Recently, an analysis of Demographic and Health Surveys from 39 countries included 74,548 children found that children 6-23 months consuming no ASF in the previous day had 1.44 greater odds of being stunted compared to children consuming all three types of ASF (egg, meat, and diary; Krasevec et al., 2017). Building off these observational studies, experimental trials, many among school-aged children in Kenya (Neumann et al., 2003), found that supplementing children's diets with ASF resulted in improved micronutrient status (Lien et al., 2009; McLean et al., 2007; Siekmann et al., 2003), physical growth (Bhandari et al., 2001; Grillenberger et al., 2003; Iannotti et al., 2017; Neumann et al., 2013b), cognitive performance (Dalton et al., 2009; Whaley et al., 2003), and physical activity (Sigman et al., 2005), and decreased their risk of morbidities (Neumann et al., 2013a) and anemia (Bauserman et al., 2015; Lien et al., 2009).

Despite the recognized importance of ASF for dietary quality, the poorest families in low- and lower-middle-income countries often rely on low-quality, plant-based diets consisting primarily of starchy staples that have low protein and micronutrient availability (Allen, 1993; 2012; Arimond & Ruel, 2004; Black et al., 2008). In low-income countries, approximately 8.5% of daily energy intake is consumed as ASF, compared with nearly 18% in the world as a whole (FAOStat Database, 2017). Among young children in particular, ASF consumption may be uncommon in some contexts (Table 1.3). Constraints to regular ASF consumption among children may include poor local availability, the relatively high cost of ASF, cultural or religious food proscriptions based on age or gender, inequitable intra-household food allocation linked to an individual's economic or social valuation, caretaker beliefs and nutritional knowledge, and prevailing local child feeding practices (Appoh & Krekling, 2005; Gittelsohn & Vastine, 2003; Pachon et al., 2007; Sigman et al., 1991).

Potential role of homestead livestock production in alleviating stunting

In theory, small-scale homestead livestock production can overcome some of these barriers, providing poor households with ASFs that are readily accessible for home consumption, thereby *directly* reducing child undernutrition through improved dietary quality. While an estimated 70% of poor rural households keep some type of livestock (Davis et al., 2007; FAO, 2009), these animals can be of low productivity due to poor genetic potential, high infectious disease burden, and sub-optimal feeding and management practices caused by technical, financial, and human capital barriers (Steinfeld, 2003), especially in smallholder mixed crop-livestock systems. Additionally, livestock often contribute to household livelihoods in multiple ways, including providing income, long-term financial security, manure fertilization and draft power, and social benefits (FAO, 2009; Herrero et al., 2013; Pell & Kristjanson, 2017; Randolph et al., 2007).

Table 1.3. Prevalence of animal source foods (ASF) consumption among children 6-23 months of age in the previous 24-hours in select low- and lower-middle-income countries, based on nationally representative surveys[a]

			In the past 24 hours, did the child consume any … ?		
Country (data source)	**Met minimum dietary diversity**	**Breastfeeding status**	**Meat, fish, or poultry**	**Eggs**	**Dairy products**
Ethiopia (DHS 2011)	4.8%	Breastfeeding Non-breastfeeding	5.3% 7.4%	8.3% 7.6%	13.1% 20.0%
Liberia (DHS 2013)	11.3%	Breastfeeding Non-breastfeeding	38.5% 53.5%	8.3% 14.4%	4.2% 6.5%
Zambia (DHS 2014)	22.0%	Breastfeeding Non-breastfeeding	37.4% 52.3%	16.8% 27.5%	4.9% 10.5%
Pakistan (DHS 2013)	22.2%	Breastfeeding Non-breastfeeding	16.2% 22.9%	23.9% 27.8%	12.2% 17.7%
Bangladesh (DHS 2014)	27.6%	Breastfeeding Non-breastfeeding	42.8% 58.3%	27.7% 41.9%	6.3% 13.1%
Nepal (DHS 2011)	37.0%	Breastfeeding Non-breastfeeding	17.0% 24.2%	8.8% 16.3%	8.6% 16.6%

Notes: [a]Data from Demographic and Health Surveys, The DHS Program

The multi-purpose utility of livestock requires a daily cost-benefit analysis on the part of livestock owners, who must weigh the many demands of their households against their limited resources (Pell & Kristjanson, 2017). As a result, livestock-owning families in many smallholder systems do not necessarily consume ASF at home on a routine basis (Randolph et al., 2007). For example, if a poor farmer is raising a small flock of chickens for the primary purpose of storing or investing her wealth, and if these chickens grow slowly, lay only 30-60 eggs per year, and have poor survival, slaughtering a chicken may be a relatively costly decision that she will only make under compelling economic or social circumstances (e.g. she has no cash to buy other food or she would like to welcome a visitor to her home). Similarly, the decision to drink milk produced at home needs to be weighed against the lost potential income that could be generated from selling that milk. Therefore, although their household may own livestock, the nutrients from ASF produced by these animals may be functionally inaccessible to the children living in livestock producing households.

Indeed, observational research on the association between livestock managed in *traditional extensive systems* and child ASF consumption and subsequent linear growth has yielded mixed findings, with the majority of the research coming out of just three countries (Kenya, Ethiopia, and Uganda). The most consistent evidence for an association between livestock ownership and child linear growth comes from analyses of the specific impacts of dairy cow or dairy goat ownership on child growth in Kenya (Nicholson et al., 2003), rural Ethiopia (Hoddinott et al., 2015; Okike et al., 2005), Uganda (Fierstein et al., 2017), and rural Rwanda (Grosse, 1998). Notably, however, the observed relationship was not always mediated through increased dairy consumption and was potentially due to a confounding effect of household wealth. Similarly, an analysis of nationally representative data from Ethiopia, Kenya, and

Uganda reported a modest overall relationship between livestock ownership and lower child stunting prevalence; however, effect sizes were very small (Mosites et al., 2015) and depended on how "livestock ownership" was operationalized in the analysis.

In contrast, in another study, Mosites et al. followed a cohort of children in western Kenya and found no association between the number of livestock owned by households and either HAZ or growth rate (Mosites et al., 2016). Azzarri et al. observed a positive effect of cattle ownership on dairy consumption and of poultry ownership on chicken consumption in rural Uganda, but found no association with child stunting and only a weak association with other measures of child nutritional status (Azzarri et al., 2015). Similarly, in Kenya, goat and cattle holdings among pastoralists were positively predictive of household milk consumption, and cattle ownership was associated with improved weight-for-age z-score (WAZ), but there was no effect on HAZ (Iannotti & Lesorogol, 2014). Children living in poor Ethiopian households with small livestock were more likely to consume eggs than those without livestock; however, they were less likely to consume milk, had lower overall dietary diversity, and were more likely to be stunted and underweight (Good, 2009). Jin and Iannotti reported that the *value* of livestock owned by a household was positively associated with child WAZ in Kenya, but not HAZ, and the effect was only observed if livestock were at least partially owned by women (Jin & Iannotti, 2014). Finally, Headey and Hirvonen reported that poultry ownership in Ethiopia was positively associated with child HAZ but that the practice of keeping poultry within the family home overnight countered that effect, highlighting the positive and negative impacts of livestock on child nutrition (Headey & Hirvonen, 2016).

Research evaluating the impact of smallholder *livestock-based interventions* on child ASF consumption, dietary quality, and/or growth and development has similarly demonstrated mixed results (Table 1.4). Among the five studies evaluating the impact of aquaculture interventions (all in Bangladesh), two reported a positive impact of the program on household fish consumption (Murshed-e-Jahan et al., 2000), while one found no difference (Roos et al., 2003), and one found a negative effect (Bouis, 2000). Only one study examined the impact of the program on nutritional status (Kumar & Quisumbing, 2010), with mixed results, depending on the outcome examined.

Thirteen studies examined the impact of dairy (cow or goat) interventions on nutrition outcomes in East Africa (n=11) and India (n=2). Among them, nine reported a positive impact (increased milk, total ASF, or nutrient intake), three reported no change or mixed results, and one reported *decreased* milk intake as a result shifting milk-use incentivized by the program. Only six reports examined dairy program impact on nutritional status. Of these, five reported a positive impact on at least one indicator of nutritional status, while five reported no change or negative impact (e.g. overweight) on at least one indicator. In other words, one study reported *only* a positive impact of dairy intensification on child nutritional status (Hoorweg et al., 2000), while the others reported either no impact or mixed results, depending on the indicators examined.

Table 1.4. Research examining the impact of small-scale livestock interventions on HH- or child-level consumption of animal source food (ASF) or key micronutrients and nutritional status in low- and lower-middle-income countries

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Aquaculture				
Bouis, 2000 (Bangladesh)	Promotion of polyculture fish production in individually- or group-managed ponds, with income-generation as main program goal	Post-intervention cross-sectional analysis of participants (n=110) and potential future participants (n=110)	• No difference in HH fish consumption between groups [a] • Participating HHs substituted more nutritious small fish for large fish, so net impact of program on nutrient intake may be negative [a]	NM
Thompson et al., 2000 (Bangladesh)	Approximately 10 different government and NGO-operated programs promoting aquaculture in the area (not well defined)	Post-intervention cross-sectional survey of participants (n=100), their non-participating neighbors (n=60), and control area HHs (n=60)	Participant HHs consumed significantly more fish compared to their neighbors and controls ($p<0.01$)	NM
Roos et al., 2003 (Bangladesh)	Integrated small indigenous fish (SIS) in carp polyculture by providing technology inputs and training	Cohort study following participants (n=59) and control HHs that do not produce fish (n=25); 1 yr follow-up	There was no difference in per capita fish consumption at any time point between producers and controls [a]	NM

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Kumar & Quisumbing, 2010 (Bangladesh)	Numerous government and NGO-operated programs promoting polyculture fish production technologies, both individually- or group-managed ponds	Repeated cross-sectional analysis of participants receiving group- or individually-owned ponds, 3 and 10 yr after program began (no baseline)	• There was no impact on per capita HH calorie availability • For group-owned ponds, nutrient consumption declined in producing HHs • For individually-owned ponds, there was a sustained increase in calorie, protein, and vit A consumption by women • There was no impact of either program on child nutrient consumption	• HAZ decreased, while BMIZ increased, among children living in participating HHs • No impact on adult BMI • Prevalence of anemia among women decreased among those with individually-owned ponds only
Murshed-e-Jahan et al., 2010 (Bangladesh)	Training and support of farmers focused on improved management techniques	Pre/post comparison of participating (n=225) and control (n=123) HHs; 3 yr follow-up	Per capita fish consumption, though above the national average in both project and control areas, increased more in project (+0.29 kg/mo) than control (+0.09 kg/mo) areas ($p<0.01$)	NM
Dairy				
Alderman et al., 1987 (India)	Established village-level dairy cooperatives, provided husbandry training and access to cross-bred cows (Operation Flood)	Pre/post comparison of HHs in intervention (n=546) and control villages (n=260); 15 mo follow-up	• HHs in intervention villages drank *less* milk • Milk producers in intervention villages had an increase in total nutrient consumption, while non-producers in those villages consumed fewer nutrients	NM

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Begum, 1994 (India)	Dairy Development Project promoted by the Indian government as an income-generating activity (program details not given)	Post-intervention cross-sectional analysis of three strata of dairy producers (small, marginal, large) compared to non-producer controls (n=360 total)	Percent of children consuming adequate protein and calories increased in a dose-dependent fashion with increasing dairy production [a]	NM
Mullins et al., 1996 (Kenya)	Promotion of milk production through cut-and-carry feeding, extension services, and loans for purchasing improved breeds (National Dairy Development Project)	Post-intervention cross-sectional survey of participating (n=35) HHs	• < 20% of produced milk was consumed at home (0.3 L/person/d) • 91% of project HHs self-reported increase home milk consumption [a]	NM
Hoorweg et al., 2000 (Kenya)	Promotion of milk production through cut-and-carry feeding, extension services, and loans for purchasing improved breeds (National Dairy Development Project)	Post-intervention cross-sectional survey of participants (n=30), their customers (n=24), and a random rural sample of non-participants (n=90)	Mean per capita milk consumption in participating HHs was *lower* than among customers, but higher than in random rural sample (200 g/d vs. 249 g/d vs. 11 g/d, $p<0.01$)	HAZ, WHZ, and WAZ were significantly higher among children 6-59 mo living in dairy or customer HHs vs. children in the random rural sample ($p<0.05$)
Ahmed et al., 2000 (Ethiopia)	Intensification of per-urban dairying among smallholder farmers through the introduction of cross-bred cows, improved management and feeding, and market development	Post-intervention cross-sectional survey of participants and non-participants, matched by wealth status (n=84)	Participating HHs consumed significantly more calories, fat, protein, retinol and Fe	NM

Table 1.4 (Continued)

Citation (Location)	Intervention	Design	Key findings: Diet or nutrient intake	Key findings: Nutritional status
Habtermariam et al., 2003 (Ethiopia)	Promotion of dairy goat production (Dairy Goat Development Project) among female-headed HHs by training in improved management and providing goats with high genetic potential on credit	Post-intervention cross-sectional survey of participants and non-participants (n=228)	No difference in ASF consumption between groups (mean= 2.75 days per week) [a]	• No difference in prevalence of adult underweight between groups [a] • Prevalence of child stunting and underweight was lower in participating HHs than in controls [a]
Ayele & Peacock, 2003 (Ethiopia)	Promoted dairy goat production (Dairy Goat Development Project) among female-headed HHs by training in improved management and providing goats with high genetic potential	Pre/post comparison of participating HHs (n=210); no control	• Per-capita availability of milk increased 100-275% post-intervention [a] • In a subsample of young children 0.5-6 y (n=39), mean frequency of milk consumption increased from 2.5 to 6.0 d/wk [a]	NM
Walingo, 2009 (Kenya)	Livestock Development Strategy promotes dairy development in women's group by providing support in fodder production, milk marketing, and distribution of heifers	Post-intervention cross-sectional analysis of randomly selected beneficiary (n=150) and matched non-beneficiary (n=150) HHs	Per capita milk consumption was higher among HHs and young children in the beneficiary group (+161.9 g/d, $p<0.01$ and +140 g/d, $p<0.01$)	There was no significant difference in women's BMI

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Walton et al., 2012 (Kenya)	Community-based dairy cooperative group (Wakulima Dairy) that buys and sells members' raw milk, provides services on credit, and provides training, including nutrition education	Post-intervention cross-sectional analysis of dairy group member (n=88) and non-member (n=23) HHs, selected through chain referral sampling	• Milk consumption was higher among women (+278 g/d, p<0.05) and children (+164 g/d, p<0.05) in member HHs • Member women and children had higher energy intakes (p<0.05) and percentage of energy from ASF (p<0.05) • Member women had higher median intakes of macro and most micronutrients [a] • Children from member HHs had lower prevalences of inadequate intakes for riboflavin, folate, and vit B12 (p<0.05 for all)	Women's BMI (p<0.05) and overweight status were associated with dairy group membership (54% of member women overweight vs. 29% of non-members)
Sadler et al., 2012 (Ethiopia)	Community-defined livestock development program (Milk Matters) aiming to improved milk supply in pastoral communities, particularly in dry season	Cohort study following HHs in participating (n=628) and control (n=359) communities; 13 mo follow-up	Greater proportion of children received milk in intervention vs. control areas at most timepoints, including at baseline [a]	Overall, WAZ "stabilized" among children in 3 of 4 intervention areas and declined in all control sites over time, but in all cases, WAZ was lower at baseline [a]

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Wyatt et al., 2013 (Kenya)	East Africa Dairy Development (EADD) project targeting smallholder farmers to promote intensification of dairy production by providing access to inputs and services	Post-intervention cross-sectional survey of participants, stratified as medium (MI, n=31) and high intensity (HI, n=31, n=30) dairy producers or non-dairy producers (control)	• Milk was introduced to infants earliest in HI (3.5 mo) and latest in control (6 mo), and increasing dairy intensity was negatively associated with exclusive breastfeeding ($p<0.05$) • Proportion of HHs where adults or children went without milk decreased with increasing intensity of dairy production ($p<0.05$) • Dairy production intensity was not associated with child dietary diversity	NM
Rawlins et al., 2014 (Rwanda)	Heifer International program providing high-producing dairy cows and training to smallholder farmers to increase dairy production and consumption	Post-intervention cross-sectional survey of beneficiaries, prospective beneficiaries who qualified but did not receive the intervention, and HHs who applied but did not qualify (n=224)	• Receiving a cow was highly correlated with increased individual dietary diversity (+1.17 food groups), driven exclusively by increased consumption of dairy • Receiving a cow was associated with drinking 9.4 L/mo more milk per person	Receiving a cow was associated with a 0.54 SD increase in HAZ ($p<0.10$) and tended towards increased WAZ (+0.40 SD, $p=0.12$) among children 0 – 5 y, but was not associated with WHZ

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Njuki et al., 2015 (Kenya)	East Africa Dairy Development (EADD) project targeting smallholder farmers to promote intensification of dairy production by providing access to inputs and services	Post-intervention cross-sectional survey of participants (n=92), stratified as low (LI), medium (MI), and high intensity (HI) dairy producers	• Children from HI HHs were more likely to drink milk than those from LI or MI (92.3% vs. 87.5% and 89.3%) and drank more milk on average per day (1.0 L vs. 0.5 and 0.5) [a] • Overall dietary diversity and ASF consumption increased with intensification level [a]	NM
Poultry				
Nielsen, 1996 (Bangladesh)	Bangladesh Rural Advancement Committee (BRAC) program distributing a technical package to support intensive poultry production by very poor women	Post-intervention cross-sectional analysis of participants, randomly selected from purposively selected areas (n= 1000)	• Average household intake of eggs increased from 2 to 5 per week [a] • Average household intake of chickens increased from 2 to 5 per year [a] • Meals with fish or meat increased from 10 to 12 per month and from 1 to 2 per month, respectively [a] • Average household intake of dairy increased from 0.8 to 2.5 L per month [a]	NM

Table 1.4 (Continued)

Citation (Location)	Intervention	Design	Key findings: Diet or nutrient intake	Key findings: Nutritional status
Nielsen et al., 2003 (Bangladesh)	Participatory Livestock Development Project, promoting semi-scavenging poultry production by women through loans and technical assistance	Post-intervention cross-sectional analysis of HHs in project (n=35) and control (n=35) villages	• The number of eggs and chickens consumed per month did not differ in project and control HHs • Overall dietary composition among women and young girls did not differ among groups • Per capita consumption of fish was marginally higher among women (+19 g /d, p=0.08) and girls (+11 g/d, p=0.06) in project HHs	NM
Knueppel et al., 2010 (Tanzania)	Newcastle disease vaccination campaign and poultry health training	Repeated cross-sectional surveys of HHs in participating and non-participating villages, 1 and 2 yr after program initiation (no baseline; n=237)	• There was no difference in maternal or child consumption of chicken meat in participating vs. control HHs • Women in project HHs ate significantly more eggs than in controls 1 yr after the program (but not after 2 yr)	NM

Table 1.4 (Continued)

Citation (Location)	Intervention	Design	Key findings: Diet or nutrient intake	Key findings: Nutritional status
Other livestock or mixed livestock program				
Galal et al., 1987 (Egypt)	More and Better Food Project promoting 31 different agricultural interventions, including poultry raising (program details not given)	Post-intervention cross-sectional analysis of participants (n= 227) and non-participants (n= not given)	• Per capita intakes of protein, animal protein, and Fe were higher in participating HHs [a] • There was no difference in per capita calorie intake [a]	• No significant difference in morbidity, feeding, or WAZ between children <36 mo in program and control HHs (n=52) [a]
English et al., 1997 and English & Badcock, 1998 (Vietnam)	Encourages horticulture, pond aquaculture, and small-animal husbandry within homestead gardens, combined with nutrition education	Cohort study following children in a project area (n=469) and control area (n=251); 15 mo follow-up	• Children in project area consumed more vegetables, fruit, energy, protein, vit A, and Fe than in control area [a] • Per capita intake of vegetables, meat, and fish increased in project but not control area [a]	• Significant decline in proportion of acute respiratory infection (from 49.5% to 11.2%, $p<0.01$) in project but not control area • Significant decline in prevalence of diarrhea (from 18.3% to 5.1%, $p<0.01$) in project but not control area • Stunting prevalence decreased in project but not control area (from 50.3% to 41.7%, $p<0.01$); no impact on wasting
Smitasiri & Dhanamitta, 1999 (Thailand)	Community-based intervention promoting poultry, rabbit, fish, and vegetable production, with nutrition education and Fe supplementation	Pre/post analysis of randomly selected children 2 – 5 yr (n=234), girls 10 – 13 yr (n=79), pregnant women (n=92), and lactating women (n=65) in participating and control areas	• Vit A intake increased in both intervention and control areas among all age groups, but more so in intervention areas [a] • No changes in fat intake in any group [a] • Fe intake increased in girls 10 – 13 yr (intervention), 2 – 5 yr children (control), and lactating women (intervention and control)[a]	• In girls 10 – 13 yr, serum retinal improved more in intervention than in control (double difference= +7.6 mcg/dl; $p<0.01$), as did serum ferritin (double difference= +31.7 ng/dl; $p<0.01$) • No change in Hb

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Ayalew et al., 1999 (Ethiopia)	Dairy Goat Development project supporting female-headed HHs was expanded to include nutrition education, gardening training, and seed distribution	Post-intervention analysis of participants (n=214) and non-participants (n=106)	• Participants consumed almost all milk at home • Children in participating HHs had slightly more diverse diets [a] • Children in participating HHs consumed milk more often than those in controls (p<0.01)	Goat ownership did not predict risk of clinical vit A deficiency
Schipani et al., 2002 (Thailand)	Government initiative promoting home vegetable gardens, fish, and small animals	Cohort study following adopting (n=30) and non-adopting (n=30) HHs; 1 yr follow-up	There was no significant difference in mean nutrient intake among children in the two groups at any timepoint	• No differences in mean Hb, ferritin, or retinol concentrations between the two groups at any timepoint • Apparently lower prevalence of stunting and underweight among children in adopting HHs [a]
Olney et al., 2009 (Cambodia)	HKI's homestead food production program promoting micronutrient-rich foods by providing inputs and technical assistance	Pre/post analysis of participating (n=300) and control (n=200) HHs	There was no program impact on HH, maternal, or child consumption of ASF, except a small increase in prevalence of egg consumption among children (+4.2%, p<0.05)	• No difference in child anthropometrics or anemia • No difference in maternal BMI or anemia

Table 1.4 (Continued)

Citation (Location)	Intervention	Design	Key findings: Diet or nutrient intake	Key findings: Nutritional status
Talukder et al., 2010 (Bangladesh, Cambodia, Nepal, and the Philippines)	HKI's homestead food production model, promoting vegetable, fruit, meat, poultry, and egg production and consumption, providing inputs training, and extension services	Pre/post analysis of participating HHs, pooled for Bangladesh and Cambodia (n= 720); control HHs sampled but data not presented for ASF outcomes	• Egg consumption by HHs, women, and children increased in Bangladesh and Cambodia by 3, 0.5, and 1 eggs/wk, respectively (p<0.05 for all) • Chicken liver consumption increased from 24% to 46% from baseline to endline in project HHs in Bangladesh and Cambodia[a] • Data from Nepal and the Philippines not presented for ASF outcomes	• Anemia prevalence among children decreased in program areas of all four countries, but it did not significantly differ from the change in control areas • Anemia prevalence among non-pregnant women decreased in project areas in Bangladesh (p=0.08) and Nepal (p<0.01), but not Cambodia
MacDonald et al., 2011 (Malawi)	Mixed livestock distribution and training, with a pay-it-forward component and nutrition education, integrated with Fe supplementation and malaria control	Pre/post analysis of participating and non-participating areas	Significant increase in HH-level consumption of eggs, chicken, goat, and rabbit meat in project HHs (p<0.05), though increase was not different from change in control areas for eggs and rabbit meat	Significant reduction in anemia prevalence among children <60 mo, pregnant women, and women of reproductive age (p<0.05), but change was not different from that in control areas for children
Miller et al., 2014 (Nepal)	Distribution of goats to rural women's groups, and provision of training, microcredit, and investments in women's empowerment (Heifer International)	Cluster RCT of 6 communities receiving the intervention at baseline (project; n=201) or 1 yr later (control; n=214); 2 yr follow-up	NM	Mean changes in HAZ and WAZ were significantly higher in intervention vs. control areas at 12 and 24 mo follow-up

Table 1.4 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Rawlins et al., 2014 (Rwanda)	Heifer International program providing high-producing meat goats and training to smallholder farmers to alleviate poverty	Post-intervention cross-sectional survey of beneficiaries, prospective beneficiaries who qualified but did not receive a donation, and HHs who applied but did not qualify (n=182)	• There was no impact of the program on individual dietary diversity • Goat donation increased per capita monthly meat consumption by 0.1 – 0.2 kg ($p<0.10$)	Meat goat donation had a positive impact on WHZ (+0.47 SD; $p<0.05$) and WAZ (+0.42 SD; $p<0.10$), but had no effect on HAZ *(Note: Mean WHZ was 0.23, so the effect on WHZ may not indicate a positive effect on child nutrition)*

Notes: [a] No statistical tests reported.

Abbreviations: ASF, animal source food; BMI, body mass index; BMIZ, body mass index z-score; Fe, iron; HAZ, height-for-age z-score; Hb, hemoglobin; HH, household; HI, high-intensity; HKI, Helen Keller International; MI, medium-intensity; NM, not measured; SD, standard deviation; vit, vitamin; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score

Among the three studies evaluating the impact of poultry development programs on nutrition outcomes, one found no impact on chicken or egg consumption or dietary quality (Nielsen et al., 2003), and another reported a significant increase in egg consumption among women (but not children) at midline, but the change was not sustained to endline (Knueppel, et al., 2010). Another study reported a positive impact of the program on ASF intake, but the author did not conduct statistical tests to support this conclusion (Nielsen, 1996). None of the studies examined program impact on any measure of nutritional status outcomes.

Eight studies examined the impact of livestock programs (e.g. poultry, fish, rabbits, goats) integrated with other initiatives, including vegetable gardening, nutrition education, supplementation, or microcredit. Of these, five reported a positive impact of the program under investigation on intakes of ASF or key micronutrients, though in all cases, this finding was tempered by contradictory findings (e.g. increased consumption in one country of study, but not the other; increased consumption of one type of ASF, but not other types; increased consumption within one target group [women], but not the other [children]). Additionally, four studies lacked statistical tests to support one or more of their conclusions. All eight studies examined at least one indicator of nutritional status, of which four reported a positive impact on at least one of their outcomes of interest; all but one reported mixed findings (i.e. positive impact on some indicators of nutritional status with no impact on others). Importantly, none of these evaluations were designed as multi-arm trials, making it impossible to distinguish which component of the intervention was responsible for any given measured impact. Finally, one study investigated the impact of a meat goat donation program in Rwanda (Rawlins et al., 2014) and reported a significant impact on child WHZ, marginal increases in household meat consumption and child

WAZ, and no effect on child HAZ. A similar program in Nepal (Miller et al., 2014) reported that the goat donation program was associated with significant increases in HAZ and WAZ.

Overall, this review of the literature suggests that programs promoting livestock development *can* have positive effect on children's diets and nutritional status in resource-poor settings, with strongest evidence for the potential of dairy development or mixed livestock-crop production programs. However, a wide range of livestock systems, mechanisms for delivery, program goals, and targeted beneficiaries were explored, and the extension of their conclusions to other programs implemented in other contexts made not be appropriate. Additionally, many of the studies suffered from methodological limitations, making it difficult to draw confident conclusions about program effectiveness. Of the 30 studies reviewed, only one was a cluster randomized controlled trial (Miller et al., 2014), while 20 were post-intervention cross-sectional or longitudinal analyses of program participants compared to non-participants (without pre-intervention baseline data) and two included no comparison groups at all. With few exceptions (notably (Rawlins et al., 2014)) the selection method for the participant and comparison groups were poorly defined and control for selection bias was rarely explicit. Fifteen studies made at least one conclusion based on quantitative data without presenting statistical tests to support their claim, and nine of these did not present any statistical tests whatsoever. Of those that did present statistical tests, many did not appropriately control for potential confounding factors.

Potential negative impacts of livestock development on child stunting and gender

There is limited, and sometimes conflicting, evidence that livestock development interventions can negatively affect child nutrition outcomes. First, there is a major concern that livestock ownership exposes young children and their pregnant or lactating mothers to zoonotic pathogens that cause clinical disease (e.g. diarrhea) or subclinical infections affecting nutritional status (e.g. environmental enteric dysfunction). Diarrheal disease is the second-leading cause of death in children under five years, responsible for over 800,000 child deaths annually ("Diarrhea: Common Illness, Global Killer," 2015). Livestock may contribute to this burden by serving as a reservoir species for important diarrheal pathogens (including *Salmonella* spp., *Campylobacter* spp., *E. coli, Listeria monocytogenes,* and *Cryptosporidium* spp) and contaminating water sources, food, and the home environment. In a recent meta-analysis, exposure to livestock was consistently associated with diarrheal illness, with a particularly high risk from exposure to poultry (Zambrano et al., 2014). Beyond the risk of diarrheal disease, research in Zimbabwe and Peru revealed that infants frequently consume chicken feces or feces-contaminated dirt during normal exploratory play (Marquis et al., 1990; Ngure et al., 2013), and there is evidence that fecal markers for environmental enteropathy and stunting odds are associated with presence of animal feces in the household compound (Headey et al., 2017), geophagy (George et al., 2015b), and corralling livestock in a child's sleep room (George et al., 2015a; Headey & Hirvonen, 2016). In addition to fecal pathogens, exposure to livestock or consumption of improperly prepared livestock products (e.g. unpasteurized milk) risk transmission of other zoonotic pathogens, such as highly pathogenic avian influenza, leptospirosis, bovine tuberculosis, brucellosis, Q-fever, and anthrax. A mapping exercise of zoonotic diseases found a strong association between global distributions of poverty, livestock ownership, and zoonoses, with the highest burden of endemic zoonoses in low- or lower-middle income countries (Nigeria, Ethiopia, Tanzania, Togo, India are the top five; (Grace et al., 2012)). Therefore, livestock distribution or intensification programs may risk contaminating children's environments and increase their exposure to pathogens with zoonotic potential.

Second, although there is a growing body of literature on the impact of agricultural interventions on women's time burden (Johnston et al., 2015), this is rarely considered in the context of livestock interventions or child nutrition. Indeed, very few of the studies reviewed here examined the significant investments of time and energy that livestock ownership requires of households, particularly women, and how that time burden might affect child nutrition outcomes. There is ample evidence that women play an important role in caring for livestock in many contexts (Brugere et al., 2001; Curry, 1996; Herath, 2008; Herrero et al., 2013; Kristjanson et al., 2014; Valdivia, 2001); as such, it is reasonable to hypothesize that livestock interventions introducing new livestock systems or promoting the intensification of existing systems would have the unintended consequence of adding to women's "time poverty" (Flintan, 2008; Mullins et al., 1996; Tangka et al., 1999; Valdivia, 2001; Wangui, 2008). This trade-off – between the benefits of an agricultural production activity and a woman's time cost – is well-documented for cropping systems (Johnston et al., 2015). This implies potentially negative implications for children's growth and development if a livestock intervention reduces a woman's ability to exclusively breastfeed (Wyatt et al., 2013), prepare meals for herself and her children, seek health care, or otherwise care for her young children (Dumas et al., 2017).

Finally, with efforts to "modernize" the livestock sector, there is a risk that female livestock keepers may lose control over livestock assets or decision-making power as the market value of the animals or animal products increases. In many contexts, women face gender-specific constraints in livestock ownership rights, decision-making power, market access, technology access (e.g. extension and breeding services, training, credit), and control over income (Curry, 1996; Dumas et al., 2017; EADD, 2013; Galiè et al., 2015; Gueye, 2000; Kristjanson et al., 2014; Njuki & Sanginga, 2013; Njuki et al. 2011; Valdivia, 2001). As a result, livestock interventions that do not explicitly address these barriers risk eroding women's control over livestock access, even if women are explicitly targeted as the intended beneficiaries of the program. This unintended consequence has been documented in dairy intensification programs, in particular, where commercialization of milk has led to men taking control over at least a portion of the milk sales (Kristjanson et al., 2014; Njuki et al., 2015; Wangui, 2008). This is important, because there is ample evidence demonstrating that women's status, control over household resources, and decision making capacity contribute to her own nutritional status and that of their children (Amugsi et al., 2016; Bhagowalia et al., 2012; Smith & Haddad, 2015; Smith et al., 2003).

Research rationale

Given the inconsistent findings, limited high-quality evidence, and concerns about unintended consequences, small-scale, *homestead-based* livestock production may not be the ideal mechanism through which to deliver ASF to young children in all low-income rural communities. The evidence is particularly scant for the impact of poultry programs. Only three of the published studies on the effect of livestock interventions on child nutrition focused exclusively on poultry (Knueppel et al., 2010; Nielsen, 1996; Nielsen et al., 2003), while four additional studies included poultry as one component of an integrated homestead food production program (Galal et al., 1987; Olney, 2009; Talukder et al., 2010) or mixed livestock distribution (MacDonald et al., 2011). With the exception of Galal et al., the results of these programs were decidedly disappointing. In a follow-up analysis of Helen Keller International's (HKI's) homestead food production program in Cambodia, Olney et al. explored why they had not uncovered a link between the program's distribution of chickens and increased egg consumption, given that this was a central component of their nutrition education program. They found that only a third of beneficiaries reported that the program increased their flock size, while only 17% reported increased egg production, in part because most of the distributed chickens died before reaching maturity (Olney et al., 2013). They additionally reported the egg consumption was almost entirely dependent on markets, as participants were reluctant to consume an egg that might later hatch to become a chicken, a phenomenon that has been reported elsewhere (Dumas et al., 2017; Gueye, 2000; Lane, 2016). Importantly, none of the studies considered the potential negative impacts of chicken distribution on child nutritional status through increased exposure to fecal pathogens.

Nonetheless, in theory, the promotion of local egg production remains a promising pathway for improving child ASF intake and nutrition outcomes through livestock (Iannotti et al., 2014). Eggs are relatively inexpensive compared to other forms of ASF, do not require a cold-chain, and can be easily consumed as an infant's first complementary food (Iannotti et al., 2014). A recent randomized controlled trial in Ecuador provided infants 6 – 9 months one egg per day for nine months and found dramatic improvements in linear growth and weight gain (Iannotti et al., 2017). Their impressive findings call for the development of scalable programs that increase the availability of eggs to vulnerable households in resource-poor communities. As outlined above, however, the current evidence suggests that the promotion of free-range village chickens is unlikely to answer this call because of their low productivity and high mortality caused by infectious diseases, predation, poor housing, and inadequate nutrition (Gueye, 2000; Wong et al., 2017), as well as the emerging concern about the health consequences for young children in close contact with poultry (Headey & Hirvonen, 2016; Marquis et al., 1990; Ngure et al., 2013; Zambrano et al., 2014).

This dissertation therefore explores an alternative, market-based poultry intervention to increase the availability of eggs in rural communities without adding to the homestead fecal pathogen load or women's time poverty in the Luangwa Valley, Zambia.

Study context

This research was conducted in partnership with a non-governmental organization, Community Markets for Conservation (COMACO; a limited-by-guarantee Zambian company). Operating in and around the Game Management Areas surrounding protected areas throughout the Luangwa Valley, COMACO aims to achieve its conservations goals through market-based projects that improve rural livelihoods, alleviate poverty, and promote food security. In collaboration with farming communities and cooperatives, COMACO identifies new approaches and appropriate technologies to diversify and enhance crop yields. Interested farmers then commit themselves to a "conservation pledge" to abandon unsustainable practices (e.g. charcoal production, illegal hunting, slash-and-burn farming) in exchange for technical support and access to COMACO's premium purchase prices for commodity crops, such as soy, groundnuts, rice, and sunflower. Key components of COMACO's farmer support include seed and input distribution, training of over 1700 Lead Farmers, demonstration farms, field workshops, and instructional and public service radio broadcasts. In addition to support for crop production, COMACO promotes diversification of household income-generating activities, and supports individuals and groups in poultry production, bee keeping, and carpentry. COMACO's objectives, methods, and outcomes are described in more detail in Chapter 2.

This work took place in four rural Chiefdoms of Zambia's Eastern Province (Jumbe, Mnkhanya, Mwanya, and Nsefu; Figure 1.1), historically defined areas not aligned with the government's administrative units. Each Chiefdom is governed by a traditional leader (or Chief) who has limited power at the national government level, but significant influence in local communities in matters of "development, land allocation, law enforcement, and dispute resolution" (Baldwin, 2015) The predominant ethnic groups in the study area are Kunda and Bisa, along with some Chewa and a small minority of Ngoni, Tumbuka, and Nsenga. At least eight different Bantu languages are spoken in the area, though the most common are mutually intelligible dialects, and most people in the study area speak Chinyanja as a first or second language. After Zambia gained independence in 1964, a singular "national identity" informed by mutual economic and political interests was officially promoted over "tribalism" (Marten & Kula, 2008). In the past 25 years, however, indigenous languages and ethnic affiliations have again become key components of the Zambian identity (Marten & Kula, 2008). Christianity is the official religion in Zambia, and as a "public religion" enshrined in the country's constitution, it plays a central and very visible role in the daily lives of Zambians (van Klinken, 2013).

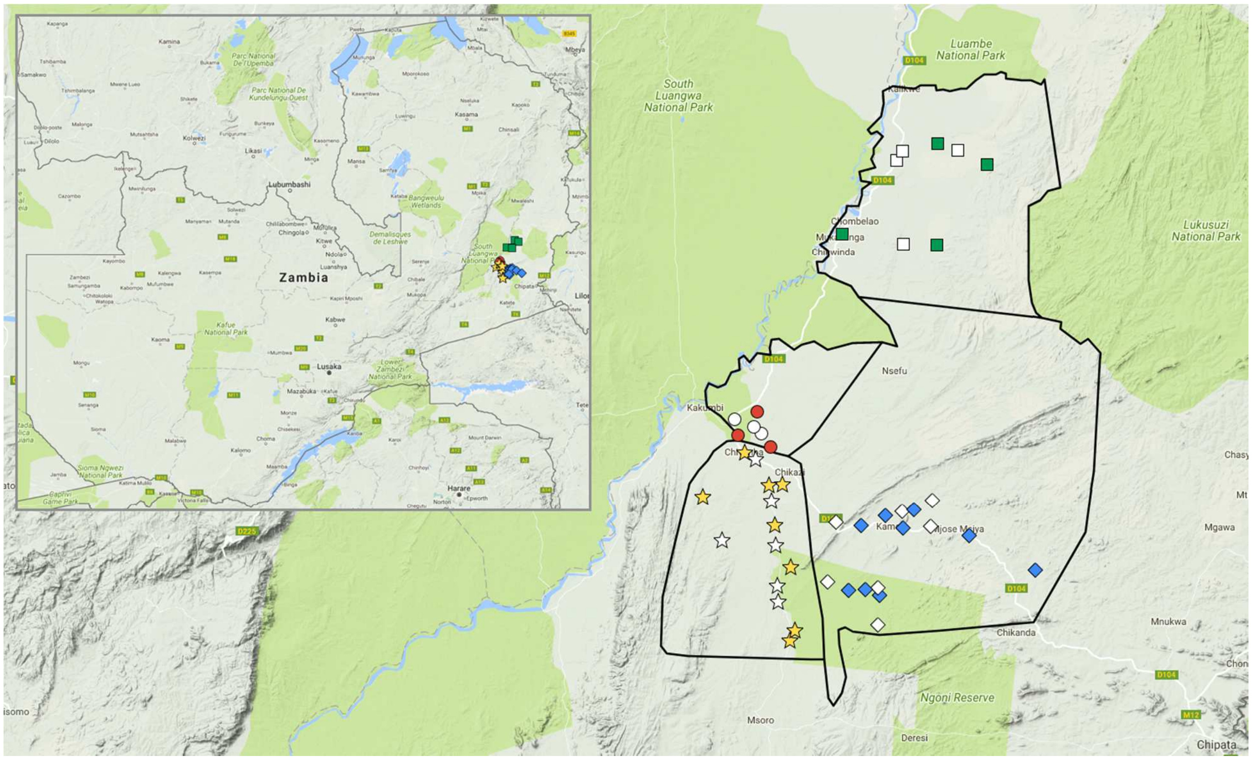


Figure 1.1. Research area in Zambia's Luangwa Valley. Egg production centers were located in the Chiefdoms of Jumbe (blue diamonds), Mnkhanya (yellow stars), Mwanya (green squares), and Nsefu (red circles). White icons indicate control areas for Chiefdoms of the same shape. Black lines roughly indicate the boarders of the four Chiefdoms according to (Dalal-Clayton & Child, 2003) and (Baldwin, 2015). Two EPCs in Jumbe and two in Mnkhanya were randomly selected to be excluded from the impact analysis (Chapter 5). Images created in Google maps.

Although the Kunda, Chewa, and Bisa of this region are all traditionally matrilineal kinship societies (Banda, 2008), men are considered the heads of household, and women experience gender inequality in education, in work, and at home. Women in Eastern Province lag behind the rest of the country in their participation in household decision making, with 20.3% of women reporting that they have no say at all in decisions about their own health care, visits to their families, or household purchases (compared with just 10% in rural areas nationally) (Central Statistical Office (CSO), Ministry of Health (MOH), ICF International, 2015). Similarly, compared to the national average, women in Eastern Province are less likely to take part in making financial decisions in the household (CSO et al., 2015). Median years of schooling in Eastern Province is just 3.2 years for men and 2.6 years for women, and nearly a quarter of the population has no formal education (22.9% of men and 24.4% of women). Half of women and one-third of men in Eastern Province cannot read at all (CSO) et al., 2015).

The vast majority of households in the Luangwa Valley rely on small-scale agriculture as their primary income generating activity (COMACO, 2014), and most are subsistence or semi-commercial farmers (Aregheore, 2009). There are three seasons in Zambia: a cool/dry season (April – August), a hot/dry season (September – November), and a warm/rainy season (November – April; (Aregheore, 2009)). Harvest occurs in the early cool/dry season (April – June), while planting season varies with rainfall, generally November – December (Figure 1.2). The main crops in Eastern Province are maize, cotton, and sunflower, sometimes supplemented with groundnuts, cassava, soy, sweet potatoes, pumpkin, and various legumes.

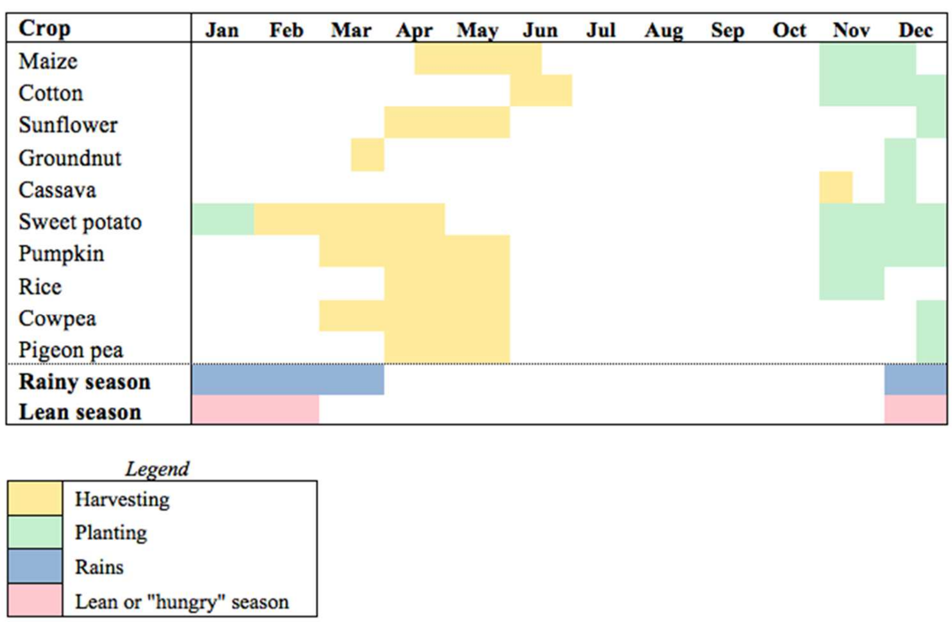


Figure 1.2. Crop calendar showing the typical planting and harvesting months for the most commonly grown crops in the study area in the Laungwa Valley, Zambia. *Source:* FAO, with confirmation from local agricultural extension officers.

However, agricultural output in the region has been historically limited by a number of factors, including: a highly inconsistent rains with frequent droughts or floods (Albrecht, 1973; Dodds & Patton, 1968; Government of the Republic of Zambia & UNDP, 2010); crop damage by elephants; endemic trypanosomiasis restricting the keeping of cattle for land preparation; a reliance on suboptimal soil management practices; and, poor access to both agricultural inputs and markets. Additionally, with limited non-agricultural employment opportunities, a unimodal rainy season, and lack of irrigation, most, if not all, of a household's annual income is generated from a single harvest from April to June. As a result, chronic food insecurity is pervasive, particularly during the "hungry season" (or "lean season") from December to March (Lewis et al., 2011), during which time the region typically experiences a major deficit of staple grains requiring government food assistance (Hoffine, 2013). During this time in particular, and when faced with stochastic shocks such as drought, flood, or crop predation, households rely heavily on timber and non-timber forest products and bushmeat harvesting.

The entire study area is located within the Game Management Areas surrounding four national parks and forest reserves, which are home to large populations of wildlife that support a significant ecotourism industry. Although the Game Management Areas were created as buffer zones to protect wildlife and support ecotourism, the expanding human population relies heavily on unsustainable coping practices to supplement the underperforming agricultural sector – including hunting, fishing, and deforestation for charcoal production and farming (Lindsey et al., 2013). The subsequent degradation of natural resources and depletion of wildlife in both the Game Management Areas and national parks (Lewis et al., 2011; Lindsey et al., 2013) has threatened this important safety net for the local population.

Intervention design

The intervention under investigation for this dissertation is a community-operated, market-based project supporting groups of small-scale egg producers, implemented by the researchers in partnership with COMACO. This support was provided through investments in human, social, and physical capital (Department for International Development (DFID), 1999), with the intention that the businesses would be financially independent and sufficiently profitable after one year of support. The groups were provided with the initial resources, training, and ongoing extension support, as described below; however, the egg producers themselves were considered to be the owners and operators of their group egg production center (EPC), meaning they were responsible for making all business decisions and retained all profits.

Twenty-four communities in four Chiefdoms were purposively assigned to receive the intervention. After obtaining consent from local traditional leadership, four to five smallholder farmers from each community were recruited by COMACO extension staff to be trained as egg producers, with 80% targeted female participation. Farmers were eligible for selection if they were members of a COMACO Poultry Producer group, had a history of successfully adopting recommended agricultural practices, and were vulnerable to food insecurity and poverty in the subjective assessment of COMACO's Area Managers.

After the EPCs were built, all of the enrolled egg producers were trained in hen health, biosecurity, food safety, and business management, with two subsequent refresher trainings. Each EPC was stocked with 40 layers at the point of lay in August 2015, and egg production began the following month. During egg production, COMACO extension staff monitored production records and intervened with groups where necessary to resolve disputes or address production concerns. However, groups had primary responsibility for their own businesses, including marketing eggs, purchasing feed, and maintaining the facility and production records. Additional details about the EPCs are provided in Chapter 4.

Research objectives and outline of chapters

The overall objective of this research is to investigate the effectiveness of the intervention to increase the consumption of eggs by women and young children. The chapters in this dissertation are presented in a linear fashion (Figure 1.3), beginning with formative research assessing the impact of interventions targeting village chickens on household resilience and results of a pilot program testing the semi-intensive egg production model (Chapter 2). This is followed by a cross-sectional study examining the association between livestock ownership and child nutrition outcomes in the study area, utilizing a novel "typologies" metric to quantify the scope of livestock activities in the household (Chapter 3). We then explore the EPC model in more detail, examining its productivity, profitability, and participant experiences with the program (Chapter 4). Finally, we analyze the impact of the intervention on the egg consumption habits, diets, and nutritional status of women and young children residing around the EPCs (Chapter 5).

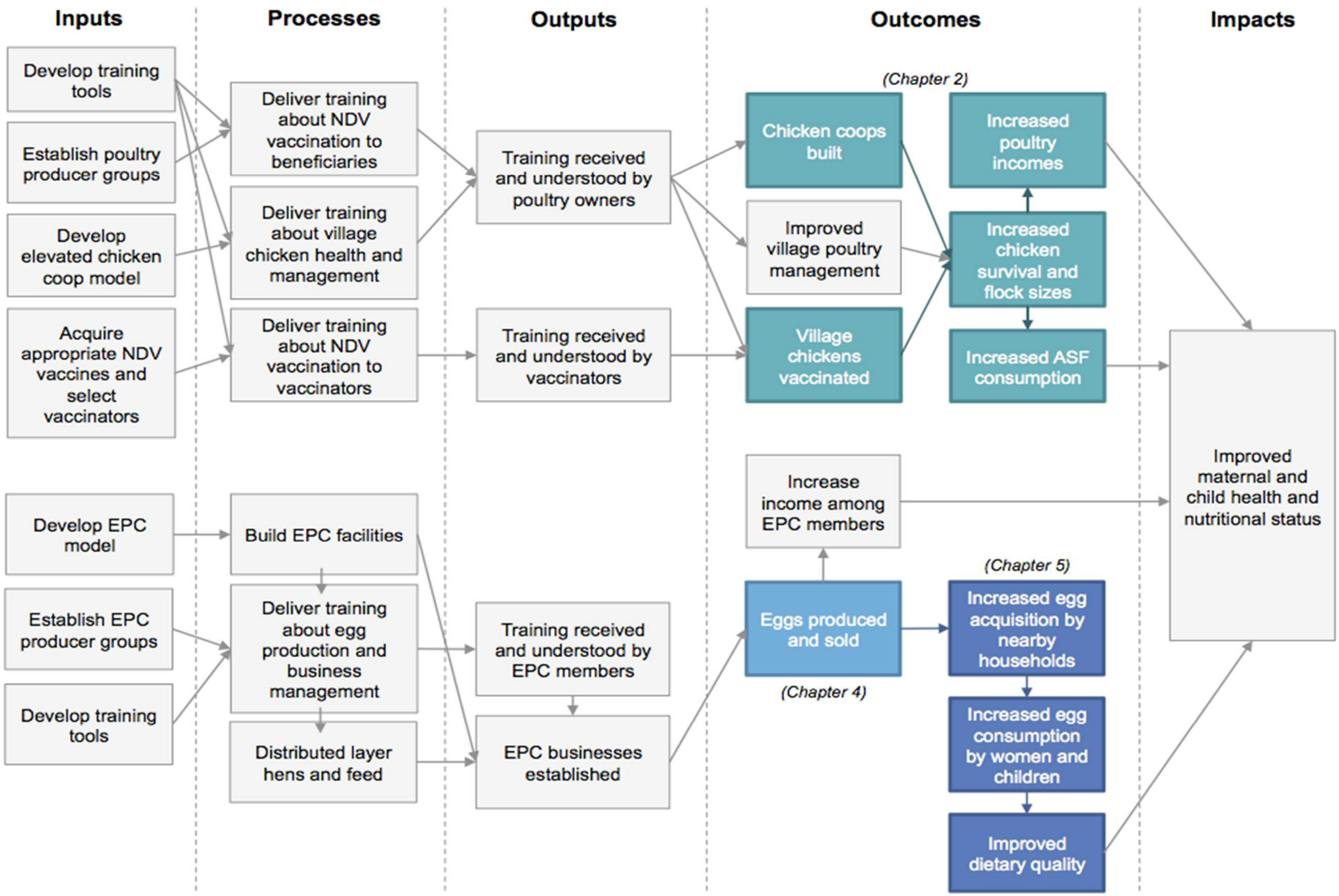


Figure 1.3. Simplified program impact pathway depicting hypothesized pathways through which COMACO's village poultry (top) and EPC (bottom) interventions may improve maternal and child health and nutrition in the Luangwa Valley

The specific research objectives of each chapter are as follows:

Chapter 2:

- To examine the impact of interventions aiming to improve the survival of village chickens on flock size, poultry profits, and ASF consumption within participating households
- To evaluate the acceptability and appropriateness of a semi-intensive egg production model as a means of enhancing the availability and consumption of eggs in participating communities

Chapter 3:

- To investigate the association between traditional livestock ownership and dietary diversity, ASF consumption, HAZ, and stunting prevalence among children using a novel livestock typology approach

Chapter 4:

- To evaluate the productivity and profitability of 24 newly-established EPCs
- To assess the impact of the EPCs on egg producer households, including on household food security and individual satisfaction with the program
- To identify programmatic challenges and barriers to success and make recommendations for improvement during scaling up

Chapter 5:

- To evaluate the impact of the EPC program on egg consumption and dietary diversity among women and young children (6 – 36 months of age) living in participating communities

- To evaluate the impact of the EPC program on the HAZ of young children (6 – 36 months of age) living in participating communities

To conclude, I will synthesize our findings and discuss the implications for practitioners seeking to implement nutrition-sensitive livestock development programs, with specific emphasis on the potential role of semi-intensive egg production programs.

References

Adair, L. S., Fall, C. H., Osmond, C., Stein, A. D., Martorell, R., Ramirez-Zea, M., et al. (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. *The Lancet*, *382*(9891), 525–534. doi: 10.1016/S0140-6736(13)60103-8

Ahmed, M. M., Jabbar, M., & Ehui, S. (2000). Household-level economic and nutritional impacts of market-oriented dairy production in the Ethiopian highlands. *Food and Nutrition Bulletin*, *21*(4), 460–465.

Albrecht, R. W. (1973). Luangwa Valley Conservation and Development Project, Zambia: Land use development proposals for the mid and upper Luangwa watershed. No. FO:DP/ZAM/68/510. Working Doc. No. 3. Rome: UNDP/FAO.

Alderman, H. (1987). Cooperative dairy development in Karnataka, India: An assessment. Washington, D.C.: International Food Policy Research Institute.

Allen, L. H., Backstrand, J. R., & Stanek, E. J. (1992). The interactive effects of dietary quality on the growth and attained size of young Mexican children. *The American Journal of Clinical Nutrition*, *56*, 353–364.

Allen, L. H. (1993). The nutrition CRSP: What is marginal malnutrition, and does it affect human function? *Nutrition Reviews*, *51*(9), 255–267.

Allen, L. H. (2003). Interventions for micronutrient deficiency control in developing countries: Past, present and future. *The Journal of Nutrition*, *133*(11), 3875S–3878S.

Allen, L. H. (2012). Global dietary patterns and diets in childhood: Implications for health outcomes. *Annals of Nutrition and Metabolism*, *61*(s1), 29–37. doi:10.1159/000346185

Allen, L. H., Backstrand, J. R., & Stanek, E. J. (1992). The interactive effects of dietary quality on the growth and attained size of young Mexican children. *The American Journal of Clinical Nutrition*, *56*, 353–364.

Amugsi, D. A., Lartey, A., Kimani-Murage, E., & Mberu, B. U. (2016). Women's participation in household decision-making and higher dietary diversity: findings from nationally representative data from Ghana. *Journal of Health, Population and Nutrition, 35(1)*, 16-24. doi:10.1186/s41043-016-0053-1

Appoh, L. Y., & Krekling, S. (2005). Maternal nutritional knowledge and child nutritional status in the Volta region of Ghana. *Maternal & Child Nutrition*, *1*(2), 100–110. doi:10.1111/j.1740-8709.2005.00016.x

Aregheore, E. M. (2009). Country pasture/forage resource profiles: Zambia. Rome: FAO. Retrieved from http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Zambia.pdf

Arimond, M., & Ruel, M. T. (2004). Dietary diversity is associated with child nutritional status: Evidence from 11 Demographic and Health Surveys. *The Journal of Nutrition*, *134*(10), 2579–2585.

Ayalew, W., Gebriel, Z. W., & Kassa, H. (1999). Reducing vitamin A deficiency in Ethiopia: Linkages with a women-focused dairy goat farming project. ICRW/OMNI Research Program, Research Report Series, No. 4. Washington, D.C.: International Center for Research on Women.

Ayele, Z., & Peacock, C. (2003). Improving access to and consumption of animal source foods in rural households: the experiences of a women-focused goat development program in the highlands of Ethiopia. *The Journal of Nutrition*, *133*(11 Suppl 2), 3981S–3986S.

Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does livestock ownership affect animal source foods consumption and child nutritional status? Evidence from rural Uganda. *Journal of Development Studies*, *51*(8), 1034–1059. doi:10.1080/00220388.2015.1018905

Baldwin, K. (2015). The Paradox of Traditional Chiefs on Democratic Africa. Cambridge, England: Cambridge University Press.

Banda, D. (2008). Education for All (EFA) and "African Indigenous Knowledge Systems (AIKS)": the Case of the Chewa People of Zambia (doctoral dissertation). University of Nottingham, Nottingham, England.

Bauserman, M., Lokangaka, A., Gado, J., Close, K., Wallace, D., Kodondi, K. K., et al. (2015). A cluster-randomized trial determining the efficacy of caterpillar cereal as a locally available and sustainable complementary food to prevent stunting and anaemia. *Public Health Nutrition*, 1785-1792. doi:10.1017/S1368980014003334

Begum, J. M. (1994). The impact of dairy development on protein and calorie intake of pre-school children. *Indian Journal of Medical Sciences*, *48*(3), 61–64.

Bhagowalia, P., Menon, P., Quisumbing, A. R., & Soundararajan, V. (2012). What dimensions of women's empowerment matter most for child nutrition? Evidence using nationally representative cata from Bangladesh. Washington, DC: International Livestock Research Institute.

Bhandari, N., Bahl, R., Nayyar, B., Khokhar, P., Rohde, J. E., & Bhan, M. K. (2001). Food supplementation with encouragement to feed it to infants from 4 to 12 months of age has a small impact on weight gain. *The Journal of Nutrition*, *131*(7), 1946–1951.

Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M., et al. (2008). Maternal and child undernutrition: global and regional exposures and health consequences. *The Lancet*, *371*(9608), 243–260. doi:10.1016/S0140-6736(07)61690-0

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451. doi:10.1016/S0140-6736(13)60937-X

Bouis, H. E. (2000). Commercial vegetable and polyculture fish production in Bangladesh: Their impacts on household income and dietary quality. *Food and Nutrition Bulletin*, *21*(4), 482–487.

Brugere, C., Mcandrew, K., & Bulcock, P. (2001). Does cage aquaculture address gender goals in development? Results of a case study in Bangladesh. *Aquaculture Economics & Management*, *5*(3-4), 179–189. doi:10.1080/13657300109380286

Central Statistical Office (CSO), Ministry of Health (MOH), ICF International. (2015). Zambia Demographic and Health Survey 2013-14. Rockville, MA, USA: CSO, MOH, and ICF.

Community Markets for Conservation (COMACO). (2014). *Community Markets for Conservation: Project description document for 2014-2018*. Lusaka, Zambia: COMACO.

Curry, J. (1996). Gender and livestock in African production systems: An introduction. *Human Ecology*, *24*(2), 149–160.

Dalal-Clayton, B., & Child, B. (2003). *Lessons from Luangwa: The story of the Luangwa integrated resource development project, Zambia.* London: International Institute for Environment and Development (IIED).

Dalton, A., Wolmarans, P., Witthuhn, R. C., van Stuijvenberg, M. E., Swanevelder, S. A., & Smuts, C. M. (2009). A randomised control trial in schoolchildren showed improvement in cognitive function after consuming a bread spread, containing fish flour from a marine source. *Prostaglandins, Leukotrienes, and Essential Fatty Acids*, *80*(2-3), 143–149. doi:10.1016/j.plefa.2008.12.006

Darapheak, C., Takano, T., Kizuki, M., Nakamura, K., & Seino, K. (2013). Consumption of animal source foods and dietary diversity reduce stunting in children in Cambodia. *International Archives of Medicine*, *6*(1), 29. doi:10.1186/1755-7682-6-29

Davis, B., Winters, P., Carletto, G., Covarrubias, K., Quinones, E., Zezza, A., et al. (2007). Rural income generating activities: A cross-country comparison. ESA Working Paper No. 07-16. Rome: FAO.

de Onis, M., & Branca, F. (2016). Childhood stunting: a global perspective. *Maternal & Child Nutrition*, *12*(S1), 12–26. doi:10.1111/mcn.12231

Department for International Development (DFID). (1999). Sustainable livelihoods guidance sheets. London: DFID. Retrieved from http://www.ennonline.net/dfidsustainableliving

Diarrhea: Common illness, global killer. (2015, December 17). *Centers for Disease Control and Prevention.* Retrieved from https://www.cdc.gov/healthywater/global/diarrhea-burden.html

Dodds, D. G., & Patton, D. R. (1968). Wildlife and land use survey of the Luangwa Valley: Report to the Government of Zambia. Rep TA2591. Rome: United Nations Development Programme (UNDP).

Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, *32*(3), 227–243.

Dumas, S. E., Maranga, A., Mbullo, P., Collins, S., Wekesa, P., Onono, M., & Young, S. L. (2017). “Men are in front at eating time, but not when it comes to rearing the chicken”: Unpacking the Gendered Benefits and Costs of Livestock Ownership in Kenya. Food and Nutrition Bulletin, *in press*.

EADD. (2013). Gender, dairy production, and marketing: Baseline surveys report (report 6). Nairobi, Kenya: East Africa Dairy Development Project/International Livestock Research Institute. Retrieved from https://cgspace.cgiar.org/handle/10568/34456

English, R. M., Badcock, J. C., Giay, T., Ngu, T., Waters, A. M., & Bennett, S. A. (1997). Effect of nutrition improvement project on morbidity from infectious diseases in preschool children in Vietnam: comparison with control commune. *BMJ*, *315*(7116), 1122–1125.

English, R., & Badcock, J. (1998). A community nutrition project in Viet Nam: Effects on child morbidity. *Food, Nutrition, and Agriculture*, *22*, 15–21.

Fierstein, J. L., Eliasziw, M., Rogers, B. L., & Forrester, J. E. (2017). Nonnative cattle ownership, diet, and child height-for-age: Evidence from the 2011 Uganda Demographic and Health Survey. *American Journal of Tropical Medicine and Hygiene*, *96*(1), 74–82. doi:10.4269/ajtmh.16-0646

Flintan, F. (2008). Women's empowerment in pastoral societies. Nairobi, Kenya: World Initiative for Sustainable Pastoralism, Global Environment Facility, International Union for Conservation of Nature, United Nations Development Programme.

FAOStat Database. Food and Agriculture Organization (FAO). (Accessed 2017, July 7) Retrieved from http://faostat3.fao.org/home/E

FAO (2009). The state of food and agriculture, 2009: Livestock in the balance.

Galal, O. M., Harrison, G. G., Abdou, A. I., & Abedin, El, A. Z. (1987). The impact of a small-scale agricultural intervention on socio-economic and health status. *Food and Nutrition*, *13*(1), 35–43.

Galiè, A., Mulema, A., Benard, M. A. M., Onzere, S. N., & Colverson, K. E. (2015). Exploring gender perceptions of resource ownership and their implications for food security among rural livestock owners in Tanzania, Ethiopia, and Nicaragua. *Agriculture & Food Security*, *4*(1), 2. doi:10.1186/s40066-015-0021-9

George, C. M., Oldja, L., Biswas, S. K., Perin, J., Lee, G. O., Ahmed, S., et al. (2015a). Fecal markers of environmental enteropathy are associated with animal exposure and caregiver hygiene in Bangladesh. *The American Journal of Tropical Medicine and Hygiene*, *93*(2), 269–275. doi:10.4269/ajtmh.14-0694

George, C. M., Oldja, L., Biswas, S., Perin, J., Lee, G. O., Kosek, M., et al. (2015b). Geophagy is associated with environmental enteropathy and stunting in children in rural Bangladesh. *The American Journal of Tropical Medicine and Hygiene*, *92*(6), 1117–1124. doi:10.4269/ajtmh.14-0672

Gittelsohn, J., & Vastine, A. E. (2003). Sociocultural and household factors impacting on the selection, allocation and consumption of animal source foods: Current knowledge and application. *The Journal of Nutrition*, *133*(11), 4036S–4041S.

Gittelsohn, J., Shankar, A. V., & West, K. P., Jr. (1997). Infant feeding practices reflect antecedent risk of xerophthalmia in Nepali children. *European Journal of Clinical Nutrition*, *51*(7), 484–490. doi:10.1038/sj.ejcn.1600435

Good, S. (2009). Animal source foods and nutrition during early life: an evaluation of the possible link between livestock keeping, food intake and nutritional status of young children in Ethiopia (doctoral dissertation). ETH Zurich, Zurich, Switzerland.

Government of the Republic of Zambia & United Nations Development Programme (UNDP). (2010). *Adaptation to the effects of drought and climate change in Agro-ecological Regions I and II in Zambia* (No. PIMS No. 3942). Lusaka, Zambia: United Nations Development Programme.

Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L., et al. (2012). Mapping of poverty and likely zoonoses hotspots. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Graham, G. G., Creed, H. M., MacLean, W. C., Kallman, C. H., Rabold, J., & Mellits, E. D. (1981). Determinants of growth among poor children: nutrient intake-achieved growth relationships. *American Journal of Clinical Nutrition*, *34*(4), 539–554.

Grillenberger, M., Neumann, C. G., Murphy, S. P., Bwibo, N. O., van't Veer, P., Hautvast, J., & West, C. E. (2003). Food supplements have a positive impact on weight gain and the addition of animal source foods increases lean body mass of Kenyan schoolchildren. *The Journal of Nutrition*, *133*(11), 3957S–3964S.

Grillenberger, M., Neumann, C. G., Murphy, S. P., Bwibo, N. O., Weiss, R. E., Jiang, L., et al. (2006). Intake of micronutrients high in animal-source foods is associated with better growth in rural Kenyan school children. *British Journal of Nutrition*, *95*(02), 379–390.

Grosse, S. D. (1999). Farm animals and children's nutritional status in rural Rwanda. Presented at Symposium on Human Nutrition and Livestock in the Developing World, 1998, October 14, (pp. 190–200). Little Rock, AR: Heifer Project International.

Gueye, E. F. (2000). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on Agriculture*, *29*(2), 129–136.

Habtemariam, K., Ayalew, W., Habte, G. Z., & Gebre, M. T. (2003). Enhancing the role of livestock production in improving nutritional status of farming families: Lessons from a dairy goat development project in Eastern Ethiopia. *Livestock Research for Rural Development*, *15*(6). Retrieved from http://www.lrrd.org/lrrd15/6/kass156.htm

Hall, A., Hanh, T. T. M., Farley, K., Quynh, T. P. N., & Valdivia, F. (2007). An evaluation of the impact of a school nutrition programme in Vietnam. *Public Health Nutrition*, *10*(08), 348–8. doi:10.1017/S1368980007382530

Headey, D., & Hirvonen, K. (2016). Is exposure to poultry harmful to child nutrition? An observational analysis for rural ethiopia. *PloS One*, *11*(8), e0160590–16. doi:10.1371/journal.pone.0160590

Headey, D., Nguyen, P., Kim, S., Rawat, R., Ruel, M., & Menon, P. (2017). Is exposure to animal feces harmful to child nutrition and health outcomes? A multicountry observational analysis. *The American Journal of Tropical Medicine and Hygiene*, *96*(4), 961–969. doi:10.4269/ajtmh.16-0270

Herath, S. (2008). Women in livestock development in Asia. *Journal of Commonwealth Veterinary Association*, *24*(1), 29–37.

Herrador, Z., Sordo, L., Gadisa, E., Moreno, J., Nieto, J., Benito, A., et al. (2014). Cross-sectional study of malnutrition and associated factors among school aged children in Rural and urban Settings of Fogera and Libo Kemkem Districts, Ethiopia. *PloS One*, *9*(9), e105880–11. doi:10.1371/journal.pone.0105880

Herrero, M., Grace, D., Njuki, J. M., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. *Animal*, *7*(s1), 3–18. doi:10.1017/S1751731112001954

Hoddinott, J., Headey, D., & Dereje, M. (2015). Cows, missing milk markets, and nutrition in rural Ethiopia. *Journal of Development Studies*, *51*(8), 958–975. doi:10.1080/00220388.2015.1018903

Hoffine, T. (2013). *Zambia Food Security Brief.* USAID Famine Early Warning Systems Network (FEWS NET). Retrieved from http://www.fews.net/southern-africa/zambia/food-security-brief/march-2014

Hoorweg, J., Leegwater, P., & Veerman, W. (2000). Nutrition in agricultural development: Intensive dairy farming by rural smallholders. *Ecology of Food and Nutrition*, *39*(6), 395–416. doi:10.1080/03670244.2000.9991627

Iannotti, L. L., & Lesorogol, C. (2014). Animal milk sustains micronutrient nutrition and child anthropometry among pastoralists in Samburu, Kenya. *American Journal of Physical Anthropology*, *155*(1), 66–76. doi:10.1002/ajpa.22547

Iannotti, L. L., Lutter, C. K., Bunn, D. A., & Stewart, C. P. (2014). Eggs: The uncracked potential for improving maternal and young child nutrition among the world's poor. *Nutrition Reviews*, *72*(6), 355–368. doi:10.1111/nure.12107

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., et al. (2017). Eggs in early complementary feeding and child growth: A randomized controlled trial. *Pediatrics*, e20163459. doi:10.1542/peds.2016-3459

Jin, M., & Iannotti, L. L. (2014). Livestock production, animal source food intake, and young child growth: The role of gender for ensuring nutrition impacts. *Social Science & Medicine*, *105*, 16–21. doi:10.1016/j.socscimed.2014.01.001

Johnston, D., Stevano, S., Malapit, H., Hull, E., & Kadiyala, S. (2015). *Agriculture, gendered time use, and nutritional outcomes: A systematic reveiw*. IFPRI Discussion Paper 01456. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Kennedy, G. L., Pedro, M. R., Seghieri, C., Nantel, G., & Brouwer, I. (2007). Dietary diversity score is a useful indicator of micronutrient intake in non-breast-feeding Filipino children. *The Journal of Nutrition*, *137*(2), 472–477.

Knueppel, D., Cardona, C., Msoffe, P., Demment, M. W., & Kaiser, L. (2010). Impact of vaccination against chicken Newcastle disease on food intake and food security in rural households in Tanzania. *Food and Nutrition Bulletin*, *31*(3), 436–445.

Krasevec, J., An, X., Kumapley, R., Bégin, F., & Frongillo, E. A. (2017). Diet quality and risk of stunting among infants and young children in low- and middle-income countries. *Maternal & Child Nutrition*, *13*(Suppl 3), e12430–11.

Krebs, N. F., Mazariegos, M., Tshefu, A., Bose, C., Sami, N., Chomba, E., et al. (2011). Meat consumption is associated with less stunting among toddlers in four diverse low-income settings. *Food and Nutrition Bulletin*, *32*(3), 185–191.

Krebs, N. F., Mazariegos, M., Chomba, E., Sami, N., Pasha, O., Tshefu, A., et al. (2012). Randomized controlled trial of meat compared with multimicronutrient-fortified cereal in infants and toddlers with high stunting rates in diverse settings. *American Journal of Clinical Nutrition*, *96*(4), 840–847. doi:10.3945/ajcn.112.041962

Kristjanson, P., Waters-Bayer, A., Johnson, N., Tipilda, A., Njuki, J. M., Baltenweck, I., et al. (2014). Livestock and Women’s Livelihoods. In Quisumbing, A. R. et al. (eds), *Gender in Agriculture: Closing the Knowledge Gap* (pp. 209–233). Dordrecht, Netherlands: Springer.

Kumar, N., & Quisumbing, A. R. (2010). *Access, adoption, and diffusion: Understanding the long-term impacts of improved vegetable and fish technologies in Bangladesh*. *IFRPI Discussion Paper*. Washington, DC: IFPRI (International Food Policy Research Institute).

Lampl, M., Johnston, F. E., & Malcolm, L. A. (2009). The effects of protein supplementation on the growth and skeletal maturation of New Guinean school children. *Annals of Human Biology*, *5*(3), 219–227. doi:10.1080/03014467800002841

Lane, J. (2016). Demystifying the pathways of impact of a livestock transfer program on household resilience & food security in Malawi. Presented at "Agriculture for Nutrition and Health Academy Week" in Addis Ababa, June 20.

Leonard, W. R., Dewalt, K. M., Stansbury, J. P., & McCaston, M. K. (2000). Influence of dietary quality on the growth of highland and coastal Ecuadorian children. *American Journal of Human Biology*, *12*(6), 825–837.

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences of the U. S. A.*, *108*(34), 13957–13962. doi:10.1073/pnas.1011538108

Lien, D. T. K., Nhung, B. T., Khan, N. C., Hop, L. T., Nga, N. T. Q., Hung, N. T., et al. (2009). Impact of milk consumption on performance and health of primary school children in rural Vietnam. *Asia Pacific Journal of Clinical Nutrition*, *18*(3), 326–334.

Lindsey, P., Nyirenda, V., Barnes, J., Becker, M., Tambling, C., Taylor, A., & Watson, F. (2013). *Zambian Game Management Areas.* Wildlife Producers Association of Zambia (WPAZ). Retrieved from http://landforlions.org/data/documents/ Lindsey-et-al-GMA-REPORT.pdf

Long, J. K., Murphy, S. P., Weiss, R. E., Nyerere, S., Bwibo, N. O., & Neumann, C. G. (2011). Meat and milk intakes and toddler growth: a comparison feeding intervention of animal-source foods in rural Kenya. *Public Health Nutrition*, *15*(06), 1100–1107. doi:10.1017/S1368980011002746

MacDonald, A. C., Main, B. J., Namarika, R. H., Yiannakis, M. E., & Mildon, A. M. (2011). Small-animal revolving funds: an innovative programming model to increase access to and consumption of animal-source foods by rural households in Malawi. In B. Thompson & L. Amoroso (Eds.), *Combating Micronutrient Deficiencies: Food-based Approaches* (pp. 137–149). Rome: FAO and CAB International.

Malcolm, L. A. (1970). Growth retardation in a New Guinea boarding school and its response to supplementary feeding. *British Journal of Nutrition*, *24*, 297–305. doi:10.1079/BJN19700029

Marquis, G. S., Habicht, J. P., Lanata, C. F., Black, R. E., & Rasmussen, K. M. (1997). Breast milk or animal-product foods improve linear growth of Peruvian toddlers consuming marginal diets. *American Journal of Clinical Nutrition*, *66*(5), 1102–1109.

Marquis, G. S., Ventura, G., Gilman, R. H., Porras, E., Miranda, E., Carbajal, L., & Pentafiel, M. (1990). Fecal contamination of shanty town toddlers in households with non-corralled poultry, Lima, Peru. *American Journal of Public Health*, *80*(2), 146–149.

Marten, L., & Kula, N. C. (2008). Zambia: 'One Zambia, One Nation, Many Languages'. In A. Simpson (Ed.), *Language and National Identity in Africa* (pp. 291–313). Oxford: Oxford University Press.

McLean, E. D., Allen, L. H., Neumann, C. G., Peerson, J. M., Siekmann, J. H., Murphy, S. P., et al. (2007). Low plasma vitamin B-12 in Kenyan school children is highly prevalent and improved by supplemental animal source foods. *The Journal of Nutrition*, *137*(3), 676–682.

Miller, L. C., Joshi, N., Lohani, M., Rogers, B., Loraditch, M., Houser, R., et al. (2014). Community development and livestock promotion in rural Nepal: effects on child growth and health. *Food and Nutrition Bulletin*, *35*(3), 312–326.

Miller, L. C., Joshi, N., Lohani, M., Singh, R., Bhatta, N., Rogers, B., et al. (2016). Head growth of undernourished children in rural Nepal: association with demographics, health and diet. *Paediatrics and International Child Health*, *36*(2), 91–101. doi:10.1080/20469047.2015.1133517

Mosites, E. M., Rabinowitz, P. M., Thumbi, S. M., Montgomery, J. M., Palmer, G. H., May, S., et al. (2015). The relationship between livestock ownership and child stunting in three countries in eastern Africa using national survey data. *PloS One*, *10*(9), e0136686–10. doi:10.1371/journal.pone.0136686

Mosites, E., Thumbi, S. M., Otiang, E., McElwain, T. F., Njenga, M. K., Rabinowitz, P. M., et al. (2016). Relations between household livestock ownership, livestock disease, and young child growth. *The Journal of Nutrition*, (146), 1118–1124. doi:10.3945/jn.115.225961

Mullins, G., Wahome, L., Tsangari, P., & Maarse, L. (1996). Impacts of intensive dairy production on smallholder farm women in coastal Kenya. *Human Ecology*, *24*(2), 231–253.

Murphy, S. P., & Allen, L. H. (2003). Nutritional importance of animal source foods. *The Journal of Nutrition*, *133*(11), 3932S–3935S.

Murshed-e-Jahan, K., Ahmed, M., & Belton, B. (2010). The impacts of aquaculture development on food security: lessons from Bangladesh. *Aquaculture Research*, *41*(4), 481–495. doi:10.1111/j.1365-2109.2009.02337.x

Muslimatun, S., & Wiradnyani, L. A. A. (2016). Dietary diversity, animal source food consumption and linear growth among children aged 1-5 years in Bandung, Indonesia: A longitudinal observational study. *The British Journal of Nutrition*, *116 Suppl 1*(S1), S27–35. doi:10.1017/S0007114515005395

Neumann, C. G., Bwibo, N. O., Jiang, L., & Weiss, R. E. (2013a). School snacks decrease morbidity in Kenyan schoolchildren: A cluster randomized, controlled feeding intervention trial. *Public Health Nutrition*, *16*(09), 1593–1604. doi:10.1017/S1368980013000876

Neumann, C. G., Bwibo, N. O., Murphy, S. P., Sigman, M., Whaley, S. E., Allen, L. H., et al. (2003). Animal source foods improve dietary quality, micronutrient status, growth and cognitive function in Kenyan school children: Background, study design and baseline findings. *The Journal of Nutrition*, *133*(11), 3941S–3949S.

Neumann, C. G., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research*, *22*(1-2), 193–220. doi:10.1016/s0271-5317(01)00374-8

Neumann, C. G., Jiang, L., Weiss, R. E., Grillenberger, M., Gewa, C. A., Siekmann, J. H., et al. (2013b). Meat supplementation increases arm muscle area in Kenyan schoolchildren. *British Journal of Nutrition*, *109*(07), 1230–1240. doi:10.1017/S0007114512003121

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., et al. (2013). Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *The American Journal of Tropical Medicine and Hygiene*, *89*(4), 709–716. http://doi.org/10.4269/ajtmh.12-0568

Nicholson, C. F., Mwangi, L., Staal, S. J., & Thornton, P. K. (2003). Dairy cow ownership and child nutritional status in Kenya. Presented at the AAEA Annual Meetings, Montreal, Quebec, Canada, July 27-30.

Nielsen, H. (1996). Socio-economic impact of smallholder livestock development project, Bangladesh (pp. 64–70). Presented at the Integrated Farming in Human Development Workshop Report. Danish Agricultural and Rural Development Advisers Forum, Tune Landboskole, Denmark.

Nielsen, H., Roos, N., & Thilsted, S. H. (2003). The impact of semi-scavenging poultry production on the consumption of animal source foods by women and girls in Bangladesh. *The Journal of Nutrition*, *133*(11 Suppl 2), 4027S–4030S.

Njuki, J. M., & Sanginga, P. C. (2013). Women, livestock ownership and markets: Bridging the gender gap in eastern and southern Africa. Abingdon, Oxon, UK: Routledge.

Njuki, J. M., Kaaria, S., Chamunorwa, A., & Chiuri, W. (2011). Linking smallholder farmers to markets, gender and intra-household dynamics: Does the choice of commodity matter? *European Journal of Development Research*, *23*(3), 426–443. doi:10.1057/ejdr.2011.8

Njuki, J. M., Wyatt, A., Baltenweck, I., Yount, K., Null, C., Ramakrishnan, U., et al. (2015). An exploratory study of dairying intensification, women's decision making, and time use and implications for child nutrition in Kenya. *European Journal of Development Research*, *28*(4), 722–740. doi:10.1057/ejdr.2015.22

Okike, I., Jabbar, M. A., Abate, G., & Ketema, L. (2005). Household and environmental factors influencing anthropometric outcomes in preschool children in a rural Ethiopian community. *Ecology of Food and Nutrition*, *44*(3), 167–187. doi:10.1080/03670240590952990

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. *Food and Nutrition Bulletin*, *30*(4), 355–369.

Olney, D. K., Vicheka, S., Kro, M., & Chakriya, C. (2013). Using program impact pathways to understand and improve program delivery, utilization, and potential for impact of Helen Keller International's Homestead Food Production Program in Cambodia. *Food and Nutrition Bulletin*, *34*(2), 169–184.

Pachon, H., Simondon, K. B., Fall, S. T., Menon, P., Ruel, M. T., Hotz, C., et al. (2007). Constraints on the delivery of animal-source foods to infants and young children: Case studies from five countries. *Food and Nutrition Bulletin*, *28*(2), 215–229.

Pell, A. N., & Kristjanson, P. (2010). Livestock development projects that make a difference:what works, what doesn't and why. In Swanepoel et al. (eds), *The Role of Livestock in Developing Communities: Enhancing Multifunctionality* (pp. 10-29). Bloemfontein, South Africa: UFS and CTA.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., et al. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800. doi:10.2527/jas.2007-0467

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., & Wydick, B. (2014). Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy*, *44*(C), 202–213. doi:10.1016/j.foodpol.2013.12.003

Roos, N., Islam, M. M., & Thilsted, S. H. (2003). Small indigenous fish species in Bangladesh: Contribution to vitamin A, calcium and iron intakes. *The Journal of Nutrition*, *133*(11 Suppl 2), 4021S–4026S.

Sadler, K., Mitchard, E., Abdi, A., Shiferaw, Y., Bekele, G., & Catley, A. (2012). Milk matters: The impact of dry season livestock support on milk supply and child nutrition in Somali region, Ethiopia. Addis Ababa, Ethiopia: Feinstein International Center, Tufts University, and Save the Children. Retrieved from https://www.savethechildren.net/sites/default/files/libraries/Milk-Matters%20Report%202012.pdf

Sari, M., de Pee, S., Bloem, M. W., Sun, K., Thorne-Lyman, A. L., Moench-Pfanner, R., et al. (2009). Higher household expenditure on animal-source and nongrain foods lowers the risk of stunting among children 0-59 months old in Indonesia: Implications of rising food prices. *The Journal of Nutrition*, *140*(1), 195S–200S. doi;10.3945/jn.109.110858

Schipani, S., van der Haar, F., Sinawat, S., & Maleevong, K. (2002). Dietary intake and nutritional status of young children in families practicing mixed home gardening in northeast Thailand. *Food and Nutrition Bulletin*, *23*(2), 175–180.

Siekmann, J. H., Allen, L. H., Bwibo, N. O., Demment, M. W., Murphy, S. P., & Neumann, C. G. (2003). Kenyan school children have multiple micronutrient deficiencies, but increased plasma vitamin B-12 is the only detectable micronutrient response to meat or milk supplementation. *The Journal of Nutrition*, *133*(11 Suppl 2), 3972S–3980S.

Sigman, M., McDonald, M. A., Neumann, C. G., & Bwibo, N. (1991). Prediction of cognitive competence in Kenyan children from toddler nutrition, family characteristics and abilities. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *32*(2), 307–320.

Sigman, M., Whaley, S. E., Neumann, C. G., Bwibo, N., Guthrie, D., Weiss, R. E., et al. (2005). Diet quality affects the playground activities of Kenyan children. *Food and Nutrition Bulletin*, *26*(2 Suppl 2), S202–12. doi:10.1177/15648265050262S211

Smitasiri, S., & Dhanamitta, S. (1999). *Sustaining behavior change to enhance micronutrient status: Community and women-based interventions in Thailand*. Washington, DC: International Center for Research on Women (ICRW) / Opportunity for Micronutrients Interventions (OMNI).

Smith, L. C., & Haddad, L. (2015). Reducing child undernutrition: Past drivers and priorities for the post-MDG era. *World Development*, *68*(C), 180–204. doi:10.1016/j.worlddev.2014.11.014

Smith, L. C., Ramakrishnan, U., Ndiaye, A., Haddad, L., & Martorell, R. (2003). The importance of women's status for child nutrition in developing countries. Washington, DC: International Food Policy Research Institute (IFPRI).

Steinfeld, H. (2003). Economic constraints on production and consumption of animal source foods for nutrition in developing countries. *The Journal of Nutrition*, *133*(11), 4054S–4061S.

Stewart, C. P., Iannotti, L. L., Dewey, K. G., Michaelsen, K. F., & Onyango, A. W. (2013). Contextualising complementary feeding in a broader framework for stunting prevention. *Maternal & Child Nutrition*, *9*(4), 27–45. doi:10.1111/mcn.12088

Steyn, N. P., Nel, J. H., Nantel, G., Kennedy, G., & Labadarios, D. (2007). Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? *Public Health Nutrition*, *9*(05), 156–7. doi:10.1079/PHN2005912

Talukder, A., Haselow, N. J., Osei, A. K., Villate, E., Reario, D., Kroeun, H., et al. (2010). Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations - lessons learned from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philippines). *Field Actions Science Report*, 1–9. Retrieved from http://factsreports.revues.org/404?file=1

Tangka, F., Ouma, E. A., & Staal, S. J. (1999). Women and the sustainable development of market-oriented dairying: evidence from the highlands of East Africa. Nairobi, Kenya: ILRI.

Thompson, P. M., Sultana, P., Nuruzzaman, M., & Khan, A. F. (2000). Impacts of aquaculture extension on pond operators and the rural community. *IIFET Proceedings*. Retrieved from https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/30440/013.pdf?sequence=1

Torun, B. (2005). Energy requirements of children and adolescents. *Public Health Nutrition*, *8*(7a), 343–26. doi:10.1079/PHN2005791

Turyashemererwa, F. M., Kikafunda, J., Annan, R., & Tumuhimbise, G. A. (2013). Dietary patterns, anthropometric status, prevalence and risk factors for anaemia among school children aged 5-11 years in Central Uganda. *Journal of Human Nutrition and Dietetics, 26 Suppl 1*, 73–81.

UNICEF. (1990). Strategy for improved nutrition of children and women in developing countries. In *UNICEF Policy Review*. New York: UNICEF.

UNICEF, WHO, & The World Bank. (2016). Levels and trends in child malnutrition: UNICEF/ WHO/ World Bank Group Joint Child Malnutrition Estimates. New York: UNICEF, WHO, & The World Bank.

Valdivia, C. (2001). Gender, livestock assets, resource management, and food security: Lessons from the SR-CRSP. *Agriculture and Human Values*, *18*(1), 27–39. doi:10.1023/A:1007613031102

van Klinken, A. S. (2013). Gay rights, the devil and the end times: public religion and the enchantment of the homosexuality debate in Zambia. *Religion*, *43*(4), 519–540. doi:10.1080/0048721X.2013.765631

Victora, C. G., Adair, L., Fall, C., Hallal, P. C., Martorell, R., Richter, L., & Sachdev, H. S. (2008). Maternal and child undernutrition: consequences for adult health and human capital. *The Lancet*, *371*(9609), 340–357. doi:10.1016/S0140-6736(07)61692-4

Walingo, M. K. (2009). Role of livestock projects in empowering women smallholder farmers for sustainable food security in rural Kenya. *African Journal of Food, Agriculture, Nutrition, and Development*, *9*(7).

Walker, S. P., Powell, C. A., & Grantham-McGregor, S. M. (1990). Dietary intakes and activity levels of stunted and non-stunted children in Kingston, Jamaica, Part 1: Dietary intakes. *European Journal of Clinical Nutrition*, *44*, 527–534.

Walker, S. P., Powell, C. A., Grantham-McGregor, S. M., Himes, J. H., & Chang, S. M. (1991). Nutritional supplementation, psychosocial stimulation, and growth of stunted children: The Jamaican study. *American Journal of Clinical Nutrition*, *54*(4), 642–648.

Walker, S. P., Chang, S. M., Powell, C. A., & Grantham-Mcgregor, S. M. (2005). Effects of early childhood psychosocial stimulation and nutritional supplementation on cognition and education in growth-stunted Jamaican children: prospective cohort study. *The Lancet*, *366*(9499), 1804–1807. doi:10.1016/S0140-6736(05)67574-5

Walton, C., Taylor, J., VanLeeuwen, J., Yeudall, F., & Mbugua, S. (2012). Associations of diet quality with dairy group membership, membership duration and non-membership for Kenyan farm women and children: a comparative study. *Public Health Nutrition*, *17*(02), 307–316. doi:10.1017/S1368980012005010

Wangui, E. E. (2008). Development interventions, changing livelihoods, and the making of female Maasai pastoralists. *Agriculture and Human Values*, *25*(3), 365–378. doi:10.1007/s10460-007-9111-z

Whaley, S. E., Sigman, M., Neumann, C. G., Bwibo, N., Guthrie, D., Weiss, R. E., et al. (2003). The impact of dietary intervention on the cognitive development of Kenyan school children. *The Journal of Nutrition*, *133*(11), 3965S–3971S.

WHO Multicentre Growth Reference Study Group. (2006). Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. *Acta Pædiatrica*, (Suppl 450), 56–65. doi:10.1080/08035320500495514

Widodo, Y., Sandjaja, S., Sumedi, E., Khouw, I., & Deurenberg, P. (2016). The effect of socio-demographic variables and dairy use on the intake of essential macro- and micronutrients in 0.5-12-year-old Indonesian children. *Asia Pacific Journal of Clinical Nutrition*, *25*(2), 356–367. doi:10.6133/apjcn.2016.25.2.09

Wong, J. T., de Bruyn, J., Bagnol, B., Grieve, H., Li, M., Pym, R., & Alders, R. G. (2017). Small-scale poultry and food security in resource-poor settings: A review. *Global Food Security*. doi:10.1016/j.gfs.2017.04.003

Wyatt, A. J., Yount, K. M., Null, C., Ramakrishnan, U., & Webb-Girard, A. (2013). Dairy intensification, mothers and children: an exploration of infant and young child feeding practices among rural dairy farmers in Kenya. *Maternal & Child Nutrition*, *11*(1), 88–103. doi:10.1111/mcn.12074

Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *108*(6), 313–325. doi:10.1093/trstmh/tru056

CHAPTER 2

Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia*

Sarah E. Dumas[1,2], Luke Lungu[3], Nathan Mulambya[3], Whiteson Daka[3], Erin McDonald[1], Emily Steubing[1], Tamika Lewis[1], Katherine Backel[1], Jarra Jagne[4], Benjamin Lucio-Martinez[4], Dale Lewis[3], Alexander J. Travis[1,2]

[1] Baker Institute for Animal Health, Cornell University, Ithaca, NY 14853, USA
[2] Atkinson Center for a Sustainable Future, Cornell University, Ithaca, NY 14853, USA
[3] Community Markets for Conservation (COMACO), Wildlife Conservation Society, Manda Hills, Lusaka, Zambia
[4] Department of Population Medicine and Diagnostic Sciences, Cornell University, Ithaca, NY 14853, USA

*A version of this manuscript was published in 2016 in *Food Security*, 8(3): 507-520, as part of a special section entitled "Linking rural livelihood resilience and food security: an international challenge."

Author contributions: SED, DL, and AJT conceptualized the research questions and study design, with input from JJ and BLM. LL, NM, and WD led implementation of the interventions, with support from SED, EM, ES, and TL. SED, EM, ES, TL, and AJT wrote data collection protocols and designed data collection instruments. SED, LL, NM, WD, EM, ES, and TL oversaw data collection. SED conducted data analysis and drafted the manuscript. All authors participated in data interpretation and critically reviewed the manuscript.

Abstract

In Zambia's Luangwa Valley, highly variable rainfall and lack of education, agricultural inputs, and market access constrain agricultural productivity, trapping smallholder farmers in chronic poverty and food insecurity. Human and animal disease (e.g. HIV and Newcastle Disease, respectively), further threaten the resilience of poor families. To cope with various shocks and stressors, many farmers employ short-term coping strategies that threaten ecosystem resilience. Community Markets for Conservation (COMACO) utilizes an agribusiness model to alleviate poverty and food insecurity through conservation farming, market development and value-added food production. COMACO promotes household, agricultural and ecological resilience along two strategic lines: improving recovery from shocks (mitigation) and reducing the risk of shock occurrence. Here we focus on two of COMACO's poultry interventions and present data showing that addressing health and management constraints within the existing village poultry system resulted in significantly improved productivity and profitability. However, once reliable productivity was achieved, farmers preferred to sell chickens rather than eat either the birds or their eggs. Sales of live birds were largely outside the community; in contrast, the sale of eggs from community-operated, semi-intensive egg production facilities was invariably within the communities. These facilities resulted in significant increases in both producer income and community consumption of eggs. This intervention therefore has the potential to improve not only producers' economic resilience, but also resilience tied to the food security and physical health of the entire community.

Introduction

USAID defines resilience as "the ability of people, household, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (USAID, 2012). Smallholder farmers in low-income countries rely on the complex interaction of social, ecological, and agricultural systems to craft livelihood strategies and achieve advantageous livelihood outcomes (e.g. food security, freedom from poverty). As such, they are extremely vulnerable to both long-term trends (e.g. climate change, land and resource degradation, endemic diseases, and population growth) and unexpected shocks (e.g. droughts, floods, market shocks, and political or ethnic conflicts). These stressors and shocks challenge their resilience, both in terms of their ability to maintain their often low-level equilibrium (chronic poverty and hunger) and their capacity to transition to a higher-level equilibrium (e.g. improved food security, income, health, and wellbeing; (Barrett & Constas, 2014)).

In Zambia's culturally and linguistically diverse Luangwa Valley, smallholder farmers have long faced social, economic, ecological, and agricultural stressors and shocks that reinforce their chronic poverty and food insecurity. This situation has worsened in recent decades because of a growing population, inadequate social, market, and physical infrastructures, human and animal disease, large-scale natural resource degradation, and increasing economic reliance on highly volatile cash crops, especially cotton (Lewis et al., 2011). Together, these factors force households to use short-term coping strategies such as unsustainable fishing practices, charcoal production, or wire snaring of game, which reduce future economic opportunities as they further deplete valuable natural resources. More information on regional vulnerabilities to agricultural production and human health and wellbeing is provided in Appendix 1.

The economic and social dependence of farming households on an underperforming agricultural system and rapidly diminishing natural resource base emphasizes the importance of recognizing the region as a *system*. This underscores the strong synergistic relationship among *ecological resilience*, the capacity of an ecosystem to absorb perturbation and maintain identity and function, *agricultural resilience*, the capacity of a farming system to maintain optimal productivity in the face of disturbances, and *social resilience*, the ability of a community or household to maintain an upward trajectory out of poverty in the face of a myriad of stressors and shocks (Adger, 2000; Barrett & Constas, 2014). In other words, the social resilience of a smallholder farming household is instrumentally linked to the resilience of the underlying natural resource and agricultural subsystems (Barrett & Constas, 2014).

Focusing on these interacting relationships, Community Markets for Conservation (COMACO) has taken a holistic systems approach to promote social, ecological, and agricultural resilience in the Luangwa Valley (Lewis et al., 2011). With over 89,100 farmer members over 77,000 km^2, COMACO utilizes a business model to maximize farmer profits. COMACO operates over the full spectrum of a vertically-integrated value chain, from training farmers in methods of conservation farming, to purchasing surplus farm products from smallholder farmers at their 259 community bulking centers, to transporting them to community trading centers for consolidation and sale into the commodities market or processing into value-added products. Profits generated are passed back to member farmers in the form of premium commodity prices and 'conservation dividends' (cash or in-kind payment for achieving conservation targets). Training and support in alternative income-generating activities such as poultry production, bee-keeping, and carpentry further mitigate the effect of any one perturbation on a household or community. Training is disseminated through a network of 3935 producer groups and their 1650 volunteer lead farmers and is aggregated in a COMACO publication for their farmers, called "Better Life Books." Additionally, over 1000 hand-powered radios have been distributed to lead farmers, and producer groups gather twice weekly for the COMACO Farm Talk radio program, which provides instruction and reinforces conservation farming techniques.

COMACO farmers have adopted 40-90% of individual conservation farming techniques (Lewis et al., 2011), with overall adoption of 67% in 2011 (COMACO, 2014). The use of conservation farming was associated with a 50% increase in maize yields, 37% increase in groundnut yields, and 40% increase in soybean yields compared to traditional methods, with increasing yields each year, according to COMACO's reports (COMACO, 2014). Approximately 50% of farmers practice crop diversification, growing three or more food crops in 2013. One of COMACO's newest interventions, a seed reserve program, allows farmers to improve disease resistance on their farm by diversifying plant genetics and reestablishing their fields in event of crop loss. In the 2012-2013 season, 11,200 farmers contributed seeds to the reserve, which currently totals 228 tons. As a result of these improvements in the agricultural system, average annual income in COMACO-member households has more than doubled since 2009 (COMACO, 2014).

Purpose and objectives

The objective of this paper is to investigate the impact of targeted interventions promoting village-level poultry production on the resilience of both the local poultry system and smallholder farming households in the Luangwa Valley. We evaluated three key parameters of the interventions targeting *village chickens*: (1) average household flock size over time and across seasons; (2) average household profitability; and (3) family consumption of chicken meat and eggs. Parameter 1 is an indicator of poultry system (agricultural) resilience, while parameters 2 and 3 are indicators of the program's impact on household resilience. For the intervention targeting *semi-intensive egg production*, we evaluated four parameters: (1) facility productivity; (2) profitability and contribution to overall household income; (3) impact on average household consumption of eggs in participating households; and (4) impact on egg consumption in surrounding communities. Parameter 1 is a measure of agricultural resilience; parameters 2 and 3 are measures of household resilience in participating household. As a proxy for dietary quality, parameter 4 is a measure of the program's impact on household resilience in the surrounding community.

First, we provide data showing that addressing health and management constraints within the extensive village poultry system resulted in improved resilience of the poultry system, as measured by significantly improved flock productivity. The intervention affected household resilience through increased poultry profitability, but not through increased consumption of poultry meat or eggs in participating households. We next provide data showing that the establishment of community-operated, semi-intensive egg production facilities was highly profitable for producers and increased household consumption of eggs in the communities surrounding the egg facilities, but not in the producing households themselves. This suggests that semi-intensive egg production may contribute to the social resilience of participating households through increased incomes; it additionally suggests that this intervention has the potential to improve household resilience in the surrounding community through improved nutrition and physical health.

Methods

Study site

This research took place in the Mambwe and Lundazi districts, which are located in Zambia's Eastern Province and have populations of 68,918 and 323,870 people, respectively (CSO, 2012). Each district is further subdivided into Chiefdoms, each governed by a traditional leader with significant local influence in their communities (Baldwin, 2015). The western border of both districts is defined by the Luangwa River, which runs along the southeastern edge of the South Luangwa and North Luangwa National Parks, home to large populations of wildlife. The average household in the Luangwa Valley is composed of seven people, 2.4 of whom are children under the age of 16 (Ngumayo, 2011). The majority of heads of household have a maximum education level of primary school or less (Ngumayo, 2011). The average net household income in the 2009-2010 farming season was $450 (US $1 ~ ZMK 5000), with 75% of earnings generated through crop production (Ngumayo, 2011). An estimated 90% of households in the Luangwa Valley rely on agriculture as their primary income generating activity (COMACO, 2014).

Conceptual framework

The hypothesized mechanisms by which COMACO's programs affect resilience in the Luangwa Valley are captured in the conceptual framework (Figure 2.1). This framework illustrates that household resilience is fundamentally linked to the resilience of the agricultural and ecological subsystems on which smallholders depend. COMACO's activities therefore aim to enhance household resilience *directly* and *indirectly* – through the promotion of agricultural and ecological resilience – using multiple complementary mechanisms (Table 2.1). Improved farming practices, farmer education, soil improvements, and seed storage promote agricultural resilience, as measured by annually increasing yields and decreasing farm relocation. These programs also increase household income through premium crop prices, increased yields, and conservation dividends, which in turn promotes household resilience by enabling increased expenditures on farming inputs, higher quality food, health care, and education. Two key indicators of social resilience in this context, then, are (1) increasing household incomes, and

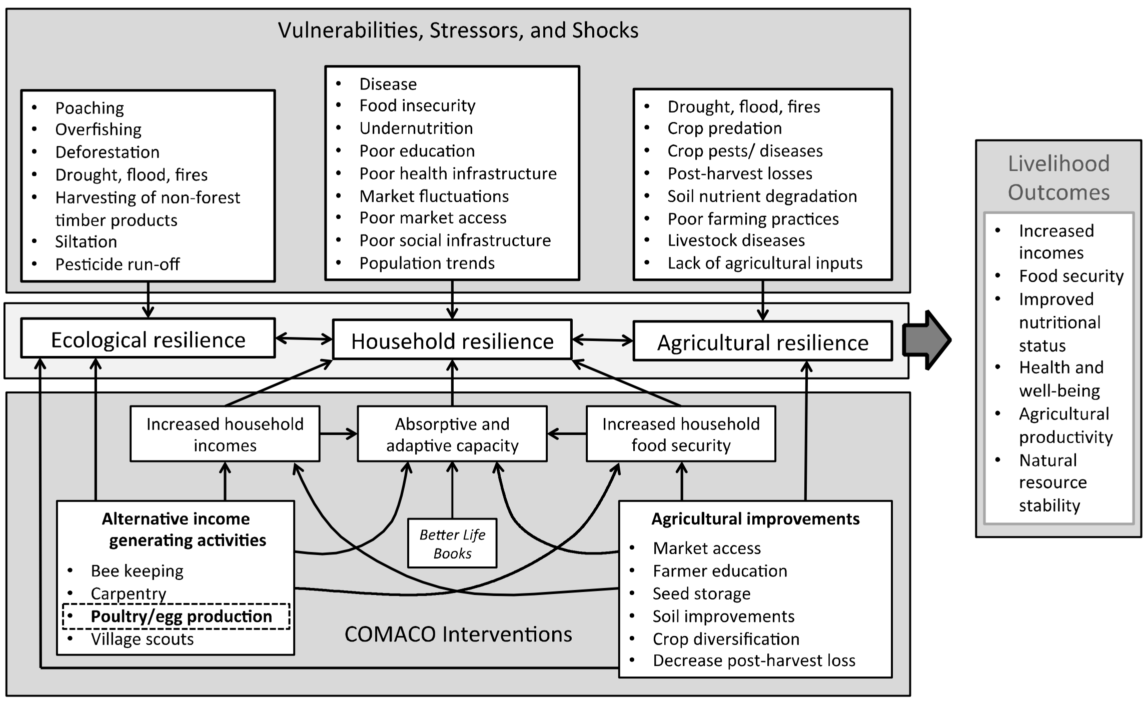


Figure 2.1. A conceptual framework illustrating the theoretical mechanisms by which COMACO interventions promote household, agricultural, and ecological resilience and the measurable livelihood outcomes that result. Agricultural programs directly promote resilience of the agricultural system, as measured by annually increasing average yields per hectare and decreased rates of farm relocation. Agricultural programs indirectly contribute to household (household) resilience by stabilizing the home generation of staple foods, increasing yields of cash crops and surplus food crops, and improving market access and produce prices. Alternative income-generating activities similarly promote household resilience through increased household incomes and, in the case of livestock interventions, the production of animal source foods for household consumption, contributing to food security. Finally, all interventions contribute to ecological resilience through decreased reliance on the routine, seasonal, and urgent use of wildlife and natural resources as a livelihood strategy.

(2) improving food security, defined as '[having] physical, social, and economic access to sufficient, safe, and nutritious food that meets [one's] dietary needs and food preferences for an active and healthy life' (FAO, 2002). In turn, income and food security theoretically promote ecological resilience by decreasing households' routine, seasonal, and urgent reliance on wildlife and natural resources, including poaching, carbon release through residue burning, charcoal production, and clearing of forested areas for plot relocation.

Table 2.1. Mechanisms by which COMACO's interventions are designed to promote social, agricultural and ecological resilience.

Social resilience
Increased household food supply (FS-D)
Diversified diets including both vegetable and ASF sources (FS-D)
Increased market access (FS-I)
Increased incomes from crops (FS-I)
Diversified income sources (FS-I)
Knowledge sharing and development of new skills (producer groups and Better Life Books, FS-I)
Agricultural resilience
Improved soil quality (FS-D, FS-I)
Increased yields (FS-D, FS-I)
Drought resistance (FS-D, FS-I)
Crop diversification (FS-D, FS-I)
Ability to reestablish plots after crop loss (FS-D, FS-I)
Improved genetic diversity of crops (FS-D, FS-I)
Access to agricultural inputs (FS-D, FS-I)
Decreased poultry losses to disease and predation (FS-D, FS-I)
Improved egg production (FS-D, FS-I)
Ecological resilience
Decreased deforestation (decreased land clearance & charcoal production)
ASF production to replace bushmeat and fishing
Decreased pesticide and herbicide use
Decreased carbon emissions from residue burning
Increased carbon sequestration in soil

Abbreviations: FS-D, food-security, direct; FS-I, food-security, indirect

Support of alternative income-generating activities further encourages household resilience by mitigating the impact of perturbations to the cropping system (e.g. crop loss or market fluctuations), thereby building adaptive capacity. Livestock interventions are a particularly promising approach to advancing household resilience because of their potential to both diversify incomes and directly improve community food security and nutritional status through increased local availability of animal source foods (ASF). ASF, such as meat, milk, and eggs, are rich in nutrients critical for growth and cognitive development (Allen, 2012; Murphy & Allen, 2003). Yet, for children of poor farmers in the Valley, ASF consumption is limited by poor livestock productivity due to endemic infectious diseases, poor quality forages, and poor access to improved breeds and veterinary care. COMACO's poultry program aims to promote the resilience of poultry systems (as measured by losses, flock size, productivity, and profitability) by addressing the constraints to extensive poultry production (village chickens) and egg production (semi-intensively raised layers).

Interventions in extensive poultry system

Improved management

The primary constraints to poultry production were identified through focus groups and key informant interviews from 2006 to 2007 (McDonald, Lewis and Travis, unpublished data). Community poultry production groups consisting of 10 to 15 farmers each were formed to facilitate the implementation of interventions. Extension workshops targeted the management constraints identified during formative research, including the building of elevated chicken houses and providing fresh water and supplemental feed.

Newcastle disease vaccination

Based on the description of flock losses and post-mortem examination of dead birds, Newcastle disease (ND) was identified as the primary constraint in village poultry production

(McDonald, Lewis and Travis, unpublished data). Two community vaccinators were selected from each area, and partners from the International Rural Poultry Centre trained selected community vaccinators following a training manual created by the International Rural Poultry Centre and COMACO (International Rural Poultry Centre & COMACO, 2007). These training sessions were repeated annually, led by students from the Cornell University College of Veterinary Medicine and COMACO extension staff.

A thermostable, live, freeze-dried vaccine, ND 'V4 HR' (Malaysian Vaccines & Pharmaceuticals, Kuala Lumpur, Malaysia), was maintained at a central location in a refrigerator, then transported in cool boxes to vaccinating areas at the start of each campaign. The vaccine was diluted and administered via eye drop following the manufacturer's instructions. Farmers paid approximately $0.05 per vaccine dose, and vaccinators were paid a base allowance plus performance-based pay of 70% of generated revenue. A vaccination campaign was performed every July, November, and April. Each vaccinator was given Household Vaccination Forms on which to record each participating farmer, the number of birds owned and vaccinated, and payment made. They also documented any significant die-offs reported in the preceding three months.

Impact assessment

Adoption of ND vaccination was assessed through continuous monitoring of the number of birds vaccinated and number of households participating, as recorded by the vaccinators in the Household Vaccination Form during the vaccination campaigns from 2007 to 2011. This was compared with the total number of poultry-owning households, estimated from Zambia's 2010 census, which counted the number of households in each of Mambwe district's Chiefdoms

(CSO, 2012), with an assumed 80% of households raising poultry (Songolo & Katongo, 2000). To investigate the adoption of improved poultry housing and its impact, we conducted a structured survey of non-randomly selected households (n= 59) in July 2011. In each of three Chiefdoms, a village was purposively selected based on accessibility, and every household within that village was surveyed. Due to the small size of these villages, in each case a neighboring village was also surveyed until 20 households were evaluated per Chiefdom. One household was dropped from the final analysis due to incomplete data.

To monitor the impact on flock sizes, community vaccinators documented household flock size every four months at the time of vaccination (n= 340 on average, range= 280 – 420). A small sample of non-participating, poultry-owning households from neighboring communities was recruited as controls and their flocks counted at each vaccination campaign (n= 100). The effect of poultry production on household income was assessed in a longitudinal survey conducted at a subset of participating households (n= 130) in four Chiefdoms during the 2011-2012 season. Selection criteria for the participants included in this survey could not be described by COMACO Monitoring and Evaluation staff. At each visit, the enumerator counted the number of chickens and interviewed the head of household to determine the number of eggs and chickens eaten and sold in the past month and at what price, and the number of losses of chickens and eggs in the past month. Because COMACO did not simultaneously survey non-participating control households, these data were compared to those from an independent survey conducted by the Luangwa Valley Ecosystem Partnership Management Initiative (n= 893), which includes data on the annual income generated through poultry and egg sales in the 2009-2010 season (Ngumayo, 2011). This survey includes information from both COMACO and non-

COMACO farmers, allowing comparison of poultry incomes for households participating in the program with all poultry-owning households in the region.

The 2011-2012 longitudinal survey data were also used to determine the impact of the interventions on family chicken and egg consumption. An additional cross-sectional survey of households in three Chiefdoms was conducted in February 2012 (n= 121); it includes data on household egg and meat consumption in both participating and non-participating households. Finally, six focus group discussions were held in the Chiefdom of Mnkhanya to discuss the motivations for rearing poultry and determinants and barriers to home consumption of poultry meat and eggs. Focus groups were held in the months of January and February 2012; each discussion consisted of between 8 and 15 people, with a total of 66 producers participating.

Semi-intensive egg production intervention

To test the economic feasibility and acceptability of a semi-intensive egg production project, three pilot facilities were constructed in June 2010 in three different Chiefdoms, each operated by a single farmer. Each farmer was provided with 10 (facility 1) or 20 (facilities 2 and 3) hybrid layer hens at the point-of-lay (20 weeks) through an interest-free loan. The costs associated with construction of the facilities were borne completely by the farmer. They received training on flock management, nutrition, hen health, egg collection, and record keeping, and their progress was checked monthly by the COMACO Poultry Extension Officer. The operator of each facility was asked to maintain daily records on the total number of eggs collected, number of eggs consumed by the family, number of eggs sold and price of each egg, and the amount and cost of feed purchased, and their records were monitored from July 2010 to May 2011. A semi-structured in-depth interview conducted after 11 months of operation assessed the market demand, their use of the income generated by the facility, and the perceived impact on family welfare. This interview was conducted in English (SED) with on-the-spot translation to Chinyanja by the COMACO Poultry Manager (LL).

To investigate the impact of the pilot layer facilities on diets in the surrounding communities, the 20 households nearest to each facility (n= 60 total) were surveyed 11 months after the initiation of the project (June 2011). The head of household was asked to describe the household demographics, household egg consumption over the past month, and estimated number of eggs consumed per month prior to the installation of the layer facility in their area. Egg consumption was then compared to that of 60 households in three matched control areas, where village chickens, road-side stalls, and shops were the only sources of eggs. Because no baseline data were collected on their prior consumption patterns, each facility owner was asked to approximate the average number of eggs consumed by the family per month in the year prior to the initiation of the project.

The details of each data collection method for both the extensive and semi-intensive poultry programs can be found in Appendix 2. All survey instruments and forms are available from the author on request. All data were analyzed using non-parametric tests (Kruskal-Wallis or Wilcoxon Rank Sum; JMP Pro Version 11.0, Copyright ©2013 SAS Institute Inc.).

Results

Improvements in extensive poultry system

Table 2.2 summarizes the adoption of recommended strategies for village poultry production and indicators of their impact four years after initiation of the interventions.

Adoption of recommended strategies

As of 2011, 395 poultry production groups had been formed composed of 3265 women and 2006 men, or an estimated 21% of the district's poultry-owning population. From July 2007 to November 2011, the ND vaccination program grew 236% in terms of the number of birds vaccinated, and 50% in the number of participating households. Using 2010 Census data, we estimate that this was still less than 3% of poultry-raising households in the district.

Table 2.2. Adoption of recommended strategies in extensive village poultry production and the impact of the program on indicators of productivity.

	Baseline[a]	2011
Adoption of techniques		
Poultry groups		
Number of groups	0	395
Number of farmers	0	5,271
NDV vaccination		
Number of HHs	280[b]	420
Number of chickens	2,900[b]	9,755
Night-time poultry housing		
Grounded (%)	NM, <5	20.3
Elevated (%)	NM, <5	71.2
Family home (%)	NM	8.5
Providing water and maize bran (%)	0	94.7
Maggots/termites (%)	0	3.5
Impact on productivity		
Avg. flock size (no. adult birds/HH)		
Vaccinating household (n= no. HH, above)	10.7[b]	30.4
Non-vaccinating household (n= 100)	10.7[b]	11.6
Income from poultry (US$/year; n= 130)	16.89[c]	40.25
HH chicken consumption (no. meals/month; n= 130)	NM	1.7

Notes: [a] Baseline estimates from 2006, unless otherwise indicated. [b] July 2007, at time of the first vaccination campaign. [c] 2001 estimate, adjusted for inflation to 2011 value (Lewis, Tembo, & Nyirenda, 2001)

Abbreviations: HH, household; NM, not measured

Impact on flock productivity

In a 2011 survey of poultry-owning households, 71.2% used the elevated housing-type promoted by the program. Farmers using the elevated housing type had significantly larger flock sizes (mean 20.4 birds) compared to those using ground housing (11.0 birds) or housing the birds in the family home (11.4 birds; $p = 0.018$). They also reported significantly fewer flock losses over the past three months as a fraction of current flock size (elevated houses= 0.30 deaths vs. grounded houses= 0.68 and family house= 0.55; $p < 0.001$).

We found an increase in the average number of adult birds owned by farmers participating in the vaccination program compared to households in control areas (Figure 2.2). Inconsistent collection of data due either to temporary funding constraints or heavy flooding and impassable roads makes statistical interpretation of possible trends of growth over time difficult. However, due to recurrent and marked seasonal fluctuations in flock sizes, it is informative to compare average household flock sizes during the same months prior to and after intervention. There was a significant increase in the average household flock size in vaccinating households from July 2007 (mean 10.9 birds) to July 2011 (mean 25.7 birds; $p < 0.001$) and from November 2007 (mean 17.8 birds) to November 2011 (mean 28.3 birds; $p < 0.001$).

Impact on poultry profitability

A 2001 survey in the Luangwa Valley found that poultry production contributed an average of only $16.89 per year (Lewis et al., 2001, adjusted for inflation to 2011 value). After interventions, a survey following 130 participating households through the 2011 – 2012 production season found an average $40.25 annual income from poultry production, a 138% increase in poultry profitability. In comparison, an independent survey of 893 households found that the average poultry-owning household in the Luangwa Valley, including those that did not participate in COMACO programs, made $27.83 from the sales of chickens and eggs in the 2009 – 2010 farming season (Ngumayo, 2011), a 65% increase in their annual profits from poultry production since 2001. This demonstrates that although poultry producers across the region saw an increase in poultry income, participants in the COMACO program realized substantially greater profits.

Impact on family ASF consumption

The same longitudinal survey following 130 households participating in the program through the 2011-2012 farming season found that an average of 0.55 chickens were eaten/ household/ mo. A separate cross-sectional survey of 121 non-participating household found that families in the study area ate an average of 1.74 meals/mo containing chicken (where one bird is typically consumed over two family meals). These data suggested that although flock size went up significantly, households were not consuming the birds or eggs. Instead, focus group discussions revealed that producers preferred to sell birds occasionally to address a specific need; similarly, rather than eat eggs at home, they preferred to allow the eggs to hatch in order to have more adult birds to sell in the future. This notion become more evident in February 2012, when COMACO poultry producers began to set up markets to intensify the sale of birds (SED, personal observation).

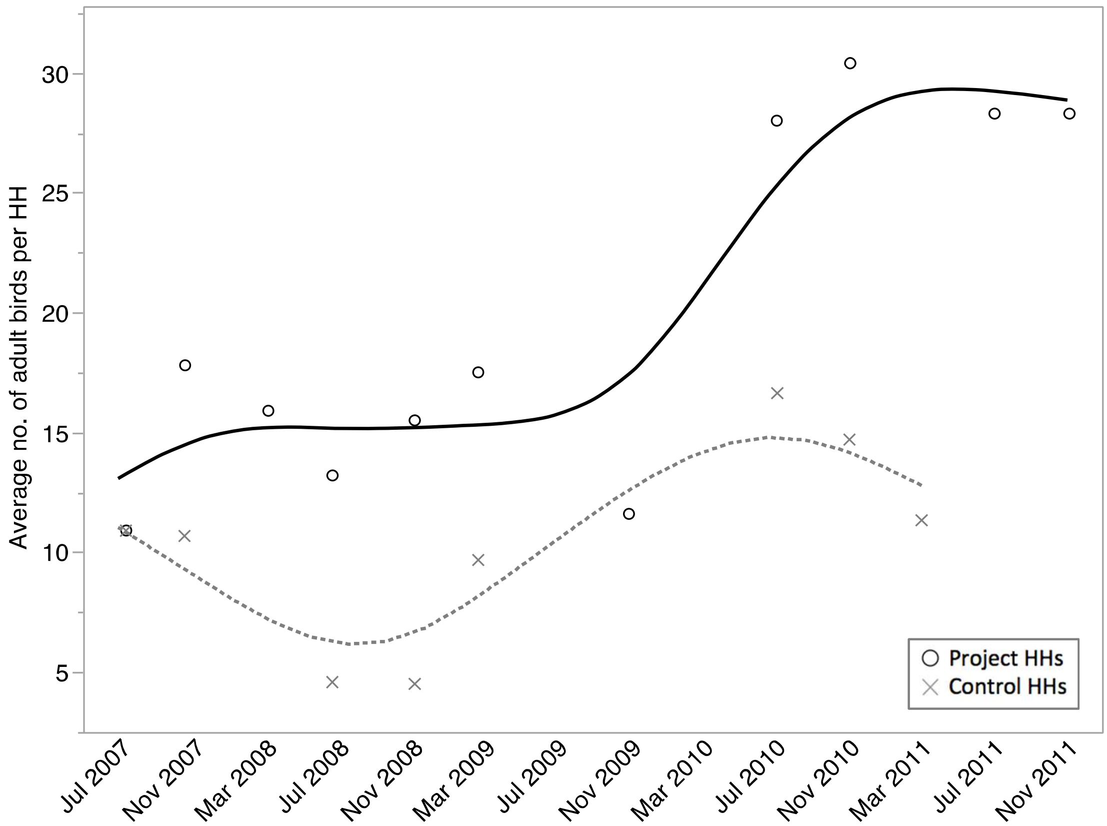


Figure 2.2. Change in average household flock size from July 2007 to November 2011 with regular Newcastle disease vaccination and improved management (Project households, n= 340 on average) versus households with improved management alone (Control households, n= 100). Vaccinations were not conducted in March 2010 or March 2011 due to heavy rains and impassable roads. Data for the July 2009 campaign were lost. Control data were not collected in March 2008, November 2009, July 2011, or November 2011 due to lack of funding. Solid black line is a smoothing spline estimating the mean flock size in project households; the gray dashed line is a smoothing spline estimating the mean flock size in control households.

Semi-intensive egg production

In response to the finding that increased flock sizes in the expansive poultry system had no impact on household poultry or egg consumption, alternative poultry development interventions were explored to promote improved community nutrition through increased ASF consumption. The idea that gained the most support among COMACO staff and poultry producers was the establishment of small-scale egg production facilities to be operated by individual households or small groups. We proposed that this model would be consistent with the business-minded approach to poultry production that farmers were taking, but would benefit community nutrition because the primary buyers would be their neighbors. Additionally, because eggs are a small and relatively inexpensive form of ASF, even poor families are able to occasionally purchase them.

Profitability and acceptability

Over the first 10 full months of production, daily egg collection records revealed an average monthly production of 22.4 eggs/hen, translating to a 74.5% average production efficiency (percentage of hens laying an egg on any given day). There was no significant difference in productivity among the three facilities (data not shown; p= 0.694). The gross income generated by facilities 1, 2, and 3 averaged $36.54, $72.25 and $66.21 per month, respectively. There was no statistically significant difference between the gross monthly income generated by facilities 2 and 3 (p=0.303), whereas the significantly lower profits in facility 1 were due to having only 10 layers instead of 20. After deducting the cost of feed and repayment of the loan for the hens, the annual net income for each facility was $113.03, $247.38 and $74.93 (facilities 1, 2 and 3, respectively).

Farming was the only source of income for the households owning facilities 1 and 3; those layer facilities resulted in a 58.3% and 54.2% increase in total net household income, respectively. The head of household for facility 2 had additional off-farm employment as a safari driver ($103 monthly); that facility therefore resulted in a 19.7% increase in total net household income. In the year-end interview, all facility owners reported high demand for eggs. The income generated from the layer facilities was primarily used for school fees, uniforms, and supplies by all three owners. The remainder of their poultry income was used to pay for food items, such as cooking oil and salt, or home-improvements. All three perceived their family's lives to be greatly improved compared to the previous year, and all three planned to reinvest in new layer hens to continue production.

Impact on local egg consumption

The community surveys found that most of the households (89%) in both project and control areas consumed eggs regularly but infrequently. The 60 households surveyed around the layer facilities consumed a mean of 22.5 eggs/household/mo compared to an estimated 13.3 eggs the year previously ($p= 0.003$) and 12.6 eggs/household/mo in control areas ($p= 0.005$; Figure 2.3A). All households reported sharing eggs equitably within the family, and the traditional taboo against women and children eating eggs common in some parts of Zambia was not practiced in any household sampled. In all three egg producer households, the number of eggs eaten per family per month ($p < 0.001$) and per person per month ($p < 0.001$) was significantly increased after the installation of the layers (Figure 2.3B). Notably, however, producer families continued to consume significantly fewer eggs per month than their neighbors (13.4 eggs/household/mo in producer households vs. 22.5 eggs/household/mo in neighboring households, $p= 0.029$) and the same as households from control areas (13.4 eggs/household/mo in producing households vs. 12.6 eggs/household/mo in control households, $p= 0.788$), suggesting that they considered egg production to be primarily an income-generating activity rather than a source of household food.

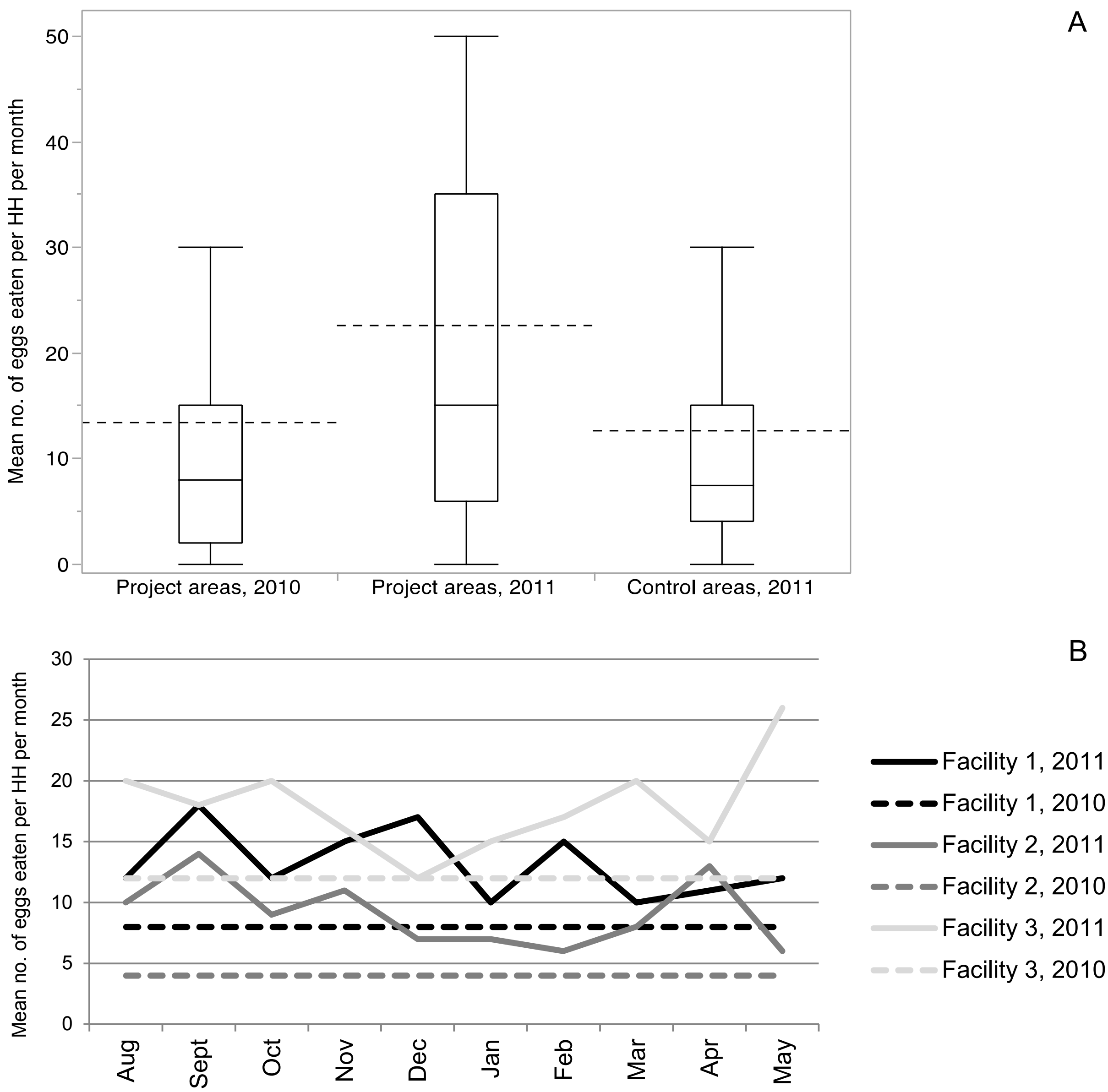


Figure 2.3. ***Panel A:*** **The self-reported number of eggs eaten per household in the past month in communities surrounding pilot egg production facilities (project areas, n= 60) and matched communities with no local egg production (control areas, n=60) after installation of the facility (2011) and before (2010, project areas only).** The data are presented in an outlier boxplot, where the boundaries of the boxes represent the first and third quartiles (Q1 and Q3, respectively, such that the length of the box indicates the interquartile range [IQR]), the solid lines within the boxes display the median, and whiskers extend to the lowest and highest datum within 1.5 x IQR of Q1 and Q3, respectively. The mean is depicted by the broken line extending through each box. Outliers are not displayed. ***Panel B:*** **Monthly egg consumption patterns in producer households (n= 3) for the 11 months after installation of the layer facilities (2011) and the year prior to installation of the layer facilities (2010, estimated).**

Discussion

Impact of improvements in extensive poultry system

Although we documented high participation in poultry production groups, participation in the ND vaccination program was low, representing only 3% of poultry owning households in the district. Similarly, while the program grew substantially in the number of birds vaccinated, the number of participating households increased more slowly over the four years of the program. Because reports from COMACO extension officers and personal observation suggest high community demand for the vaccine and support of the program, these trends likely reflect the limited roll-out of the program over a small part of the COMACO operational area.

However, expansion of the program is warranted. Our analyses suggest that the resilience of the extensive village poultry production system was significantly enhanced through ND vaccination and modest improvements in husbandry, as measured by fewer flock losses and increased average household flock sizes. As proposed in Figure 2.1, improved poultry production can promote smallholder household resilience through a number of mechanisms: (1) increased household income; (2) diversification of household income, making them more resilient to unexpected shocks and trends affecting crops (adaptive capacity); (3) increased food security as a result of improved access to poultry meat and eggs; and (4) indirectly (and more long-term) through improved ecological resilience as a result of decreased dependence on wildlife and natural resources to cope with shocks affecting cropping systems. This research explored the association between household resilience and the resilience of the poultry subsystem through linkages (1) and (3) only. The data support the hypothesis that simple interventions in the backyard poultry systems can result in increased household income. However, the data did not demonstrate any association between the interventions and consumption of poultry meat and eggs in participating households. This suggests that improvements in backyard poultry production did not have any direct effect on participating households' dietary quality, though it might have unmeasured *indirect* effects on nutrition and food security through increased food expenditures, income diversification, and ecological resilience.

The substantial increase in flock sizes and the profitability of poultry after only four years of intervention is consistent with other studies of ND vaccination in village chickens (Harrison & Alders, 2009; Harun, 2009; Mgomezulu et al., 2009). However, despite increased flock sizes, families in our sample reported eating only a modest amount of village chickens and eggs produced by their village chickens. Although no baseline dietary information is available for comparison, the per capita consumption of poultry in Zambia is 3.1 kg/yr (FAO, 2014) compared to < 1 kg/yr in our sample. Similarly, the average Zambian eats approximately 62 eggs/yr (FAO, 2014; Speedy, 2003), compared with only 34.1 eggs/yr in our sample of households without an egg production facility in their community (assuming the month surveyed is typical for the year). Taken together, these findings indicate that despite larger flock sizes resulting from our intervention, farmers in this study consumed far less poultry and eggs than the national average, which was itself far below the global average (Speedy, 2003).

There are two likely explanations for this finding. First, prior to intervention, smallholder poultry farmers reported that the most common reason to consume a chicken is when it was showing signs of disease or had just died (Bagnol, 2007). As flock morbidity and mortality were reduced through vaccination and improved husbandry, eating chickens increasingly required the slaughter of a healthy bird—a difficult adjustment. Similarly, in focus groups, poultry owners reported infrequently eating eggs from backyard chickens, preferring to let them hatch to increase flock size and counteract the frequent losses they traditionally experienced, a phenomenon that has been reported elsewhere in Africa (Gueye, 2000; Lane, 2016; de Bruyn et al., 2017). Second, in follow-up focus group and surveys, farmers reported that they preferred to sell birds rather than slaughter them for home consumption, suggesting that once production became reliable, they considered poultry production to be chiefly an income-generating activity. Poultry income was primarily used to pay for school supplies, medical fees, or household items. Healthy chickens were consumed only on special occasions, such as to feed a visitor or holidays. Indeed, a review of the impact of smallholder livestock development on human nutrition found that although interventions can improve the productivity of livestock, slaughtering animals for home consumption remains infrequent and that "a significant share, if not most, of the production will be sold rather than consumed on-farm" (Randolph et al., 2007), a conclusion that is consistent with our data. Other research examining the effect of livestock production interventions on household dietary quality have found conflicting results, and three reviews have concluded that, to date, there is no high-quality evidence supporting the hypothesis that improved household livestock production is associated with improved nutritional status in the producing household (Leroy & Frongillo, 2007; Masset et al., 2012; Webb-Girard et al., 2012).

Impact of semi-intensive egg production

In contrast, the results of the egg layer pilot program supported the hypothesis that semi-intensive egg production could impact social resilience through both a substantial increase in income for producer households and a significant increase in community consumption of ASF. The layer hens performed well, even in the extreme climate of the Luangwa Valley. The facilities had a meaningful impact on the overall household income for the producers, giving them an economic incentive to continue production. The impact of the layer facilities on the community consumption of eggs was staggering, with the average person in a village surrounding a facility predicted to consume as many eggs per year (66.6 eggs/yr) as the average Zambian (62 eggs/yr; (Speedy, 2003)), and far in excess of those living in control area that same year.

The potential impact of livestock interventions on social resilience through improved nutritional status has not been well explored in the literature. Numerous studies have shown that feeding ASF to children increases physical growth, cognitive development, immune function, and school performance in undernourished populations in developing countries (Allen, 2012; Iannotti et al., 2017; McLean et al., 2007; Murphy & Allen, 2003; Neumann et al., 2002; Randolph et al., 2007; Sigman et al., 2005; Whaley et al., 2003). These in turn impact an individual's ability to contribute productively as an adult to her community and national economy (Figure 2.4). Compared to plant foods, ASF contain more iron, zinc, vitamins A, D and E, riboflavin, and amino acids. These nutrients also tend to be more bioavailable from ASF compared to plant-based sources, and ASF are the *only* source of vitamin B12 and heme iron. Yet, the barriers to routine ASF consumption in rural Zambia are significant, including cost, lack of local access, food safety concerns in the absence of a reliable cold-chain, and lack of caregiver awareness about ideal feeding practices. Eggs are relatively inexpensive compared to other forms of ASF, making their regular consumption more affordable. Importantly, even in tropical climes, they require no cold-chain for up to a month if properly stored.

Results presented here suggest that local production of eggs in a semi-intensive production system has the potential to sustainably provide poor rural families with a fresh, safe, low-cost form of ASF. Further research will explore the effect of this increased access and consumption on child nutritional status and community resilience. It should be noted that the pilot program did not contain a nutrition education component, a characteristic previously found to increase ASF consumption in livestock development interventions (Leroy & Frongillo, 2007). Future expansion of village-scale egg layer production should be integrated with a nutritional education program.

Finally, it is notable that although two of the initial owners of the pilots were men, in both cases, their wives took over management and financial responsibility of the facility. This indicates that owning and operating an egg laying facility is a socially acceptable livelihood activity for women. Worldwide, women and girls are most at risk for extreme poverty. This, combined with the fact that targeting women as the beneficiaries of agricultural interventions has been shown to have the greatest impact on family nutrition (Leroy & Frongillo, 2007), suggests that future expansion of the project should focus on women as the owners and operators of layer facilities in order to have the greatest impact on family health and welfare.

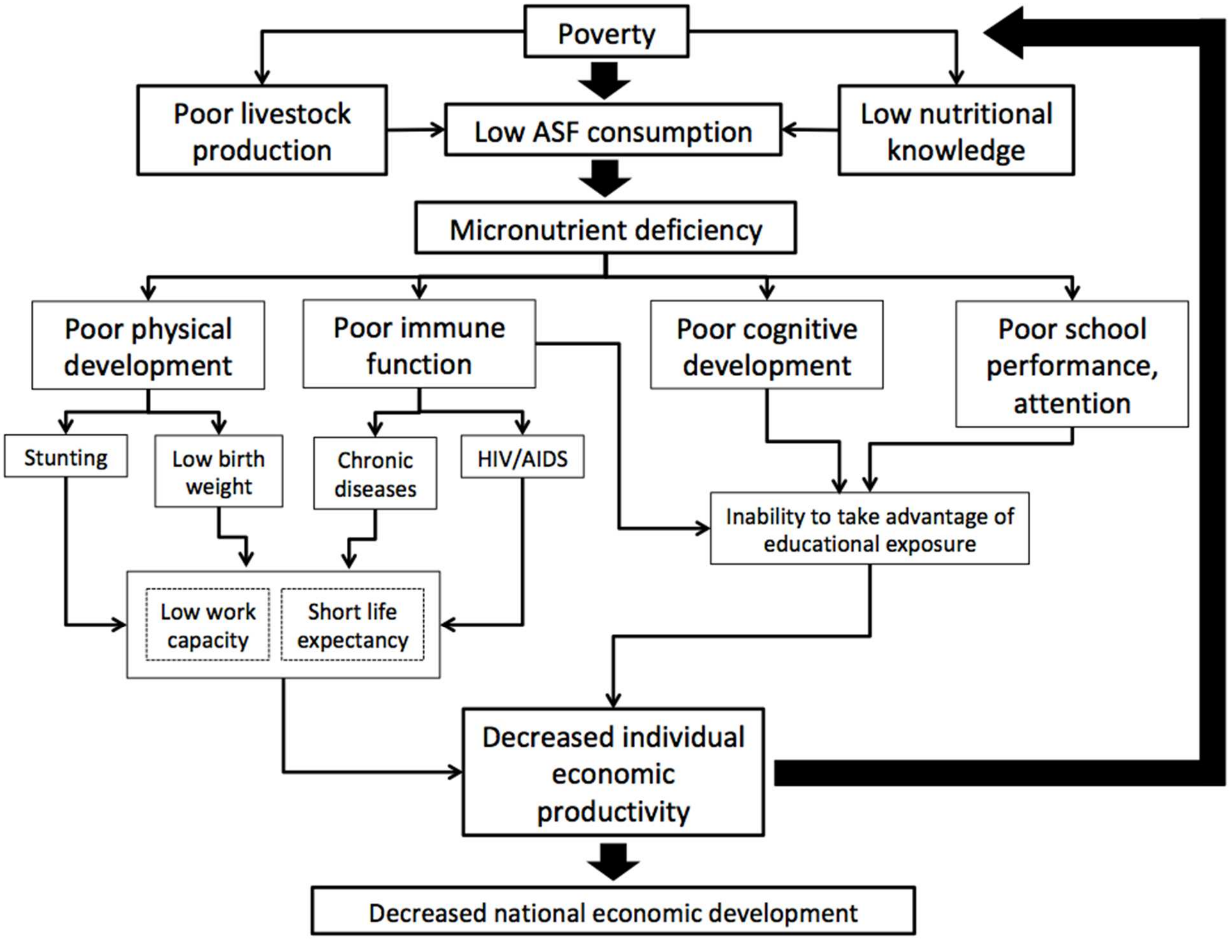


Figure 2.4. Theoretical mechanisms by which poverty and low ASF consumption lead to poor human health and economic development, with negative implications for household and regional resilience.

Limitations and future directions

There are a number of limitations to this study that should be noted. First, in the absence of a measured stressor or shock, we are limited in our ability to measure the resilience resulting from our programs. Instead, we must rely on static outcome measures as indicators of *potential* resilience. For example, while we argue that increased average flock sizes over time are an indicator of a more resilient village poultry system, we lack an objective measure of a stressor or shock (e.g. local Newcastle disease outbreak among unvaccinated flocks) to allow us to quantify it. Similarly, we suggest that increased household income among egg producers contributes to household resilience based on qualitative data from in-depth interviews with producers; again, however, without measures of actual shocks and household responses, this cannot be quantified. Second, financial and technical limitations affected our ability to collect suitable control data in some cases, forcing us to rely on less appropriate counterfactuals. For instance, to assess the impact of the intervention of the profitability of village poultry, we relied on secondary analysis of a dataset that contained both COMACO and non-COMACO members, which may have made the difference in profitability appear artificially smaller than it actually was.

Finally, our exploration of the impact of local egg production on social resilience of the surrounding community is based on a small sample size of just 120 households in six communities (three project and three control areas). Additional research with a larger sample size is needed to further explore the link between local egg production and household resilience mediated by nutrition. For example, despite their increased physical availability, will eggs be economically accessible for the poorest households in these communities on a routine basis? If a nutritional education program convinces parents to increase their household food expenditures on eggs, will it come at the expense of grain and vegetable expenditures, leading to a net reduction in calories and certain micronutrients? Importantly, will the number of eggs that families are able to or interested in consuming be sufficient to have a significant impact on nutritional outcomes? These questions need to be explored to identify the exact mechanisms by which local egg production affects the resilience of the Luangwa Valley system.

References

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, *24*(3), 347–364. doi:10.1191/030913200701540465

Allen, L. H. (2012). Global dietary patterns and diets in childhood: Implications for health outcomes. *Annals of Nutrition and Metabolism*, *61*(s1), 29–37. doi:10.1159/000346185

Bagnol, B. (2007). Improvement of village poultry production by communities surrounding South Luangwa National Park, Zambia: Participatory rural appraisal. Trip Report to COMACO, WCS, and KYEEMA Foundation. Maputo, Mozambique: International Rural Poultry Centre.

Baldwin, K. (2015). The Paradox of Traditional Chiefs on Democratic Africa. Cambridge, England: Cambridge University Press.

Barrett, C. B., & Constas, M. A. (2014). Toward a theory of resilience for international development applications. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(40), 14625–14630. doi:10.1073/pnas.1320880111

Central Statistical Office (CSO). (2012). 2010 Census of Population and Housing, Zambia. Lusaka, Zambia: Central Statistical Office.

Community Markets for Conservation (COMACO). (2014). Community Markets for Conservation: Project Description Document for 2014-2018. Lusaka, Zambia: COMACO.

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Maulaga, W., Thomson, P. C., & Alders, R. G. (2017). Characterising infant and young child feeding practices and the consumption of poultry products in rural Tanzania: A mixed methods approach. *Maternal & Child Nutrition*. http://doi.org/10.1111/mcn.12550

Food and Agriculture Organization (FAO). (2002). The State of Food Insecurity in the World, 2001. Rome: FAO.

Food and Agriculture Organization (FAO). (2014). *FAOSTAT Database*. Retrieved from http://faostat3.fao.org/home/E

Gueye, E. F. (2000). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on Agriculture*, *29*(2), 129–136.

Harrison, J. L., & Alders, R. G. (2009). An assessment of chicken husbandry including Newcastle disease control in rural areas of Chibuto, Mozambique. *Tropical Animal Health and Production*, *42*(4), 729–736. doi:10.1007/s11250-009-9480-y

Harun, M., Alders, R. G., Sprowles, L., Bagnol, B., Cambaza, A. B., Msami, H. M., & Mgomezulu, R. A. (2009). Southern Africa Newcastle Disease Control Project impact studies: baseline and participatory rural appraisal results. In Alders, R.G., Spradbrow, P.B., & Young, M.P. (Eds.), *Village chickens, poverty alleviation and the sustainable control of Newcastle Disease: Proceedings of an international conference* (pp. 96–101). Dar es Salaam, Tanzania: ACIAR.

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., et al. (2017). Eggs in early complementary feeding and child growth: A randomized controlled trial. *Pediatrics*, e20163459. doi:10.1542/peds.2016-3459

International Rural Poultry Centre & COMACO. (2007). Controlling Newcastle disease in village chickens: A manual for extension workers. Lusaka, Zambia: Wildlife Conservation Society.

Lane, J. (2016). Demystifying the pathways of impact of a livestock transfer program on household resilience & food security in Malawi. Presented at "Agriculture for Nutrition and Health Academy Week" in Addis Ababa, June 20.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition*, *137*(10), 2311–2316.

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences of the U. S. A.*, *108*(34), 13957–13962.

Lewis, D., Tembo, N., & Nyirenda, P. (2001). Baseline analysis of rural household incomes in Luangwa Valley. Lusaka, Zambia: Wildlife Conservation Society.

Masset, E., Haddad, L., Cornelius, A., & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *BMJ*, *344*, d8222–d8222. doi:10.1136/bmj.d8222

McLean, E. D., Allen, L. H., Neumann, C. G., Peerson, J. M., Siekmann, J. H., Murphy, S. P., et al. (2007). Low plasma vitamin B-12 in Kenyan school children is highly prevalent and improved by supplemental animal source foods. *The Journal of Nutrition*, *137*(3), 676–682.

Mgomezulu, R. A., Alders, R. G., & Chikungwa, P. B. (2009). Trials with a thermotolerant I-2 Newcastle disease vaccine in confined Australorp chickens and scavenging village chickens in Malawi. In Alders, R.G., Spradbrow, P.B., & Young, M.P. (Eds.), *Village chickens, poverty alleviation and the sustainable control of Newcastle Disease: Proceedings of an international conference* (pp. 84–95). Dar es Salaam, Tanzania: ACIAR.

Murphy, S. P., & Allen, L. H. (2003). Nutritional importance of animal source foods. *The Journal of Nutrition*, *133*(11), 3932S–3935S.

Neumann, C. G., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research*, *22*(1-2), 193–220. doi:10.1016/S0271-5317(01)00374-8

Ngumayo, J. C. (2011). *Baseline study on rural community household livelihoods, gender, and social change in Eastern Province*. Lusaka, Zambia: Luangwa Valley Ecosystem Integrated Conservation and Livelihood Project.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., et al. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800. doi:10.2527/jas.2007-0467

Sigman, M., Whaley, S. E., Neumann, C. G., Bwibo, N., Guthrie, D., Weiss, R. E., et al. (2005). Diet quality affects the playground activities of Kenyan children. *Food and Nutrition Bulletin*, *26*(2 Suppl 2), S202–12. doi:10.1177/15648265050262S211

Songolo, A., & Katongo, J. C. (2000). Country Report: Zambia. In R. G. Alders & P. B. Spradbrow (Eds.), *SADC Planning Workshop on Newcastle Disease Control in Village Chickens* (pp. 43–45). Maputo, Mozambique.

Speedy, A. W. (2003). Global production and consumption of animal source foods. *The Journal of Nutrition*, *133*(11 Suppl 2), 4048S–4053S.

USAID. (2012). Building resilience to recurrent crisis: USAID policy and program guidance. Washington, DC: USAID.

Webb-Girard, A., Self, J. L., McAuliffe, C., & Olude, O. (2012). The effects of household food production strategies on the health and nutrition outcomes of women and young children: A systematic review. *Paediatric and Perinatal Epidemiology*, *26*(s1), 205–222. doi:10.1111/j.1365-3016.2012.01282.x

Whaley, S. E., Sigman, M., Neumann, C. G., Bwibo, N., Guthrie, D., Weiss, R. E., et al. (2003). The impact of dietary intervention on the cognitive development of Kenyan school children. *The Journal of Nutrition*, *133*(11), 3965S–3971S.

CHAPTER 3

Examining the association between livestock ownership typologies and child nutrition in the Luangwa Valley, Zambia*

Sarah E. Dumas[1,2], Lea Kassa[3], Sera L. Young[4,5,6], Alexander J. Travis[1,2]

[1] Baker Institute for Animal Health, Cornell University College of Veterinary Medicine, Ithaca, NY 14853, USA
[2] Atkinson Center for a Sustainable Future, Cornell University, Ithaca, NY 14853, USA
[3] College of Arts and Sciences, Cornell University, Ithaca, NY 14853, USA
[4] Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853, USA
[5] Program in International Nutrition, Cornell University, Ithaca, NY 14853, USA
[6] Department of Anthropology, Northwestern University, Evanston, IL, 60208, USA

* This manuscript has been accepted by PLOS ONE, and a revised version is currently under review.

Author contributions: SED and LK conceptualized the research question, with input from SLY and AJT, and SED and AJT designed the study. SED and AJT wrote data collection protocols and designed data collection instruments, with input from SLY. SED oversaw data collection. SED and LK conducted data analysis, and SED drafted the manuscript. All authors participated in data interpretation and critically reviewed the manuscript.

Abstract

Objective: To investigate the association between livestock ownership and dietary diversity, animal-source food consumption, height-for-age z-score, and stunting among children living in wildlife “buffer zones” of Zambia’s Luangwa Valley using a novel livestock typology approach. ***Methods:*** We conducted a cross-sectional study of 838 children aged 6-36 months. Households were categorized into typologies based on the types and numbers of animals owned, ranging from no livestock to large numbers of mixed livestock. We used multilevel mixed-effects linear and logistic regression to examine the association between livestock typologies and four nutrition-related outcomes of interest. Results were compared with analyses using more common binary and count measures of livestock ownership. ***Results:*** No measure of livestock ownership was significantly associated with children’s odds of animal-source food consumption, child height-for-age z-score, or stunting odds. Livestock ownership Type 2 (having a small number of poultry) was surprisingly associated with decreased child dietary diversity (β= -0.477; $p<0.01$) relative to owning no livestock. Similarly, in comparison models, chicken ownership was negatively associated with dietary diversity (β= -0.320; $p<0.01$), but increasing numbers of chickens were positively associated with dietary diversity (β= 0.022; $p<0.01$). Notably, neither child dietary diversity nor animal-source food consumption was significantly associated with height, perhaps due to unusually high prevalences of morbidities. ***Conclusions:*** Our novel typologies methodology allowed for an efficient and a more in-depth examination of the differential impact of livestock ownership patterns compared to typical binary or count measures of livestock ownership. We found that these patterns were not positively associated with child nutrition outcomes in this context. Development and conservation programs focusing on livestock must carefully consider the complex relationship between livestock ownership and

nutrition outcomes – including how livestock are utilized by the target population – when attempting to use livestock as a means of improving child nutrition.

Introduction

Nearly 161 million children under the age of five years, or 24.5% of the world's children, are stunted as a result of chronic undernutrition (Black et al., 2013; de Onis & Branca, 2016). Stunting is a well documented risk factor for poor motor development, cognitive function, and immune function, increased risk of morbidity and mortality from infectious diseases, and decreased economic productivity in adulthood (Adair et al., 2013; Black et al., 2013; de Onis & Branca, 2016; UNICEF, 2013; Victora et al., 2008). Almost all stunting occurs in the "first 1000 days" (from conception to two years of age), and its devastating impacts on cognitive and physical development are largely irreversible (Black et al., 2013; de Onis & Branca, 2016).

Stunting has a multifactorial and complex etiology, but its two most important proximate determinants are 1) poor dietary quality among pregnant women, infants, and young children and 2) a high exposure to pathogens causing clinical disease (e.g. diarrhea) or subclinical infection (e.g. environmental enteric dysfunction; (Black et al., 2013)). Livestock ownership by low-income rural households can influence both pathways, and the net impact of livestock ownership on stunting may therefore be positive, negative, or neutral, depending on the context.

Livestock production is commonly promoted as a livelihood strategy that can improve children's access to high-quality animal-source foods (ASF; including meat, milk, and eggs) and increase household incomes. In addition, livestock can positively influence child nutrition through a number of other pathways (Figure 3.1), including: empowering women; improving crop yields through nutrient cycling, manure fertilizer, and draft power; or as a "living savings account" for storage of capital and consumption smoothing (Herrero et al., 2013; Njuki & Sanginga, 2013; Randolph et al., 2007). Livestock ownership can also potentially worsen a child's nutritional status by exposing them to zoonotic pathogens, increasing maternal time burden, competing for household resources, or increasing maternal or child energy demands because of the physical labor required to rear livestock (Herrero et al., 2013; Randolph et al., 2007).

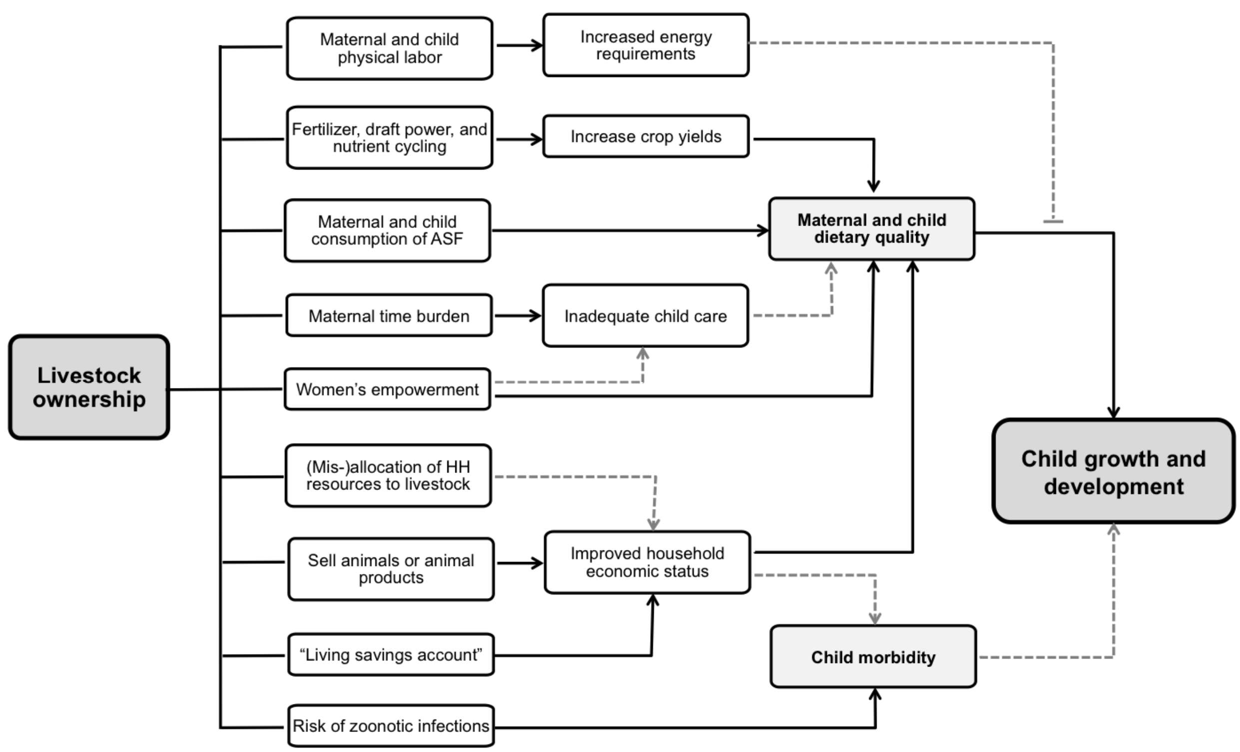


Figure 3.1. Simplified conceptual framework detailing the key pathways linking livestock ownership to child growth and development. Black solid lines indicate positive influence; grey dashed lines indicate negative influence. Arrows indicate causation; capped lines indicate effect modification.

Recent research on the impact of livestock managed in traditional extensive systems in sub-Saharan Africa on child stunting has yielded mixed findings (Appendix 3), with the most consistent evidence for a positive effect coming from analyses of the specific impact of dairy cow or goat ownership (Fierstein et al., 2017; Grosse, 1998; Hoddinott et al., 2015; Nicholson et al., 2003; Okike et al., 2005). However, others have reported no association between livestock ownership and stunting (Azzarri et al., 2015; Iannotti & Lesorogol, 2014; Mosites et al., 2016), a modest relationship depending on how “livestock ownership” was operationalized (Jin & Iannotti, 2014; Mosites et al., 2015), or even a negative effect in some situations (Headey & Hirvonen, 2016; Good, 2009). These disparate findings suggest that the link between livestock ownership and child nutrition is complex and context specific, and further research is clearly warranted to better understand this relationship.

One limitation to the existing body of research is the lack of consensus on how to appropriately measure livestock ownership. The most commonly employed measures are a binary indicator of any livestock ownership (e.g. (Headey & Hirvonen, 2016; Hoddinott et al., 2015; Zimmermann, 2008)) or an absolute count of the animals owned (e.g. (Azzarri et al., 2015; Mosites et al., 2016; Nicholson et al., 2003)). Both methods have clear limitations: a binary indicator of livestock ownership assumes that ownership of one animal has an equal effect on child nutrition as ownership of many animals, while an absolute count of animals assumes that all species and breeds have an equal effect on child nutrition. Both assumptions may be flawed within the borders of our conceptual framework, because the types and numbers of animals that a household owns may affect the amount and frequency of ASF produced for home consumption, the child’s overall exposure to animal feces, the animals’ total contribution to household income or savings, and the amount of household time and labor required.

For example, a household that owns a single village chicken is highly unlikely to slaughter, sell, or eat any of its eggs in the short-term, because the economic incentive is to first allow the flock to grow in order to capitalize on the initial investment of buying that chicken. In contrast, a household owning 30 chickens is able to remove eggs regularly and slaughter or sell chickens as needed without dramatically altering flock dynamics. On the other hand, 30 chickens produce markedly more feces, potentially increasing a child's risk of diarrheal disease or environmental enteric dysfunction, while a single chicken will likely pose a smaller risk. A binary measure of livestock ownership would treat both households simply as "livestock owners", missing the fact that they use and benefit from (or are harmed by) their animals in very different ways and to different degrees. Similarly, a single dairy cow can provide daily milk for both sale and home consumption, whereas a single male goat can only be sold or slaughtered once. At the same time, compared to the buck, the dairy cow will require significantly more time and labor to feed and care for it, potentially competing for household resources and maternal time. A count measure of livestock ownership would nonetheless weight each animal equally.

An alternative approach that would capture the differential effects of various types and numbers of livestock would be to use an index, such as the Tropical Livestock Unit (TLU; e.g. (Mosites et al., 2015; Okike et al., 2005)) score or resale value of the animal (Jin & Iannotti, 2014), to combine a household's total livestock holdings into a single variable. These methods, however, undervalue small animals and overvalue large animals, which may not be appropriate for assessing the impact on child nutrition outcomes given that small animals can be more readily bartered, sold, or slaughtered to provide food or income on an as-needed basis than can larger, more valuable animals.

In response to these limitations, we have employed a method that combines a household's TLU with the total number of animals they own to assign them to one of five livestock ownership typologies: no animals of any kind (Type 1); few animals, mostly poultry (Type 2); moderate number of animals, mostly poultry (Type 3); few animals, mixed small and large livestock species (Type 4); and moderate to large number of animals, mixed small and large livestock species (Type 5). This approach assumes that the pattern of livestock ownership (e.g. having a very small flock of chickens, or a moderately sized herd of goats and cattle) is a better proxy measure for how people use their livestock, and that this construct – how people use livestock – is in fact the main determining link between livestock ownership and child nutrition outcomes. Because this is a novel approach, we also used more conventional measures of livestock ownership (binary measure of any livestock, total counts and counts of individual species, and TLU) to validate our findings.

The Luangwa Valley in Zambia's Eastern Province presents a unique setting in which to test this methodology and study the link between livestock ownership and child nutrition outcomes. A growing population in the Valley resides within Game Management Areas ("buffer zones") surrounding national parks and forest reserves, and families rely heavily on the land and natural resources, including wildlife (Lewis et al., 2011). Although crop farming is the primary income generating activity, yields are inadequate to sustain most households throughout the year (Lewis et al., 2011). Livestock are therefore an important supplementary livelihood activity for many families and an important potential alternative to unsustainable natural resource use. However, livestock production is constrained by poor forages; minimal access to veterinary care and extension services; wildlife predation; endemic infectious diseases; and indigenous breeds with limited genetic potential for growth and production. For these reasons, livestock ownership is mostly restricted to small numbers of chickens, goats, and pigs raised in traditional scavenging or foraging systems, with chickens being the most commonly owned (Dumas et al., 2016).

Our objective was to investigate the association between livestock ownership and child diets and anthropometric status in smallholder farming households in the Luangwa Valley. Specifically, we asked three key questions:

1) Is livestock ownership associated with child dietary diversity?
2) Is livestock ownership associated with child ASF consumption?
3) Is livestock ownership associated with child HAZ or stunting?

Based on the existing literature and our knowledge of livestock ownership in the region, we hypothesized that livestock ownership would be significantly positively associated with child dietary diversity and ASF consumption, but not HAZ or odds of stunting. This research contributes to the growing body of literature examining the impact of livestock ownership on child nutrition. Using a large sample of young children under 36 months and a unique measure of livestock ownership, we build a greater understanding of the complexities of this relationship in a unique population. As populations expand in similar "buffer zones" around protected areas throughout the world, this study additionally offers insight to how livestock are utilized within this context, with important implications for rural development, public health, and wildlife conservation projects in these areas.

Methods

Study area and population

This research took place in 40 rural field sites in Mambwe and Lundazi Districts of Zambia's Eastern Province, located in four traditionally defined areas (Chiefdoms) in the Luangwa Valley. Sites were purposively selected to take part in a poultry development project by a local non-governmental organization (see "Study context" below). Because villages in the area are very small, multiple villages were included in most field sites (mean 5.6 villages per field site, 222 villages in total). The entire study area is located within the Game Management Areas surrounding four national parks and forest reserves, areas that are home to large populations of wildlife that support a considerable tourism industry.

Although there are limited population data available at the Chiefdom level, Zambia as a whole continues to struggle with poverty, food insecurity, and sub-optimal health, particularly in rural areas. As of the most recent national census, 77.9% of rural households were characterized as in poverty, and 57.7% were in extreme poverty (*Revised Sixth National Development Plan, 2013-2016*, 2014). The HIV epidemic affects 13.3% of Zambian adults (Central Statistical Office (CSO) et al., 2015), while high incidences of malaria, tuberculosis, and maternal, infant, and child morbidities and mortalities strain an overburdened health system (*National Health Strategic Plan 2011-2015*, 2011). Food security is tenuous for most households, varying dramatically from year to year due to frequent droughts and floods, and smallholder farmers in the Luangwa Valley experience particularly high rates of food insecurity during the lean season, from September to March (Lewis et al., 2011).

Study context

This is secondary analysis of baseline data collected as part of a larger impact evaluation study being carried out in partnership with Community Markets for Conservation (COMACO; www.itswild.org; Dumas et al., 2016; Lewis et al., 2011). The objective of the primary research is to test if an intervention promoting village-scale egg production can improve dietary quality and growth among children 6-36 months of age in participating communities. The data presented here reflect "traditional" livestock ownership practices and dietary behavior and were all collected prior to start of that intervention. The study is registered at ClinicalTrials.gov (ID: NCT02516852); the details will be reported elsewhere after all data are analyzed.

Data collection

Data were collected over four weeks prior to the intervention, from mid-December 2014 to mid-January 2015. Each field site was marked with a GPS point representing the approximate center of the site. Inclusion criteria for participation were: 1) the household was located ≤ 1.5 km from the field site GPS point; and 2) a child 6-36 months of age lived in the household.

The 20 eligible households nearest to the central GPS point of each field site were recruited and enrolled in the study, for a target of approximately 800 total households. All children 6-36 months of age living within enrolled households were included, and one child from each household was randomly selected during the analysis phase. Individuals underwent a thorough consenting process and the research staff administered in-home questionnaires (Appendix 4) to collect information about household composition, asset ownership, farm production, food security, maternal and child dietary diversity and ASF consumption, child morbidities and breastfeeding history, and subjective maternal wellbeing. Infant and young child feeding practices were measured following WHO recommendations (WHO, 2010). Child ASF consumption was measured by asking the mother to recall the number of times her child ate meat, fish, *kapenta* (small freshwater fish, usually dried), dairy products, or eggs in the past week. Child morbidity was operationalized as a dichotomous variable, with "morbidity" defined as having any diarrhea, vomiting, fever, or rapid or difficult breathing with coughing in the past

14 days, as observed and recalled by the mother, or malaria diagnosed by a health professional in the past 14 days.

Height and weight measures were then taken on the mother and child using standardized seca 872 electronic scales with mother/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. The entire procedure, including questionnaires and anthropometry, lasted approximately 45 minutes per household.

Variable definitions

Exposure variables

Households were assigned to one of five "livestock ownership typologies" based on the types and numbers of livestock they owned. To create this typology, we generated two standard measures: 1) total number of animals owned, where all species are equally weighted; and, 2) a TLU score, which uses a weighted value for each species to estimate the total value of their livestock holdings. The TLU weighting factors used were 0.70 for cattle, 0.20 for pigs, 0.10 for sheep and goats, 0.02 for ducks and guinea fowl, 0.01 for chickens, and 0.005 for pigeons (Njuki et al., 2011). Then, each variable was categorized into tertiles, and the two categorical variables were cross-tabulated, revealing five distinct patterns, or typologies, of livestock ownership (Tables 3.1 and 3.2). For comparison, we additionally considered eleven other measures of livestock ownership: binary measure of any livestock ownership; total number of animals owned;

TLU owned; binary measures of any chickens, any goats, any pigs, and any cattle; and individual counts of the number of chickens, goats, pigs, and cattle.

Table 3.1. Five patterns of livestock ownership, or typologies, were defined by the total number of livestock and tropical livestock units (TLU) owned by household.

		TLU, tertiles			
		1	**2**	**3**	Total number of households
Total number of livestock, tertiles	**1**	**n= 309**	0	0	309
	2	0	**n= 196**	**n= 54**	250
	3	0	**n= 62**	**n= 217**	279
Total number of households		309	258	271	**838**

Table 3.2. Characteristics of the five livestock ownership typologies.

	Type 1 (n= 309)	Type 2 (n= 196)	Type 3 (n= 62)	Type 4 (n=54)	Type 5 (n= 217)
Description	No livestock of any kind	Few animals, mostly poultry (e.g. 4 chickens)	Moderate number of animals, mostly poultry (e.g. 10 chickens)	Few animals, mixed large and small livestock (e.g. 2 goats, 2 pigs, 7 chickens)	Many animals, mixed large and small livestock (e.g. 2 cattle, 2 sheep, 15 chickens)
Mean TLU (range)		0.04 (0.01 - 0.11)	0.1 (0.09 - 0.12)	0.67 (0.14 - 3.50)	1.75 (0.13 - 20.08)
Mean no. of animals (range)		4.22 (1 - 8)	10.56 (9 - 14)	4.83 (1 - 8)	22.51 (9 - 119)
Own chickens (%)		96.9%	100.0%	40.7%	94.0%
No. of chickens, mean (range)		4.1 (0 - 8)	10.1 (6 - 12)	1.4 (0 - 7)	13.3 (0 - 50)
Own goats (%)		1.0%	0.0%	40.7%	33.6%
No. of goats, mean (range)		0.01 (0 - 1)	0.0	1.3 (0 - 7)	2.2 (0 - 42)
Own pigs (%)		0.0%	0.0%	53.7%	30.9%
No. of pigs, mean (range)		0.0	0.0	1.6 (0 - 7)	2.7 (0 - 42)
Own cattle (%)		0.0%	0.0%	13.0%	21.7%
No. of cattle, mean (range)		0.0	0.0	0.3 (0 - 5)	1.1 (0 - 15)
Own ducks (%)		5.1%	1.6%	0.0%	12.9%
No. of ducks, mean (range)		0.1 (0 - 5)	0.0 (0 - 3)	0.0	0.7 (0 - 11)
Own pigeons (%)		0.5%	8.1%	0.0%	6.0%
No. of pigeons, mean (range)		0.02 (0 - 3)	0.5 (0 - 8)	0.0	1.7 (0 - 80)
Own guinea fowl (%)		1.0%	0.0%	1.9%	6.0%
No. of guinea fowl, mean (range)		0.02 (0 - 2)	0.0	0.1 (0 - 7)	0.4 (0 - 26)
Own sheep (%)		0.0%	0.0%	5.6%	4.1%
No. of sheep, mean (range)		0.0	0.0	0.2 (0 - 4)	0.4 (0 - 33)

Outcome variables

The child's dietary quality was assessed with two measures: 1) individual dietary diversity score (DDS), the number of food groups out of seven consumed by the child in the 24 hours prior to the survey (World Health Organization (WHO), 2010); and 2) a dichotomous indicator that the child consumed any ASF over the past 7 days. Nutritional status was assessed by child HAZ, where the reference population is based on the WHO Child Growth Standards. Children with HAZ < -2 were classified as stunted, and outliers with HAZ values > +6 or < -6 were excluded during data cleaning as biologically implausible (n=3) (WHO, 2006).

Control and descriptive variables

Because livestock are often used in rural areas as an instrument for wealth storage, household wealth was controlled for in all models to eliminate the concern that any association between livestock ownership and child diets or nutrition represented a general effect of wealth, rather than a specific effect of livestock. Wealth was assessed with an asset index generated using principal components analysis based on indicators for household dwelling quality and size, electricity access, use of paid agricultural labor, and ownership of various household assets (TV, radio, CD or DVD player, bicycle, mobile phone, plough, mattress, bed, sofa, table, solar panel, battery, bank account). Livestock ownership was not included. The first component (eigenvalue= 5.830, explaining 29.2% of the variability in the sample, Cronbach's alpha= 0.857) was retained and used to generate a tertile measure of wealth.

Additional covariates were household size; sex of head of household and whether he or she had completed primary school; maternal age, height, and body mass index (BMI); and child sex, age, and breastfeeding history (binary indicator of whether they were exclusively breastfed to 6 months of age based on the mother's response to eight questions about the timing of her initiation, duration, and cessation of breastfeeding and the introduction of water and solid foods). Household COMACO membership status was initially included in all models but was highly non-significant and was not included in final models. Similarly, distance from the central GPS point was considered as a potential confounder on the assumption that more remote households maybe be systematically worse off than those more centrally located. However, distance from the central GPS point was not significantly correlated with the asset index or household food insecurity. Given this, along with the fact that each field site was composed of multiple villages, distance from the GPS point was not included in any final models. Household food insecurity over the one month prior to the survey was assessed by the Household Food Insecurity Access Scale (HFIAS; (Coates et al., 2007)), retained for descriptive purposes as a continuous variable from 0 (completely food secure) to 27 (severely food insecure) and categorized as food security (HFIAS= 0), mildly food insecurity (HFIAS= 1 – 9), moderately food insecure (HFIAS= 10 – 18), or severely food insecure (HFIAS= 19 – 27).

Data handling

Data were collected on handheld Android mobile devices (Samsung Galaxy Tab 4 7.0, Samsung Electronics Co., Suwon, South Korea) using ODK Collect (Open Data Kit, https://opendatakit.org/). Data were pulled daily from the tablets using ODK Briefcase and stored on a password-secured local server. Data cleaning and analysis were completed in Stata (Stata/IC version 14.0, StataCorp, College Station, Texas).

Analytical methods

Descriptive analysis of all variables was first performed to better understand the characteristics of the study population. Bivariate analyses (chi-squared and ANOVA) of the association between measures of livestock ownership and measures of child DDS, ASF consumption, and stunting status were performed. Associations were considered significant at $p < 0.05$.

To further examine the association between livestock ownership and continuous outcomes of interest (DDS and HAZ), we fitted multi-level mixed effect models with field site random effects nested within Chiefdom to account for potential clustering of outcomes within communities. To examine the association between livestock ownership and binary outcomes of interest (any ASF consumption and stunting), we fitted generalized linear mixed effect models (GLMM) with a binomial family and logit-link function, again with field site random-effects nested within Chiefdom. All models included controls for household characteristics (household size, wealth, sex of head of household and whether they completed primary school), maternal age, child characteristics (sex, age, and age squared). Models for HAZ and stunting additionally included control variables for maternal BMI and height, child breastfeeding history, and recent child history of any morbidity. Covariates were selected a priori based on the literature.

Ethical Standards Disclosure

All procedures, protocols, and research materials underwent an internal review process at COMACO and were approved by the Institutional Review Board at Cornell University (Protocol ID#: 1402004456). In the field, approval was first obtained from Senior Chief Nsefu and Chiefs Mnkhanya, Jumbe, and Mwanya, who granted permission for all field activities in their respective Chiefdoms. We then met individually with key Village Headmen from selected field sites to inform them of our activities and obtain their support. At the time of enrollment, all participants provided individual written informed consent; separate consents were obtained for the household interview, the maternal interview, and parental consent for anthropometric measurements. In the case of an illiterate participant, 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.

Results

Of the 838 eligible children with complete dietary recall and livestock ownership data, biologically plausible anthropometric data were available for 835. Despite record high cereal production in 2014 (FAOSTAT Database), food insecurity was prevalent at the time of data collection (the start of the lean season, when the previous year's harvest has largely been completely consumed, but new crops have not yet reached harvest), with 43.7% of households reporting mild food insecurity and 41.1% reporting moderate or severe food insecurity over the past 30 days (Table 3.3).

Table 3.3. Characteristics of participating households and children (n= 838).

Household characteristics	
Household size, mean (SD)	5.3 (2.2)
Number of children under 5 years, mean (SD)	1.5 (0.7)
Head of household age, mean years (SD)	34.6 (9.9)
Head of household sex, % female	20.6
Head of household education, % completing primary	57.5
Electricity access, %	27.7
Protected water source, %	79.1
Thatch roofing on house, %	64.0
Mud flooring in house, %	85.9
Latrine type in household	
None	2.3
Shared pit latrine[a]	50.8
Private pit latrine[a]	46.9
Household Food Insecurity Access Scale, mean (SD)	8.2 (5.9)
Food secure (HFIAS= 0), %	15.2
Mildly food insecure (HFIAS= 1 – 9) , %	43.7
Moderately food insecurity (HFIAS= 10 – 18), %	37.6
Severely food insecure (HFIAS= 19 – 27), %	3.5

Table 3.3 (Continued)

Child characteristics	
Age, mean months (SD)	21.2 (8.6)
Sex, % female	53.2
Ever breastfed, %	88.2
Exclusively breastfed to 6 months, %	54.3
Currently breastfeeding, %	45.2
Fever in the past 14 days, %	55.4
Diarrhea in the past 14 days, %	45.2
Acute respiratory illness in the past 14 days, %	24.3
≥ 1 morbidity in the past 14 days, %	75.4
Dietary diversity score, mean out of seven (SD)	3.4 (1.5)
Minimum dietary diversity met (≥ 4 food groups eaten), %	41.1
Minimum acceptable diet met (children 6-24mo), %	18.4
Any ASF consumption in the past 7d, %	81.6
Frequency of ASF consumption in past 7d, mean (SD)	5.2 (4.8)
HAZ, mean (SD)	-1.65 (1.38)
Stunted (HAZ< -2), %	40.0
Severely stunted (HAZ< -3), %	13.9

Notes: [a]Traditional pit latrine. There were no Ventilated Improved Pit [VIP] latrines, pit latrines with slabs, or otherwise improved latrines.

Abbreviations: ASF, animal source foods; HAZ, height-for-age z-score

Mean child DDS was low, with less than half of children having consumed a minimally diverse diet the day before the survey. While the majority of children had been breastfed at some point in their lifetime, just over half were exclusively breastfed to 6 months of age. Three quarters of women reported that their child experienced at least one morbidity in the 14 days prior to the survey, with the majority experiencing multiple morbidities. Prevalence of stunting and severe stunting was very high (Table 3.3).

Overall, 63.1% of households owned livestock of some kind, with chickens being the most commonly owned, followed by goats and pigs (Table 3.4). Despite widespread ownership of at least one animal, total livestock holdings were small, with a median TLU of just 0.05, the equivalent of five chickens. Livestock ownership patterns varied significantly by Chiefdom ($p < 0.001$; Figure 3.2). Mwanya and Nsefu Chiefdoms, in particular, had a high number of households categorized as Type 1 or Type 2 typologies, while Jumbe and Mnkhanya Chiefdoms had a high number of households categorized as Type 4 or Type 5.

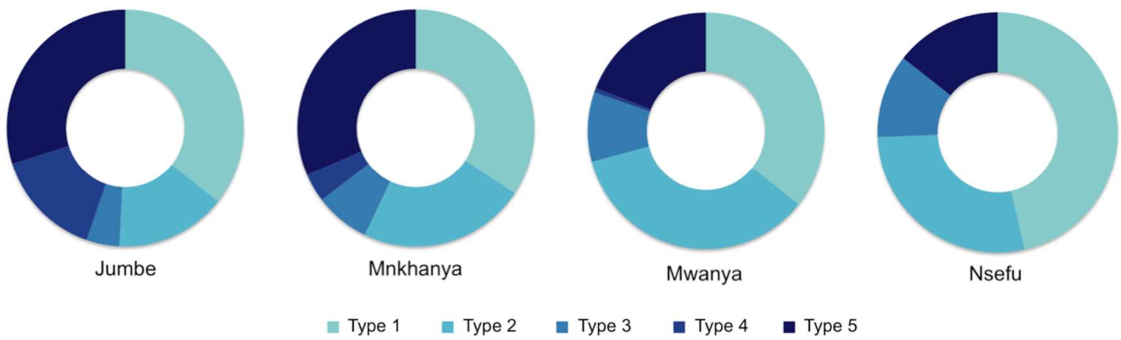


Figure 3.2. The distribution of livestock typologies in the four Chiefdoms. Typologies were defined as follows: no animals of any kind (Type 1); few animals, mostly poultry (Type 2); moderate number of animals, mostly poultry (Type 3); few animals, mixed small and large livestock species (Type 4); and moderate to large number of animals, mixed small and large livestock species (Type 5).

No measure of livestock ownership was significantly associated with stunting or meeting the minimum DDS in unadjusted t-tests or chi-squared tests (Table 3.4). There was a marginally lower prevalence of any livestock ownership among households where the index child was stunted, but this difference was not statistically significant. In unadjusted comparisons, cattle and guinea fowl ownership were associated with significantly higher ASF consumption (Table 3.4), but these associations lost significance after controlling for household, maternal, and child characteristics (data not shown). The chi-squared test indicates that a child's ASF consumption is not independent of their household's livestock ownership typology (p= 0.006). In particular, children living in a household with no livestock (Type 1) are overrepresented in the medium ASF tertile, while children living in Type 5 households are overrepresented in the high ASF tertile.

Is livestock ownership associated with child dietary diversity?

In the multi-level mixed effect model, livestock ownership Type 2 was associated with significantly lower DDS among children (Table 3.5 and Appendix 5). The analysis was followed by a post-hoc pairwise comparison among the five levels of livestock typology using a Sidak correction for multiple comparisons; DDS was only significantly different between children living in households with livestock ownership Type 1 and Type 2 ($\beta = -0.50$, $p = 0.002$, with children living in Type 2 households having lower DDS). Living in Mwanya was associated with significantly higher DDS. Education of the head of household, wealth, maternal age, and child age were strongly predictive of increased DDS, while household size was strongly predictive of decreased DDS. A recent history of illness was positively predictive of DDS, which may reflect a local practice of giving children raw eggs with traditional medicines, though further investigation of this idea is beyond the scope of this paper.

Table 3.4. Unadjusted associations between various measures of livestock ownership and stunting, dietary diversity, or animal source food consumption.

Variable	Overall	Not Stunted[a]	Stunted[a]	p-value	Low DDS[b]	High DDS[b]	p-value	Low ASF[c]	Medium ASF[c]	High ASF[c]	p-value
Children, n	838	501	334		494	344		301	316	221	
Ownership of any livestock, %	63.1%	65.7%	59.6%	0.074	63.2%	63.1%	0.982	66.4%	57.9%	66.1%	0.051
Chicken	57.0%	59.1%	54.2%	0.162	57.5%	56.4%	0.753	60.5%	52.2%	59.3%	0.087
Goat	11.6%	11.4%	12.0%	0.792	12.1%	10.8%	0.537	11.6%	10.1%	13.6%	0.471
Pig	11.5%	11.8%	11.1%	0.757	11.9%	10.8%	0.596	14.3%	9.5%	10.4%	0.148
Cattle	6.4%	6.4%	6.3%	0.954	6.3%	6.7%	0.812	4.7%	5.4%	10.4%	**0.019**
Ducks	4.7%	5.4%	3.6%	0.229	4.9%	4.4%	0.737	5.6%	4.4%	3.6%	0.539
Pigeon	2.3%	2.6%	1.8%	0.449	2.2%	2.3%	0.925	0.7%	3.5%	2.7%	0.055
Guinea fowl	1.9%	1.4%	2.7%	0.181	1.8%	2.0%	0.825	0.3%	1.9%	4.1%	**0.009**
Sheep	1.4%	1.2%	1.5%	0.711	1.6%	1.2%	0.585	1.0%	1.6%	1.8%	0.713
Total number of animals owned, mean (SD)	7.91 (12.12)	8.05 (11.36)	7.70 (13.21)	0.684	8.01 (13.66)	7.77 (9.50)	0.778	7.43 (11.64)	7.76 (13.59)	8.78 (10.41)	0.437
TLU, mean (SD)	0.51 (1.63)	0.50 (1.49)	0.54 (1.81)	0.733	0.53 (1.82)	0.49 (1.29)	0.742	0.52 (1.71)	0.47 (1.75)	0.57 (1.29)	0.809
Livestock Typology[d]											
Type 1	36.9%	34.3%	40.4%		36.8%	36.9%		33.6%	42.1%	33.9%	
Type 2	23.4%	25.2%	21.0%		25.3%	20.6%		26.6%	23.1%	19.5%	
Type 3	7.4%	8.4%	6.0%	0.194	6.1%	9.3%	0.301	7.0%	7.9%	7.2%	**0.006**
Type 4	6.4%	5.8%	7.5%		6.3%	6.7%		9.6%	3.5%	6.3%	
Type 5	25.9%	26.4%	25.2%		25.5%	26.5%		23.3%	23.4%	33.0%	

Notes: [a]Stunted is defined as a height-for-age z-score of < -2. [b]Low DD is defined as eating 0-3 out of 7 food groups in the 24 hours preceding the survey; high DD is eating 4-7 food groups. [c]ASF consumption was defined as number of times a child consumed any ASF in the past 7 days; cutoffs for tertiles of ASF consumption were constructed by dividing the study population roughly into thirds, such that low ASF= 0-2 times, medium ASF= 3-7 times, and high ASF= 8-29 times. [d]Hierarchical livestock typology: Type 1= no livestock; Type 2= few poultry; Type 3= many poultry; Type 4= few mixed livestock; Type 5= many mixed livestock.

Abbreviations: DDS, dietary diversity score; ASF, animal source foods; TLU, Tropical Livestock Units

Table 3.5. Summary of multi-level mixed effect model (maximum likelihood estimates) assessing the effect of livestock ownership typology on child dietary diversity (n= 811)[a]

	Adjusted regression coefficient (95% CI)	**P-value**
Livestock ownership typology[b] (vs. Type 1)		
Type 2	-0.460 (-0.716, -0.204)	**<0.001**
Type 3	-0.206 (-0.600, 0.187)	0.306
Type 4	-0.326 (-0.750, 0.099)	0.132
Type 5	-0.150 (-0.418, 0.118)	0.273
Household size	-0.065 (-0.114, -0.015)	**0.010**
Female head of household	-0.239 (-0.493, 0.015)	0.065
Head of household completed primary education	0.273 (0.071, 0.475)	**0.008**
SES tertile		
Medium vs. low	0.299 (0.064, 0.535)	**0.013**
High vs. low	0.374 (0.122, 0.627)	**0.004**
Maternal age, years	0.019 (0.005, 0.032)	**0.005**
Female child	-0.033 (-0.222, 0.156)	0.733
Child age, months	0.180 (0.121, 0.238)	**<0.001**
Child age, months, squared	-0.003 (-0.004, -0.002)	**<0.001**
History of morbidity, past 14d	0.235 (0.009, 0.461)	**0.042**
Chiefdom (vs. Jumbe)		
Mnkhanya	0.126 (-0.144, 0.395)	0.361
Mwanya	0.348 (0.030, 0.665)	**0.032**
Nsefu	-0.142 (-0.483, 0.199)	0.413
Between household (Level 1) variance	*1.823*	
Between village (Level 2) variance	*0.029*	
ICC	*0.016*	
Overall R^2	*0.126*	

Notes: [a] Model includes fixed effects of Chiefdom and random effect of field site (village). [b] Hierarchical livestock typology: Type 1= no livestock; Type 2= few poultry; Type 3= many poultry; Type 4= few mixed livestock; Type 5= many mixed livestock

Abbreviations: SES, socioeconomic status; ICC, intraclass correlation coefficient

Is livestock ownership associated with child ASF consumption?

In generalized linear mixed effect models, no livestock typology was significantly associated with odds of child ASF consumption, although Type 5 typology approached significance (Table 3.6 and Appendix 5). In a post-hoc pairwise comparison among Chiefdoms, the odds of any ASF consumption were significantly higher among children in Mwanya versus those in Mnkhanya (OR= 3.61, p= 0.016) and Nsefu (OR= 4.95, p= 0.004). The highest tertile of household wealth and child age were the only other significant predictors of child ASF consumption. In the initial models, a recent history of morbidity was considered as a potential predictor of child ASF consumption; however, it was not significant and did not meaningfully affect the point estimates for the other predictors, and it was therefore dropped from the final regression in order to retain the most parsimonious model.

Table 3.6. Summary of generalized linear mixed effect model (maximum likelihood estimates) assessing the effects of livestock ownership typology on odds of any ASF consumption in the past 7 days (n= 812)[a]

	Adjusted odds ratio (95% CI)	**P-value**
Livestock ownership typology[b] (vs. Type 1)		
Type 2	0.976 (0.582, 1.636)	0.927
Type 3	0.932 (0.419, 2.075)	0.864
Type 4	0.682 (0.313, 1.488)	0.336
Type 5	1.782 (0.990, 3.207)	0.054
Household size	0.975 (0.879, 1.083)	0.639
Female head of household	1.011 (0.595, 1.719)	0.966
Head of household completed primary education	1.245 (0.818, 1.894)	0.307
SES tertile		
Medium vs. low	1.348 (0.847, 2.145)	0.208
High vs. low	2.009 (1.183, 3.411)	**0.010**
Maternal age, years	1.020 (0.991, 1.050)	0.139
Female child	1.001 (0.678, 1.478)	0.980
Child age, months	1.347 (1.203, 1.508)	**<0.001**
Child age, months, squared	0.994 (0.991, 0.997)	**<0.001**
Chiefdom (vs. Jumbe)		
Mnkhanya	0.689 (0.387, 1.227)	0.206
Mwanya	2.706 (1.186, 6.174)	**0.018**
Nsefu	0.488 (0.245, 0.972)	**0.041**
Between village (Level 2) variance	*0.176*	
ICC	*0.051*	
Overall R^2	*0.138*	

Notes: [a] Model includes fixed effects of Chiefdom and random effect of field site (village). [b] Hierarchical livestock typology: Type 1= no livestock; Type 2= few poultry; Type 3= many poultry; Type 4= few mixed livestock; Type 5= many mixed livestock

Abbreviations: SES, socioeconomic status; ICC, intraclass correlation coefficient

Is livestock ownership associated with child HAZ or stunting?

Livestock ownership typology was not significantly associated with child HAZ (Table 3.7 and Appendix 5) or stunting odds (Table 3.8 and Appendix 5). In both models, maternal BMI, maternal height, and female sex of the child were strongly associated with higher HAZ and decreased odds of stunting, while child age was strongly associated with lower HAZ and increased odds of stunting. Wealth was not associated with HAZ or stunting odds. Despite differences in DDS and ASF consumption by Chiefdom, there was no difference in mean HAZ or stunting odds across Chiefdoms. Although no households in the sample had an improved sanitation facility, having a private (vs. shared) latrine was included in initial models for both HAZ and stunting outcomes but was associated with high p-values (0.618 and 0.970, respectively) and had no effect on the estimates or p-values of other covariates in the model. It was therefore not included in the final models based on a tenuous theoretical connection between private sanitation facilities and child nutrition outcomes.

Table 3.7. Summary of multi-level mixed effect model (maximum likelihood estimates) assessing the effect of livestock typology on child height-for-age z-score (n= 799)[a]

	Adjusted regression coefficient (95% CI)	**P-value**
Livestock ownership typology[b] (vs. Type 1)		
Type 2	0.206 (-0.025, 0.438)	0.080
Type 3	0.036 (-0.315, 0.388)	0.840
Type 4	-0.326 (-0.705, 0.052)	0.091
Type 5	-0.032 (-0.274, 0.211)	0.798
Household size	-0.017 (-0.061, 0.028)	0.460
Female head of household	-0.030 (-0.258, 0.197)	0.793
Head of household completed primary education	-0.013 (-0.193, 0.169)	0.893
SES tertile		
Medium vs. low	0.190 (-0.021, 0.401	0.078
High vs. low	0.155 (-0.071, 0.380)	0.179
Maternal age, years	0.000 (-0.012, 0.012)	0.942
Maternal BMI	0.043 (0.015, 0.072)	**0.003**
Maternal height, cm	0.052 (0.038, 0.067)	**<0.001**
Female child	0.339 (0.169, 0.508)	**<0.001**
Child age, months	-0.122 (-0.175, -0.069)	**<0.001**
Child age, months, squared	0.002 (0.001, 0.003)	**<0.001**
Child exclusively breastfed to 6mo	-0.039 (-0.214, 0.139)	0.664
History of any morbidity, past 14d	-0.102 (-0.307, 0.101)	0.327
Any ASF consumed in past 7d	-0.038 (-0.265, 0.189)	0.743
Chiefdom (vs. Jumbe)		
Mnkhanya	-0.165 (-0.378, 0.047)	0.130
Mwanya	-0.179 (-0.433, 0.076)	0.158
Nsefu	-0.095 (-0.365, 0.175)	0.507
Between household (Level 1) variance	*1.452*	
Between village (Level 2) variance	*0.000*	
ICC	*0.000*	
Overall R^2	*0.140*	

Notes: [a] Model includes fixed effects of Chiefdom and random effect of field site (village). [b] Hierarchical livestock typology: Type 1= no livestock; Type 2= few poultry; Type 3= many poultry; Type 4= few mixed livestock; Type 5= many mixed livestock

Abbreviations: SES, socioeconomic status; BMI, body mass index; ASF, animal source foods; ICC, intraclass correlation coefficient

Table 3.8. Summary of generalized linear mixed effect model (maximum likelihood estimates) assessing the effects of livestock ownership typology on odds of child stunting (n= 804)[a]

	Adjusted odds ratio (95% CI)	**P-value**
Livestock ownership typology[b] (vs. Type 1)		
Type 2	0.682 (0.444, 1.046)	0.080
Type 3	0.751 (0.386, 1.460)	0.399
Type 4	1.411 (0.712, 2.798)	0.324
Type 5	1.019 (0.651, 1.597)	0.934
Household size	1.061 (0.976, 1.152)	0.163
Female head of household	0.870 (0.571, 1.325)	0.516
Head of household completed primary education	1.129 (0.808, 1.579)	0.476
SES tertile		
Medium vs. low	0.806 (0.547, 1.191)	0.280
High vs. low	0.818 (0.540, 1.242)	0.346
Maternal age, years	0.986 (0.965, 1.001)	0.222
Maternal BMI	0.935 (0.886, 0.987)	**0.015**
Maternal height, cm	0.900 (0.873, 0.927)	**<0.001**
Female child	0.619 (0.453, 0.849)	**0.003**
Child age, months	1.232 (1.111, 1.367)	**<0.001**
Child age, months, squared	0.996 (0.994, 0.998)	**0.001**
Child exclusively breastfed to 6mo	0.885 (0.639, 1.225)	0.461
History of any morbidity, past 14d	1.162 (0.796, 1.696)	0.438
Any ASF consumed in past 7d	1.124 (0.732, 1.725)	0.595
Chiefdom (vs. Jumbe)		
Mnkhanya	1.177 (0.751, 1.845)	0.476
Mwanya	1.082 (0.635, 1.843)	0.772
Nsefu	1.085 (0.612, 1.924)	0.780
Between village (Level 2) variance	*0.089*	
ICC	*0.026*	
Overall R^2	*0.149*	

Notes: [a] Model includes fixed effects of Chiefdom and random effect of field site (village). [b] Hierarchical livestock typology: Type 1= no livestock; Type 2= few poultry; Type 3= many poultry; Type 4= few mixed livestock; Type 5= many mixed livestock

Abbreviations: SES, socioeconomic status; BMI, body mass index; ICC, intraclass correlation coefficient

Are more commonly used measures of livestock ownership associated with child nutrition outcomes?

We compared our findings using the typologies method with those using more traditional measures of livestock exposure. These analyses found that child DDS was negatively associated with any livestock ownership (β= -0.331, p= 0.002) or any chicken ownership (β= -0.320, p=

0.002; Appendix 6). In both models, among livestock or chicken owners, increasing numbers of chickens, but not other animals, was positively associated with DDS (β= 0.016, p= 0.042 and β= 0.022, p= 0.009, respectively). No other measure of livestock ownership was significantly associated with DDS, ASF consumption, HAZ, or stunting (Appendix 6). These results are strikingly similar to those found using livestock typologies as the sole measure of livestock ownership, which found a negative effect of livestock ownership on child DDS only among Type 2 livestock owners but not among those with larger livestock holdings or more valuable animals.

Discussion

In this analysis, livestock ownership was not significantly associated with children's odds of ASF consumption, HAZ, or odds of stunting in the Luangwa Valley. Furthermore, owning a small number of mostly poultry (Type 2) was actually associated with decreased overall child DDS compared to child DDS among households having no livestock (Type 1), an unexpected finding that diverges from traditional livestock development thinking. This finding was supported by additional analyses using more common measures of livestock ownership, which found that while owning any livestock was associated with significantly lower DDS, the association was almost entirely attributable to owning less than 15-20 chickens. This research reveals the complex association between livestock ownership and child nutrition outcomes in rural smallholder farming households and thereby helps lay the groundwork for the design of a livestock development programs that can optimize the impact on child diets and nutritional status in the Luangwa Valley. It additionally highlights the value of using a typologies approach as a proxy for how people use their livestock to uncover the differential and nuanced impact of various types and numbers of livestock on child nutrition outcomes.

Our data do not support the hypothesis that ownership of livestock is *necessarily* associated with greater ASF consumption among children. Because total livestock holdings in this population were very small on average, with a median TLU of just 0.05 (equivalent to five chickens), the slaughtering of animals for home consumption is likely very rare in most households, giving children few opportunities to benefit from livestock through more frequent meat consumption. Indeed, although the most commonly owned livestock were chickens, previous research has found that households here were reluctant to slaughter them for home consumption, preferring to sell chickens to pay school fees or cover emergency expenses (Dumas et al., 2016). That research also found that households rarely consumed eggs from village chickens, instead allowing them to hatch to increase flock sizes (Dumas et al., 2016). Similarly, consumption of goat, sheep, or cow's milk produced by the household was extremely uncommon in this study, with nearly 90% of households reporting that they purchase milk from shops on the rare occasions they consume it (data not shown). Therefore, in general, livestock were not kept by this population for routine ASF consumption at home, which is consistent with our finding that livestock ownership was not associated with higher ASF consumption or greater DDS.

Because we did not collect data on household income and expenditures, women's empowerment, or crop yields, we cannot determine if traditional livestock ownership was associated with the other potential intermediate outcomes outlined in Figure 3.1. However, our analyses did not reveal an association between traditional livestock ownership and higher HAZ or lower odds of stunting in this population. We therefore conclude that if livestock did positively impact these unmeasured intermediate outcomes, the effect was: 1) too small to significantly improve child linear growth; 2) negated by negative consequences of livestock ownership; or 3) dwarfed by other factors responsible for child stunting (e.g. high prevalence of recent illness). Although not examined in this study, there are several reports that livestock ownership negatively affects child nutrition through increased pathogen exposure (George et al., 2015; Headey & Hirvonen, 2016; Marquis et al., 1990; Mosites et al., 2016; Ngure et al., 2013; Thumbi et al., 2015; Zambrano et al., 2014), increased maternal labor demands (Mullins et al., 1996; Njuki et al., 2015), or premature introduction of ASF to children (Wyatt et al., 2013). Our finding of a very high incidence of child morbidity additionally suggests that overall health might be constraining any potential positive impact of livestock ownership. Notably, neither ASF consumption nor DDS were significantly associated with HAZ or stunting odds (data not shown), further suggesting that diet may not be the primary determinant of stunting in this population.

Several methodological features of our current work provide insights that can help in intervention design and in monitoring and evaluation. First, our approach differed from several previous studies investigating the link between livestock ownership and child nutrition by categorizing total livestock holdings into five distinct typologies of livestock ownership. This approach allowed us to examine the differential impact of, for example, one chicken versus 15 chickens, or 15 chickens versus 15 goats, nuances which are lost when using binary or absolute count measures of livestock exposure. For example, had a single binary indicator been used as the only measure of livestock ownership, we would have concluded that livestock ownership was negatively associated with child DDS ($\beta = -0.331$; $p<0.002$; Appendix 6). Upon closer examination, however, we see that this association can be accounted for almost entirely by ownership of chickens ($\beta = -0.320$; $p<0.002$). Furthermore, the negative effect of owning chickens decreases with each additional chicken owned (β= 0.022, p= 0.009), such that flocks greater with more than 15 chickens are no longer negatively associated with DDS. The typologies methodology therefore proved more efficient than an approach that tested multiple measures of livestock ownership individually and arrived at the same conclusion, while avoiding potential concerns of multicollinearity, which would prevent counts of multiple species from being considered in a single regression. In areas that are not dominated by holdings of a single particular species, our new methodology combining metrics might prove more informative and adaptive to different study sites, in which different typologies might need to be defined to reflect local environmental and cultural contexts.

Second, the majority of similar studies have been in a population of children under 5 years (with the exception of Nicholson et al. (Nicholson et al., 2003), which studied children under 6 years, and Gross (Grosse, 1998), which studied only children 2-5 years), and only a minority disaggregated their results by child age. Given that almost all stunting occurs from conception to 24 months of age, this approach assumes that – for the older children in the study – a household's livestock holdings did not change significantly over the two to three year period preceding measurement. By studying children 6-36 months, we have limited the lag from the time of meaningful exposure to the measurement of outcomes.

Finally, the context of our study site provides potential insights for people studying issues of "One Health," a paradigm that explores the interconnected health relationships between people, domestic animals, and the environment (Barrett & Osofsky, 2013). The Luangwa Valley is a prime example of how these interactions operate in "buffer zones" around protected wildlife areas (Lewis et al., 2011), where livestock production can be limited by predation and endemic infectious diseases at the wildlife-livestock interface (Bengis et al., 2002; Distefano, 2005). As a result, fish and wildlife populations remain an important source of ASF for many communities living around protected areas (Brashares et al., 2011; Golden et al., 2011), which may diminish the importance of domestic animals as a source of ASF, and instead encourage their use as sources of income (Dumas et al., 2016). Indeed, in this study, children living in Mwanya had the greatest dietary diversity and odds of ASF consumption, despite their low livestock ownership, high relative poverty (43.4% of households were categorized in the poorest tertile of the study population), and very poor market access and infrastructure. This, combined with anecdotal and published evidence, suggests a high dietary dependence on fish and wildlife population, which may therefore reduce the need for livestock to provide ASF (Lewis et al., 2011). Human populations living around similar protected areas throughout Africa are growing rapidly (Wittemyer et al., 2008) and this study is among the first to examine the role of livestock production on child diets and nutrition within this unique context. Our results suggest that livestock-focused public health, development, and wildlife conservation programs operating in these areas should include nutrition behavior change communication and other program elements if they intend to positively impact child nutrition.

There are also some limitations to this analysis that should be considered when interpreting our results. First, both project and control communities were purposively selected to participate in the primary study based on their relationships with COMACO. We controlled for this non-probability based sampling strategy in our regression models, using random-effects variables to capture unobserved community factors and fixed-effects variables to control for observed household, maternal, and child characteristics. However, there are other factors that were either unmeasured (e.g. maternal education and self-efficacy, profession, ethnic group) or were largely unobservable within the context of our surveys (e.g. livestock management abilities, exposure to shocks such as catastrophic medical issues or idiosyncratic crop loss in the preceding year), that could modify or confound the relationship between livestock ownership and child outcomes. Second, because these data were not collected with the primary objective of evaluating the association between livestock ownership and child nutrition, we were only able to quantitatively evaluate one of the many hypothesized pathways in this relationship (i.e. ASF consumption). Additional data are necessary to consider all of the theoretical pathways linking livestock to child nutrition outcomes outlined in Figure 3.1. Finally, the cross-sectional nature of this analysis prevents us from appreciating any temporal components to the relationship between livestock ownership and child nutrition outcomes. For example, a family currently owning livestock may have only recently acquired it, meaning the child has not had the opportunity to benefit from (or be harmed by) those livestock. Conversely, a family owning relatively few chickens might have previously had more birds but been forced to sell by a recent economic or medical shock. Children in that circumstance might have less evidence of stunting because of prior household conditions, but have lower DDS because of their current situation. A longitudinal study would better capture and quantify a child's "lifetime exposure" to livestock ownership from conception.

These limitations notwithstanding, this research contributes to the growing body of literature suggesting that the link between livestock production and child nutrition outcomes is complex and likely highly context-specific. Livestock distribution is a common component of many rural development programs operated by charitable organizations aiming to improve income and/or ASF consumption. Our findings suggest, however, that simply *owning* livestock does not improve child diets or nutrition status in all situations. In light of this, development organizations must carefully consider how their target population traditionally uses livestock and integrate ancillary elements into their program package. These might include nutrition and hygiene behavior change communication, training in optimal management practices, providing access to markets for ASF, and/or providing access to veterinary services. In these ways, they might ensure that *ownership* of livestock translates into actual nutritional benefits for children.

References

Adair, L. S., Fall, C. H., Osmond, C., Stein, A. D., Martorell, R., Ramirez-Zea, M., et al. (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. *The Lancet*, *382*(9891), 525–534.

Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does livestock ownership affect animal source foods consumption and child nutritional status? Evidence from rural Uganda. *Journal of Development Studies*, *51*(8), 1034–1059.

Barrett, M. A., & Osofsky, S. A. (2013). One Health: interdependence of people, other species, and the planet. In: *Jekels Epidemiology, Biostatistics, Preventive Medicine, and Public Health* (4 ed., pp. 364–377). Philadelphia: Elsevier / Saunders.

Bengis, R. G., Kock, R. A., & Fischer, J. (2002). Infectious animal diseases: the wildlife/livestock interface. *Revue Scientifique Et Technique-Office International Des Epizooties*, *21*(1), 53–65.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451.

Brashares, J. S., Golden, C. D., Weinbaum, K. Z., Barrett, C. B., & Okello, G. V. (2011). Economic and geographic drivers of wildlife consumption in rural Africa. *Proceedings of the National Academy of Sciences U. S. A.*, *108*(34), 13931–13936.

Central Statistical Office (CSO), Ministry of Health (MOH), ICF International. (2015). Zambia Demographic and Health Survey 2013-14. Rockville, MA: ICF International.

Coates, J., Swindale, A., & Bilinsky, P. (2007). *Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide (v. 3)*. Washington D.C.: FHI 360 and Food and Nutrition Technical Assistance Project (FANTA).

Cogill, B. (2003). Anthropometric Indicators Measurement Guide. Washington D.C.: FANTA.

de Onis, M., & Branca, F. (2016). Childhood stunting: a global perspective. *Maternal & Child Nutrition*, *12*(S1), 12–26.

Distefano, E. (2005). *Human-Wildlife Conflict worldwide: collection of case studies, analysis of management strategies and good practices*. Rome: Food and Agricultural Organization of the United Nations (FAO). Retrieved from http://www.fao.org/3/a-au241e.pdf

Dumas, S. E., Lungu, L., Mulambya, N., Daka, W., McDonald, E., Steubing, E., et al. (2016). Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia. *Food Security*, *8*, 507–520.

Fierstein, J. L., Eliasziw, M., Rogers, B. L., & Forrester, J. E. (2017). Nonnative cattle ownership, diet, and child height-for-age: evidence from the 2011 Uganda Demographic and Health Survey. *American Journal of Tropical Medicine and Hygiene*, *96*(1), 74–82.

Food and Agriculture Organization (FAO). *FAOSTAT Database*. FAO. Retrieved from http://faostat3.fao.org/home/E

George, C. M., Oldja, L., Biswas, S. K., Perin, J., Lee, G. O., Ahmed, S., et al. (2015). Fecal markers of environmental enteropathy are associated with animal exposure and caregiver hygiene in Bangladesh. *American Journal of Tropical Medicine and Hygiene*, *93*(2), 269–275.

Golden, C. D., Fernald, L. C. H., Brashares, J. S., Rasolofoniaina, B. J. R., & Kremen, C. (2011). Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. *Proceedings of the National Academy of Sciences*, *108*(49), 19653–19656.

Good, S. (2009). Animal source foods and nutrition during early life: an evaluation of the possible link between livestock keeping, food intake and nutritional status of young children in Ethiopia (doctoral dissertation). ETH Zurich, Zurich, Switzerland.

Grosse, S. D. (1999). Farm animals and children's nutritional status in rural Rwanda. Presented at Symposium on Human Nutrition and Livestock in the Developing World, 1998, October 14, (pp. 190–200). Little Rock, AR: Heifer Project International.

Headey, D., & Hirvonen, K. (2016). Is exposure to poultry harmful to child nutrition? An observational analysis for rural Ethiopia. *PloS One*, *11*(8), e0160590–16.

Herrero, M., Grace, D., Njuki, J. M., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. *Animal*, *7*(s1), 3–18.

Hoddinott, J., Headey, D., & Dereje, M. (2015). Cows, missing milk markets, and nutrition in rural Ethiopia. *Journal of Development Studies*, *51*(8), 958–975.

Iannotti, L. L., & Lesorogol, C. (2014). Animal milk sustains micronutrient nutrition and child anthropometry among pastoralists in Samburu, Kenya. *American Journal of Physical Anthropology*, *155*(1), 66–76.

Jin, M., & Iannotti, L. L. (2014). Livestock production, animal source food intake, and young child growth: The role of gender for ensuring nutrition impacts. *Social Science & Medicine*, *105*, 16–21.

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences*, *108*(34), 13957–13962.

Marquis, G. S., Ventura, G., Gilman, R. H., Porras, E., Miranda, E., Carbajal, L., & Pentafiel, M. (1990). Fecal contamination of shanty town toddlers in households with non-corralled poultry, Lima, Peru. *American Journal of Public Health*, *80*(2), 146–149.

Mosites, E. M., Rabinowitz, P. M., Thumbi, S. M., Montgomery, J. M., Palmer, G. H., May, S., et al. (2015). The Relationship between Livestock Ownership and Child Stunting in Three

Countries in Eastern Africa Using National Survey Data. *PloS One*, *10*(9), e0136686–10.

Mosites, E., Thumbi, S. M., Otiang, E., McElwain, T. F., Njenga, M. K., Rabinowitz, P. M., et al. (2016). Relations between household livestock ownership, livestock disease, and young child growth. *The Journal of Nutrition*, (146), 1118–1124.

Mullins, G., Wahome, L., Tsangari, P., & Maarse, L. (1996). Impacts of intensive dairy production on smallholder farm women in coastal Kenya. *Human Ecology*, *24*(2), 231–253.

National Health Strategic Plan 2011-2015. (2011). Zambia Ministry of Health.

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., et al. (2013). Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *American Journal of Tropical Medicine and Hygiene*, *89*(4), 709–716.

Nicholson, C. F., Mwangi, L., Staal, S. J., & Thornton, P. K. (2003). Dairy cow ownership and child nutritional status in Kenya. Presented at the AAEA Annual Meetings, Montreal, Quebec, Canada.

Njuki, J. M., & Sanginga, P. C. (2013). Women, livestock ownership and markets: Bridging the gender gap in eastern and southern Africa. Abingdon, Oxon, UK: Routledge.

Njuki, J. M., Poole, J., Johnson, N., Baltenweck, I., Pali, P., Zaibet, L., & Mburu, S. (2011). Gender, Livestock, and Livelihood Indicators. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Njuki, J. M., Wyatt, A., Baltenweck, I., Yount, K., Null, C., Ramakrishnan, U., et al. (2015). An exploratory study of dairying intensification, women's decision making, and time use and implications for child nutrition in Kenya. *European Journal of Development Research*, *28*(4), 722–740.

Okike, I., Jabbar, M. A., Abate, G., & Ketema, L. (2005). Household and environmental factors influencing anthropometric outcomes in preschool children in a rural Ethiopian community. *Ecology of Food and Nutrition*, *44*(3), 167–187.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., et al. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800.

Revised Sixth National Development Plan, 2013-2016. (2014). Revised Sixth National Development Plan, 2013-2016. Lusaka: Zambian Ministry of Finance.

Thumbi, S. M., Njenga, M. K., Marsh, T. L., Noh, S., Otiang, E., Munyua, P., et al. (2015). Linking human health and livestock health: a "One-Health" platform for integrated analysis of human health, livestock health, and economic welfare in livestock dependent communities. *PloS One*, *10*(3), e0120761–18.

UNICEF. (2013). Improving child nutrition: the achievable imperative for global progress. New York: UNICEF.

Victora, C. G., Adair, L., Fall, C., Hallal, P. C., Martorell, R., Richter, L., & Sachdev, H. S. (2008). Maternal and child undernutrition: consequences for adult health and human capital. *The Lancet*, *371*(9609), 340–357.

Wittemyer, G., Elsen, P., Bean, W. T., Burton, A. C. O., & Brashares, J. S. (2008). Accelerated human population growth at protected area edges. *Science*, *321*(5885), 123–126.

World Health Organization (WHO). (2006). WHO Child Growth Standards. Geneva: World

Health Organization.
WHO. (2010). Indicators for Assessing Infant and Young Child Feeding Practices, Part 2: Measurement. Geneva: WHO.
Wyatt, A. J., Yount, K. M., Null, C., Ramakrishnan, U., & Webb-Girard, A. (2013). Dairy intensification, mothers and children: an exploration of infant and young child feeding practices among rural dairy farmers in Kenya. *Maternal & Child Nutrition*, *11*(1), 88–103.
Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *108*(6), 313–325.

CHAPTER 4

Assessing the productivity, profitability, producer satisfaction, and programmatic challenges of small-scale egg production centers in rural Zambia

Abstract

Local production of eggs is a promising approach to improve physical and economic access to animal source foods (ASF) in rural communities of low-income countries while also improving livelihoods of smallholder farmers. To date, however, published research has focused exclusively on village chickens raised in extensive production systems. We therefore explored an alternative intervention that promotes small-scale, community-owned and -operated egg production centers (EPCs) utilizing semi-intensive production practices and layer hens. Overall, 800 hens in twenty EPCs produced 156,188 eggs, with a mean hen-day percent lay of 50.8% (range of mean among EPCs 31.2 – 73.1%) and average profits of 3261 kwacha (range 579 – 6453, or US$ 56 – 619). Although the mean productivity was below industry benchmarks, performance varied dramatically among individual EPCs, and some approached optimal performance. Group characteristics that predicted higher egg production included female-only groups ($\beta=0.115$, $p=0.001$), higher mean group wealth at baseline ($\beta=0.026$, $p=0.012$), longer history of partnering with a local NGO ($\beta=0.046$, $p=0.012$), and smaller mean household size ($\beta=0.037$, $p=0.018$). There was no significant difference in the change in household food security among members of the egg producer groups compared to their neighbors after the first year of the program. Importantly, however, participants were overwhelmingly satisfied with the program, noted important benefits of their participation for their families, and intended to continue the egg production business the following year. Our findings suggest that the EPC model can be successfully scaled-up in appropriate rural communities to provide families with access to reliable and affordable ASF.

Introduction

Animal source foods (ASF; including meat, milk, and eggs) are rich in protein, energy, and micronutrients, and several studies have found an association between ASF consumption and improved child nutrition (Darapheak et al., 2013; Dror & Allen, 2011; Grillenberger et al., 2003; Krebs et al., 2011; Neumann et al., 2013; Krasevec et al., 2017). Yet, for many children in rural communities of low-income countries, ASF remain physically, economically, or socially inaccessible (Gittelsohn & Vastine, 2003; Pachon et al., 2007). Numerous programs have attempted to utilize homestead livestock development as a means of enhancing ASF access in rural or semi-rural communities, thereby improving the dietary quality of children with high risk of undernutrition. However, to date, there is little evidence that livestock interventions have consistently improved nutrition outcomes (Leroy & Frongillo, 2007; Masset et al., 2012; Webb-Girard et al., 2012).

Small-scale dairy production programs have demonstrated the greatest success in enhancing ASF consumption in participating households, in part because they allow participants to sell some of the milk while retaining a portion for daily consumption at home (Ayele & Peacock, 2003; Hoorweg et al., 2000; Njuki et al., 2015; Rawlins et al., 2014; Walingo, 2009; Wyatt et al., 2013). Egg production similarly has the advantage of allowing producer households to balance the need to sell most of their product and retain some of the high-quality ASF for regular home-consumption. Compared to other forms of ASF, eggs are relatively inexpensive, and even in tropical climes, they do not require refrigeration for safe storage. In contrast to other livestock systems that are often culturally under the control of men, poultry production has been shown to be a socially acceptable income-generating activity for women in a diversity of settings (Dumas et al., 2017; Galiè et al., 2015; Gueye, 2000; Wong et al., 2017). A recent randomized controlled trial in Ecuador provided infants 6 – 9 months with one egg per day for nine months and found dramatic improvements in linear growth and weight gain compared to controls (Iannotti et al., 2017).

Despite these advantages, research on the use of small-scale egg production to improve diets in rural, low-income communities has focused entirely on extensive poultry systems (Iannotti et al., 2014), and the current evidence suggests that these systems are unlikely to effectively increase egg consumption. To date, programs promoting extensive "backyard" poultry production have had modest or no effect on household egg consumption (Dumas et al., 2016; Knueppel et al. 2010; Nielsen et al., 2003; Olney et al., 2009; Talukder et al., 2010), likely due to the combined effects of genetic limitations of indigenous breeds (Gueye, 2000; Wong et al., 2017), high flock mortality (Alders et al., 2010; Olney et al., 2013), and farmers' preference to incubate eggs as a means of expanding their flocks and offsetting high mortality (Dumas et al., 2016; de Bruyn et al., 2017; Gueye, 2000; Lane, 2016; Olney et al., 2013). Furthermore, there is an emerging concern that extensive poultry ownership puts young children in close contact with chicken feces, increasing their risk of environmental enteric dysfunction, diarrheal and respiratory infections, and stunted growth (Headey & Hirvonen, 2016; Ngure et al., 2013).

We therefore explored an alternative intervention that promotes small-scale, semi-intensive egg production as a means of increasing community access to ASF through local livestock. The program was piloted in 2010 with three highly motivated farmers living in different communities in the Luangwa Valley, Zambia, each given 10-20 layer hens. Over one year, approximately 13,000 eggs were produced and sold locally, resulting in a 44% increase in average household annual income for the three producers and 79% increase in average egg consumption in their surrounding communities compared to control areas (Dumas et al., 2016).

These results suggested that semi-intensive egg production might be a reasonable approach for improving rural food environments where fish and wildlife populations are depleted and access to markets is limited. In order to assess the potential for long-term economic sustainability of this model at scale, however, it is critical to establish that the intervention is sufficiently productive, profitable, and acceptable to producers living in variable conditions to incentivize their continued participation and investment in the program long-term.

We established 24 new group-owned and -operated, semi-intensive egg production centers (EPCs) throughout the Luangwa Valley and aimed to: 1) measure the productivity and profitability of the EPCs; 2) explore determinants of their productivity; 3) assess their impact on household food security among members of the egg production group; 4) explore participants' satisfaction with the project and its perceived benefits; and 5) identify production challenges and areas for improvement.

Methods

Study area

This research was conducted in 24 rural communities in Zambia's Eastern Province within four traditionally defined areas, or Chiefdoms: Mnkhanya (8 communities), Jumbe (9), Nsefu (3), and Mwanya (4). The entire study area was located within the Game Management Areas surrounding four national parks and forest reserves, and the nearest small town is Mfuwe. The communities were purposively selected by our implementing partner, Community Markets for Conservation (COMACO; www.itswild.org), based on internal program targets and resource availability. Working with farming communities, COMACO aims to achieve its conservations goals through market-based projects that improve rural livelihoods, alleviate poverty, and promote food security throughout the region.

The vast majority of households in the Luangwa Valley rely on small-scale, rain-fed agriculture as their primary income generating activity (COMACO, 2014). However, agricultural productivity has historically been limited by inconsistent rains, suboptimal agricultural practices, and poor access to fertilizer and other inputs (Government of the Republic of Zambia & UNDP, 2010; Lewis et al., 2011). As a result, chronic food insecurity is pervasive, particularly during the "hungry season" from roughly September to March (Lewis et al., 2011). Nationally, dietary quality is extremely poor (CSO et al., 2015) and, with 40% of children stunted (CSO et al., 2015), chronic undernutrition is a significant public health concern.

Participant recruitment and enrollment

Meetings were held with the Chiefs and key village Headmen to explain the project and obtain their support. In June 2014, four to five smallholder farmers from each of the 24 purposively selected communities were recruited by COMACO extension staff to be trained as "egg producers" to operated the single ECP in their community as a group. Individuals were eligible for selection as egg producers if they were members of a COMACO Poultry Producer group (which focuses on backyard/village chicken production), had a history of successfully adopting recommended agricultural practices, and were vulnerable to food insecurity and poverty based on the subjective assessment of COMACO Area Managers in consultation with the community's Lead Farmer and traditional leaders. Across the 24 EPCs, we aimed to have women make up at least 80% of egg producers, with no more than one man per group.

Egg production intervention

The program was designed as a community-operated, market-based intervention. The initial resources, training, and ongoing extension support were provided; however, the egg producers themselves were the owners and operators of the group EPC in their community, meaning they were responsible for making all business decisions and retained all profits.

Egg producer groups selected a location for the EPC that: 1) was within 30 meters of one member's home; 2) was centrally located within the community; 3) was not susceptible to flooding during heavy rains; 4) had ample shade; and 5) allowed for adequate ventilation. They were then tasked with clearing an 8m x 7m plot of land at that location and molding bricks in preparation for construction of their group's facility. The design of the EPC (Appendix 7) was adapted from a previous pilot project in the area (Dumas et al., 2016) in consultation with three local builders and following the welfare specifications of the Royal Society for the Prevention of Cruelty to Animals (www.rspca.org.uk). Local bricklayers and carpenters completed construction from August to November 2014.

In January 2015, all egg producers were trained in hen health, biosecurity, food safety, and business management by COMACO's Poultry Manager with expert consultation from a pullet dealer. Refresher trainings were held with 1-2 egg producers from each EPC in August 2015 and January 2016. Each EPC was stocked with 40 Isa Brown pullets in August 2015 and provided with one month of layer mash. During egg production, COMACO extension staff monitored production records and intervened with groups where necessary to resolve disputes or address production concerns. However, groups had primary responsibility for their own businesses, including marketing eggs, purchasing feed, and maintaining the facility and production records.

Data collection and analysis

Due to incomplete data in some EPCs and their surrounding communities, the number of EPCs included in analysis varied by outcome (Figure 4.1).

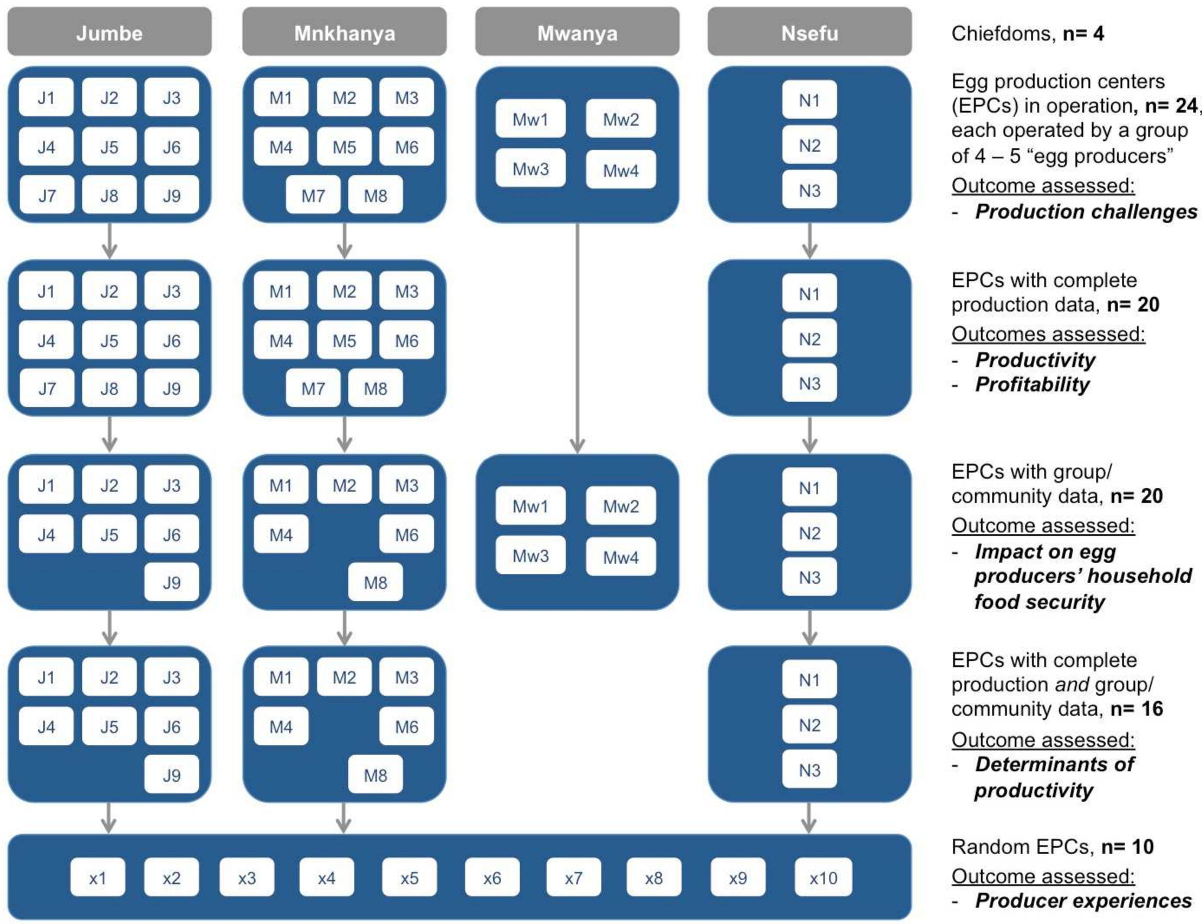


Figure 4.1. **Structure of the data included in the analysis of each outcome.**

EPC productivity

Groups maintained daily production and sales records that documented the number of eggs collected and sold, sale price, expenses, and management concerns (Appendix 8). Completed production and sales records were available for 306 total months, from September 2015 to the time the "spent" hens were sold as meat, the timing of which varied by EPC and was based on the producer groups' own assessments. Only 16 total records could be recovered from the four EPCs in Mwanya (range: 2 – 7 per EPC compared to 12-17 months of records per EPC in all other areas), likely because of the region's distance, seasonally inaccessible roads, and cost of transport. Due to this lack of data, the four EPCs in Mwanya were excluded from further analysis of productivity and profitability (Figure 4.1). In the remaining 20 EPCs, four months of records were lost and five were omitted because the data were not consistent with the remainder of the records from that EPC (Appendix 9). Records were collected monthly by COMACO extension staff and were entered into an electronic database using Microsoft Excel (Microsoft Excel for Mac 2011, version 14.7.2) and cleaned and analyzed in Stata (Stata/IC version 14.0, StataCorp).

Layer productivity was measured as hen-day percent lay, defined as the percent of hens that laid an egg on any given day (North, 1990):

$$Hen\text{-}day\ percent\ lay = \frac{Number\ of\ eggs\ produced\ on\ a\ day}{Number\ of\ hens\ in\ the\ flock\ on\ that\ day}\ x\ 100$$

Hen-day percent lay was averaged weekly for each EPC to visualize and model trends in productivity.

Determinants of productivity

In order to investigate potential predictors of EPC productivity, community and group-level data were extracted from a second study investigating the impact of the EPCs on community egg consumption. Because of time and resource constraints, 20 of the 24 communities with EPCs were randomly selected to participate in that impact analysis. Of these 20, four were in Mwanya – where productivity data were incomplete – leaving 16 EPCs included in the current analysis of determinants of EPC productivity (Figure 4.1). Details on the data collection process and results of the impact analysis are described elsewhere (see Chapter 5).

Briefly, data were collected at two time points in the year prior to the start of egg production and at two time points during egg production, allowing us to capture seasonal change in household food security relative to the farming cycle: June 2014 (the dry season, 1-3 months post-harvest, baseline 1), December 2014 (the rainy season, at the start of the "hungry season", baseline 2), December 2015 (midline), and June 2016 (endline). For the purposes of the current analysis, the values were averaged over the two baseline time points to generate potential group and community level predictors of productivity. The Level-2 variables initially considered for inclusion in the model are in Appendix 10, along with their definition. The correlation of variables with mean overall group productivity was determined, and variables with $|r| \geq 0.20$ were considered in initial models. During the modeling phase, the variables with the highest p-values were removed from the model sequentially until only variables with $p \leq 0.20$ were retained in the final model. Total weekly morbidity and mortality were the only Level-1 covariates available for consideration.

We fit a polynomial random-effects model with a random intercept for each EPC, to account for clustering within flocks, and a random coefficient of time, to allow the effect of time to vary between clusters. We used the maximum likelihood estimation method to fit the model

$$y_{ij} = \beta_1 + \beta_2 t_{ij} + \beta_3 t_{ij}^2 + \beta_4 t_{ij}^3 + \beta_5 t_{ij}^4 + \beta_6 x_{ij1} + \cdots + \beta_{(k+5)} x_{ijk} + \zeta_{1j} + \zeta_{2j} t_{ij} + \epsilon_{ij}$$

where y_{ij} is the mean weekly productivity for EPC *j* at occasion *i*, t_{ij} is the age of the hens (in weeks) in EPC *j* at occasion *i*, x_{ij1} through x_{ijk} are *k* Level-1 and Level-2 covariates (defined below), ζ_{1j} and ζ_{2j} are the EPC-specific random intercept and EPC-specific random slope, respectively (i.e. the deviation of EPC *j*'s intercept and slope from the mean intercept and slopes), and ϵ_{ij} is the idiosyncratic residual at observation *(i, j)*. The random coefficient model assumes that, given all covariates, both ζ_{1j} and ζ_{2j} are normally distributed, with constant variance, the expectation of zero (Level-2 heteroskedasticity), and are uncorrelated across EPCs. It also assumes that, given the covariates and the random effects, Level-1 residuals ϵ_{ij} are normally distributed, have a constant variance with the expectation of zero (Level-1 heteroskedasticity), and are mutually uncorrelated across both occasions and EPCs. Robust standard errors were used to obtain valid standard errors in the face of Level-1 heteroskedasticity or autocorrelation.

EPC profitability

The profitability of each EPC was measured by net income generated during the production cycle (profits from egg sales less expenses for feed, vaccines, and other miscellaneous costs). The 20 EPCs with complete production records were included in this analysis (Figure 4.1). Income was measured in Zambian kwacha (K), where the mean value of K 1 = US$ 0.096 over the period from September 2015 to January 2017.

Impact on egg producers' household food security

The impact of the EPC program on individual household welfare among EPC group members was assessed quantitatively and qualitatively. Quantitatively, the impact of the program was measured by tracking changes in household food security in all producer households from twenty randomly selected EPCs (n=83) compared to that of their neighbors (n=375). These data were extracted from the same study described above, which assessed the impact of the program on community egg consumption around 20 randomly selected EPCs. Because productivity data were not required for this analysis, all 20 EPCs with community data, including Mwanya, were included in this analysis (Figure 4.1). Household food security was assessed by the Household

Food Insecurity Access Scale (HFIAS; (Kennedy et al., 2011)), a 9-item questionnaire that asks about the frequency of experiences of food insecurity over the preceding 4 weeks. Summation of all 9 items results in a score of 0 (food secure) to 27 (severely food insecure) for the household. Questionnaires were administered to the egg producer or head of household (e.g. the egg producer's husband) and to neighboring households at four time points. The neighbors were recruited for participation in the impact analysis study based on their proximity to the EPC (<1.5 km) and if they had child 6-36 months of age.

The effect of household egg producer status on change in household food security over time was tested using the fixed-effects multiple linear regression model

$$y_{ij} = \alpha_j + \beta_1 E_j + \beta_2 T_{ij} + \beta_3 E_j * T_{ij} + \beta_4 x_{4ij} + \ \dots + \beta_p x_{pij} + \epsilon_{ij}$$

where y_{ij} is the mean HFIAS for field site j at time point i, α_j are the fixed, unknown field site-specific intercepts, E_j is the time-constant dummy variable for being an egg producer, T_{ij} is the categorical variable for time point (baseline 1, baseline 2, midline, and endline), x_{4ij} through x_{pij} are $p - 4$ household-level covariates differing between the egg producers and their neighbors at baseline, and ϵ_{ij} is the idiosyncratic residual at observation *(i, j)*. The interaction of time point and egg producer status was considered the "treatment effect". Robust standard errors were used to guard against heteroskedasticity. Fixed-effects models control for time-invariant characteristics of the individual communities, giving consistent estimates for the effect of time point and egg producer status on household food security without requiring information on time-invariant characteristics of the communities (e.g. culture, religion, etc.).

Producer acceptability and experiences

To explore program acceptability and experiences among egg producers, qualitative data were collected from a sub-set of egg producers (n=10) in July 2016, ten months after egg production began, using in-depth interviews. To ensure experiences from numerous EPCs were captured, ten of the 20 EPCs with production records were randomly selected and one group member was randomly selected from each of those EPCs (Figure 4.1). The interviews were conducted in Chinyanja by a local research staff member, following an interview guide (Appendix 11). During the interviews, the producer was asked about the division of labor and time allocation, individual satisfaction with the program, the subjective impact of the program on individual and household welfare, and their plans for continuation of the business in subsequent years. Interviews were audio recorded and translated/transcribed into English. The interview transcripts were analyzed in Dedoose (SocioCultural Research Consultants LLC, version 7.1.3, Los Angeles, CA, www.dedoose.com) using thematic coding as themes emerged in the transcripts. Salience of themes was determined with simple frequencies, and deviant cases were carefully examined.

Production challenges

In addition to the in-depth interviews mentioned above, one of the authors, a veterinarian (S.E.D.), visited each of the 24 EPCs three months into production (late November to mid-December 2015) to observe conditions and practices at the egg production facilities and hold group meetings. These meetings were conducted in English and translated on the spot to Chinyanja or Bisa by a research staff member. Topics discussed included flock morbidity and mortality, recent productivity, challenges, market demand, profits, group dynamics, and husbandry practices. Each facility was also inspected for cleanliness, artificial light use, feeder and drinker height, nesting space, biosecurity practices, and flock health; records were also inspected for completeness. Some recommendations for improvements were made on the spot. Questions about hand washing practices were included in the individual questionnaires described above.

Case studies of positive and negative outliers

Finally, EPC outliers were identified based on their total profits and examined in detail to isolate common characteristics that may have determined their success or failure. This analysis synthesized data from multiple sources described above, including production records, in-depth interviews with individual producers, notes from group meetings held three months into production, personal observations (S.E.D.), and conversations with COMACO extension staff.

Ethical standards

All procedures and materials used in this study were approved by the Institutional Review Board at Cornell University. Traditional leadership first agreed to the study, and all individuals then provided written informed consent prior to participating.

Results

Description of producers

The average group consisted of 4.6 people (range 3 – 6). Thirteen of the 24 groups were women-only and the remaining eleven were mixed-gender but majority women. In total, 110 producers took part in the program, the majority of whom were married women with less than a primary school education (Table 4.1).

Table 4.1. Characteristics of egg producers at enrollment (baseline 1; n= 80)[a]

Age, mean (SD)	40.2 (10.7)
Gender, % female	85.9%
Marital status, % married	81.9%
Highest education, %	
None	13.8%
Some primary	46.3%
Completed primary	22.5%
Some secondary	17.5%
Household size, mean (SD)	6.6 (2.2)
At least one child under 5 yr in household	81.3%
HFIAS, mean (SD)	8.3 (5.9)

Notes: [a] 20 of the 24 EPCs were randomly selected to participate in producer surveys. Of the 92 individuals in these 20 groups, 12 producers did not complete the baseline survey due to scheduling conflicts at the time of data collection.

Abbreviations: HFIAS, Household Food Insecurity Access Scale

Production and determinants of productivity

Overall, the 20 EPCs with completed production records reported producing 156,188 eggs in 302,761 hen-days, with a mean hen-day percent lay of 50.8% (range of mean among EPCs 31.2 – 73.1%). Peak lay was recorded between 34 and 39 weeks of age, over which period mean percent lay was 74.5%. Throughout the laying period, productivity remained well below the ideal productivity for this breed of hens raised in an alternative (i.e. non-caged) system (*Isa Brown Product Guide: Alternative Production Systems*), and – in contrast to a typical, smooth production graph – productivity varied significantly from week to week (Figure 4.2).

All EPCs experienced two large shocks affecting production. In the first shock, beginning early October and lasting through the first half of November 2015 (24-30 weeks of age), producers and extension staff reported that extreme ambient temperatures depressed production. Thirteen of the EPCs experienced morbidities (152 illnesses in total) and mortalities (74 deaths in total) during this time period due to a suspected bacterial infection secondary to heat stress. The second shock was in February 2016 (41 weeks of age), when the COMACO hammer mill was down and the production of layer mash was suspended for over one month. Some groups were able to purchase other brands of feed during this time, but it was more expensive and perceived to be of lower quality. Although productivity rebounded after the heat shock in October, it remained relatively depressed after the long period without feed and never fully recovered to expected levels.

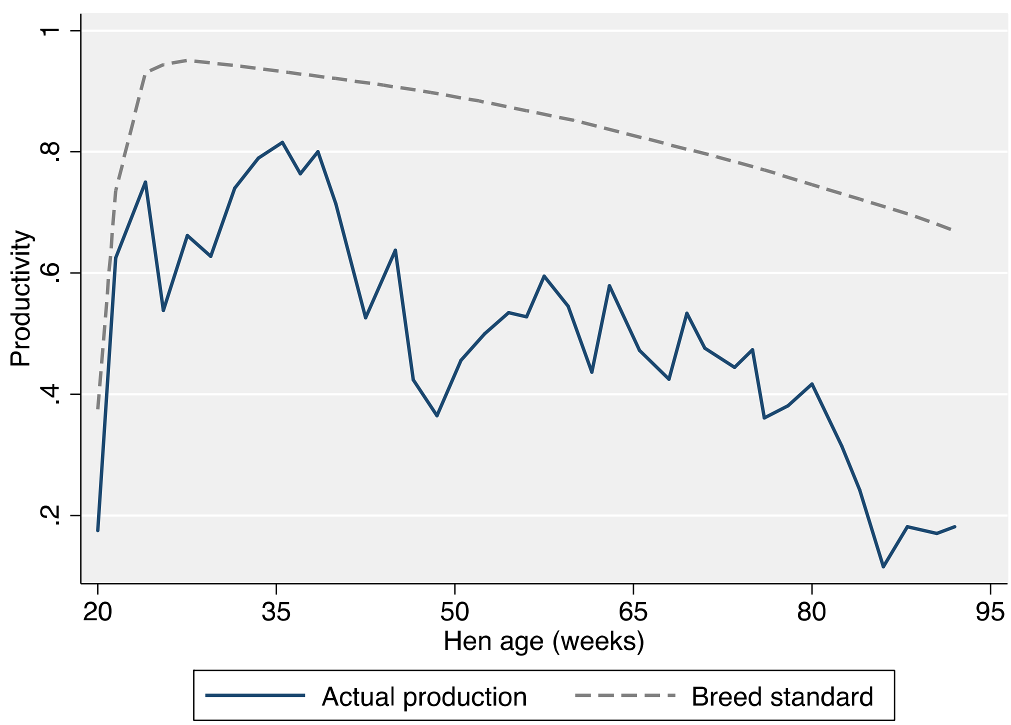


Figure 4.2. Median weekly productivity in the EPCs (n=20; solid navy line) compared to the breed's expected weekly productivity (dashed gray line).

There were dramatic differences in both the overall productivity among EPCs (Table 4.2) and the change in productivity over time (Figure 4.3). In the final polynomial random effects model, having at least one man in the group was associated with an 11.5 percentage point (p.p.) decrease in mean weekly productivity and a one person increase in the mean household size among group members was associated with a 3.7 p.p. decrease in mean weekly productivity (Table 4.3). Productivity was significantly positively associated with greater EPC distance from a paved road, mean baseline food insecurity in group members' households, mean baseline group wealth, and mean years as members of COMACO. Productivity was not significantly predicted by weekly flock morbidity or mortality, group size, or prevalence of COMACO membership in the surrounding community.

Table 4.2. Total egg production, mean productivity, and total profits generated by 20 EPCs over one laying period starting in September 2015.

Chiefdom	Field site	No. of days recorded	No. eggs produced	Mean productivity[a]	Total profits (K)
Jumbe	J1	427	8532	50.4%	4891
	J2	387	5360	35.0%	845
	J3	367	3668	31.2%	579
	J4	397	7923	55.3%	4348
	J5	396	5394	44.1%	1236
	J6	396	6309	40.8%	1889
	J7	426	9814	59.4%	4524
	J8	415	9103	56.7%	2530
	J9	425	5085	31.3%	1688
Mnkhanya	M1	438	5652	36.0%	1441
	M2	488	10883	58.0%	4104
	M3	457	5266	43.1%	3029
	M4	488	12190	73.1%	6453
	M5	427	6579	45.8%	2342
	M6	482	9562	53.9%	5219
	M7	481	5797	44.0%	2663
	M8	519	8882	47.7%	3743
Nsefu	N1	460	11919	65.0%	5362
	N2	450	8781	66.7%	3700
	N3	457	9489	67.4%	4649
Mean (SD)		439 (39)	7809 (2400)	50.3% (12.1%)	3261 (1620)

Notes: [a] Mean productivity was measured as hen-day percent lay averaged over the entire production cycle in that EPC.

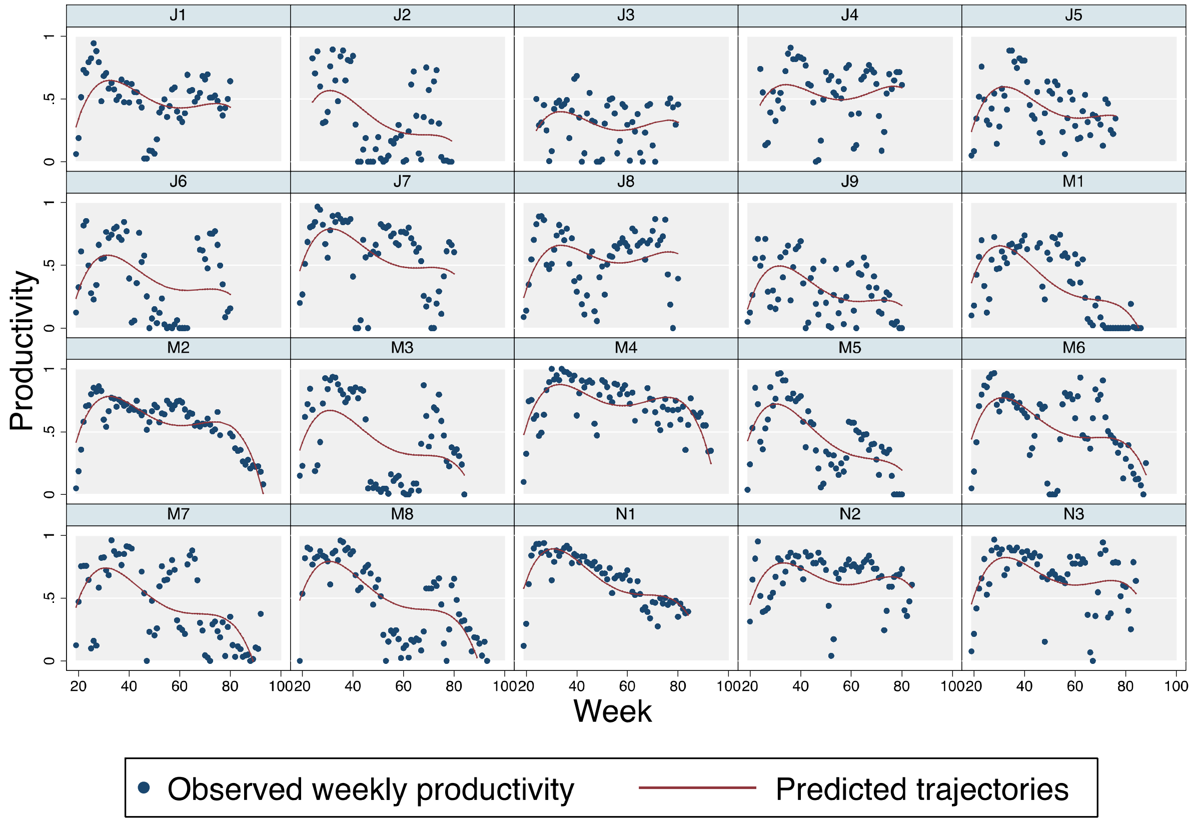


Figure 4.3. Observed mean weekly productivity for each of the 20 EPCs and their productivity trajectories predicted by the random effects fourth-degree polynomial model with only time covariates.

Table 4.3. Maximum likelihood estimates with robust standard errors for the random-coefficient models estimating determinants of mean weekly productivity, with (full model) and without (limited model) covariates.

	Full model			**Limited model**		
	Coef.	SE	p-value	Coef.	SE	p-value
Fixed part						
Week	0.078	0.008	< 0.001	0.072	0.008	< 0.001
$Week^2$	-0.005	0.001	< 0.001	-0.004	0.001	< 0.001
$Week^3$	9.39×10^{-5}	1.54×10^{-5}	< 0.001	8.63×10^{-5}	1.39×10^{-5}	< 0.001
$Week^4$	-6.36×10^{-7}	1.14×10^{-7}	< 0.001	-5.85×10^{-7}	1.03×10^{-7}	< 0.001
Morbidity	-0.001	0.001	0.157			
Distance from paved road, km	0.006	0.002	0.002			
One or more men in group	-0.115	0.035	0.001			
Mean group HFIAS	0.022	0.006	< 0.001			
Mean group household size	-0.037	0.018	0.042			
Mean group wealth	0.026	0.012	0.032			
Mean years in COMACO	0.046	0.012	0.032			
Random part						
SD(intercept)	0.003			0.003		
SD(slope of week)	0.061			0.115		
SD(within cluster residual error)	0.205			0.213		
Log likelihood	139.67			120.17		
Wald chi2	1398.17	df=11		185.27	df=4	
AIC	-249.33			-224.33		
BIC	-175.36			-183.09		
n	1024			1280		
Clusters	16			20		
Total R^2	0.2826			0.1802		
Level-2 R^2	0.1542			0.2055		
Level-1 R^2	0.3092			0.2598		

Profitability

At the end of the production cycle, group savings averaged K 3261 (SD 1620; ~US$ 313, SD $156), ranging from K 6453 ($619) for a group in Mnkhanya to K 579 ($56) for a group in Jumbe (Table 4.2). In comparison, had the flocks maintained ideal productivity, they could have expected an estimated K 6290 ($604) in mean profits.[1] Profitability was highly correlated with productivity (r= 0.852, Figure 4.4), where a 10 p.p. increase in mean hen-day percent lay was associated with a K 1155.3 increase in total profits ($p<0.001$). When the 20 EPCs are categorized by productivity, the lowest quintile (mean productivity= 33.4%) averaged K 1138 in profits, while the middle quintile (mean productivity= 49.5%) averaged K 4049 in profits, and the highest performing quintile (mean productivity= 68.1%) averaged K 5041 in profits.

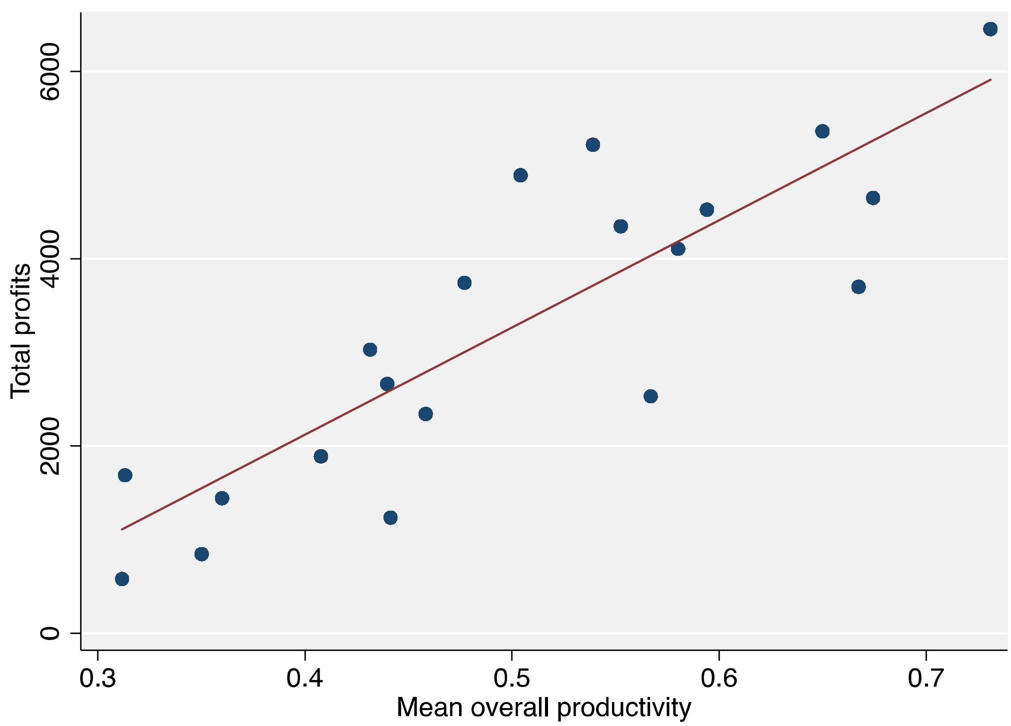


Figure 4.4. Total EPC profits is predicted by its productivity ($p< 0.001$). Each blue dot indicates the total profits and overall mean productivity of one of the 20 EPCs for which complete data is available. The red line is the line of best fit.

[1] Calculated based on the production curve in Figure 4.1, with a laying period from 18-80 weeks, 90% liveability, and age-dependent feed requirements from (*Isa Brown Product Guide: Alternative Production Systems*). Additional average costs of K 40 per month were included to account for purchasing plastic bags, batteries (for lights), and transport to purchase feed (not required by all groups). Income assumes eggs were sold at K1 each, the most commonly cited selling price by producers.

Change in household food security

Compared to their neighbors, EPC egg producers had a significantly higher mean asset index (p=0.046) and were significantly more food secure (p=0.032 for HFIAS and p= 0.028 for HHS) at Baseline 1. They also had significantly older heads of household (p<0.001), were significantly more likely to own other livestock (p=0.001), and had larger household sizes (p<0.001; Table 4.4). The older age of head of household and their larger household sizes are likely due to the sampling of only households with young children for the neighbors group.

Table 4.4. Characteristics of egg producer households and neighboring households at enrollment (Baseline 1)

	Producer households (n= 80)	**Neighboring households (n= 375)**	**p-value**
Age of head of household, mean (SD)	44.7 (11.7)	36.5 (10.9)	<0.001
Highest education of head of household, %			0.987
None	11.4%	10.7%	
Some primary	26.6%	27.6%	
Completed primary	26.6%	24.9%	
Some secondary	29.1%	29.8%	
Completed secondary	6.3%	7.1%	
Household size, mean (SD)	6.6 (2.1)	5.7 (2.1)	<0.001
Gender of head of household, % female	17.7%	14.4%	0.325
Any electricity, %	31.6%	24.3%	0.193
Protected drinking water, %	60.8%	65.1%	0.509
Any livestock ownership, %	81.0%	61.1%	0.001
Asset index, mean (SD)	0.6 (2.3)	-0.1 (2.5)	0.046
HFIAS, mean (SD)	8.2 (5.9)	10.0 (6.6)	0.036
HHS status			
Little to no household hunger	78.8%	71.7%	
Moderate household hunger	21.3%	20.1%	0.028
Severe household hunger	0.0%	8.3%	

Abbreviations: HFIAS, Household Food Insecurity Access Scale; HHS, Household Hunger Scale

In fixed-effects models, household food insecurity declined significantly with time in both egg producer households ($p<0.001$ for trend) and among their neighbors ($p<0.001$ for trend; Figure 4.5). In a difference-in-difference analysis with fixed-effects controlling for community-level clustering and household characteristics, there was no difference between egg producers and their neighbors in the estimated mean food security at either midline ($\beta= 0.67$, $p= 0.514$) or endline ($\beta= -0.15$, $p= 0.778$).

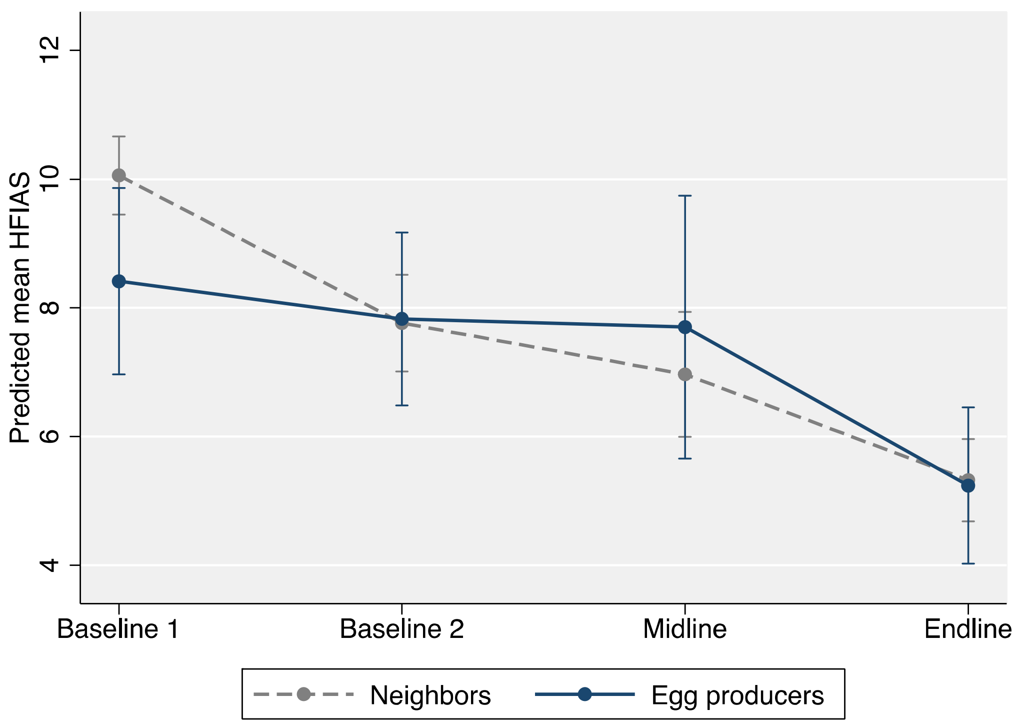


Figure 4.5. Change in predicted mean household food insecurity with 95% confidence intervals, as measured by the Household Food Insecurity Access Scale (HFIAS), in egg producer households (mean n= 83 at each time point) and neighboring households who are not members of the EPC group (mean n= 365 at each time point). Estimates are linear predictions for the fixed portion of the model only (marginal estimates).

Producer acceptability and experiences

Program benefits

Producers were overwhelmingly satisfied with the program, and all expressed interest in continuing egg production the following year. Financial benefits were the most commonly mentioned benefit of the program (mentioned by all but one respondent), though no group was regularly distributing profits to their group members. Rather, each group chose to retain a "group savings account" held by their elected Treasurers. From these savings, groups were able to jointly invest in other income-generating activities (mentioned by 8 of 10 respondents), such as selling cooking oil, petrol, or salt or investing in other livestock.

> *"So far with the money that we have raised, we have bought a pig and we have started running a piggery. We have got 9 pigs now that the female pig we bought has just given birth to 8 piglets." – Female participant, 41 years-old, Jumbe*
>
> *"I have seen the benefits, for instance, I bought a [female] sheep. So every year the sheep will be multiplying and at the end of it all, I will have a flock." – Female participant, 42 years-old, Jumbe*

Most of the participants said their group had given each member cash from the account on at least one occasion, most commonly during the rainy season when food and cash are scarce.

> *"Once in a while we do share [some of the money], and it assists us to buy books for our school going children. Then, in the rainy season, we were able to buy bags of maize meal to share amongst members. As you know, here in the villages, we face serious food shortages in the rainy season." – Female participant, 41 years-old, Jumbe*

More than half of the participants said they or another member of their group had borrowed from the group to cover an unexpected household expense, which they repaid with interest to the group.

> *"A few months ago I had a serious problem. I was looking after a family member who was sick. I was assisted with money to take her to the hospital. I also used the same money to pay someone to help me prepare my field." – Female participant, 30 years-old, Mnkhanya*

> *"We help any group member who presents a problem to the group with money, and the member pays back to the group when she finds money in the long run." – Female participant, 39 years-old, Mnkhanya*

Notably, on the occasions that a portion of the income was distributed among members, most of the female participants reported retaining control over the money once it was brought into the home. Of the female egg producers surveyed at endline (n= 74), 77.0% reported that they were totally or mostly responsible for deciding how to use the income from the egg business, while only 13.5% reported that their husbands were totally or mostly in charge, and 9.5% said they decided jointly with their husbands. Female control of egg production earnings was significantly higher in female-headed households (89.9%) than in male-headed households (61.8%; $p<0.001$).

> *"Since am not alone [and] my husband is the head of the household, he is the one who makes decisions [about what to buy with my share of money from the poultry program]." – Female participant, 42 years-old, Jumbe*

Control of income was marginally higher among male producers (n= 11), 81.8% of whom said they were totally or mostly responsible for the egg production income and 18.2% of whom reported jointly controlling the income with their spouse.

During in-depth interviews, most participants said that having access to eggs is an important benefit of the program, though most said they only rarely distributed eggs among group members. More commonly, an individual member would buy eggs from the group, as would any customer, on an as needed basis to avoid cutting into their profits.

> *"[…] you know that it's difficult to access game meat, so eggs are the only source of protein that we have. We have observed that children who eat eggs grow healthy and do not suffer from malnutrition. Even us [adults], at least we can have a change of relish." – Female participant, 30 years-old, Mnkhanya*

> *"It helps because now we are able to buy eggs in our village. In my case, it helps a lot, because I am keeping a grandson who has sickle cell anemia. I find it easy now to get eggs for a special meal that I prepare for him to boost his blood." – Female participant, 52 years-old, Mnkhanya*

> *"This program has benefited us and families in the area […] In the past we use to face challenges to buy [meat or vegetables to eat with our "nsima", the maize staple food of Zambia], because markets are far away from this place. But now, eggs are at our doorstep." – Female participant, 41 years-old, Jumbe*

Collectively, the comments strongly conveyed a sense of pride associated with providing their community with eggs. Producers from all communities reported that demand for eggs was very high, and most sold out of eggs the same day they were laid.

Group dynamics and time investment

All groups in our study chose to work on a rotating basis, with each individual responsible for all activities in the egg production facility for the day, working either alone or with one other person. Nearly all participants expressed satisfaction with this arrangement and said that they were able to work well together as a group. Although all participants were members of a traditional, COMACO-supported agricultural cooperative that provided inputs, services, and market access to its members, the EPC model – in which the production resources were jointly owned and collectively managed – was a new experience for them. Nonetheless, all participants felt that operating the EPC as a group was preferable to doing so alone, because the time burden for each individual was minimal. Respondents reported working 1-2 hours per day, usually twice per week, and none felt that this time requirement negatively affected their other responsibilities or rest time.

> *"I have not suffered any draw back, since I only spend minutes working in the poultry house and go back home and continue with personal activities." – Female participant, 41 years-old, Jumbe*

> *"I am happy with the way we are working. By [sharing the work], we are actually giving ourselves time to do other activities in our respective homes." – Female participant, 39 years-old, Mnkhanya*

Additionally, this system of work allocation allows some members to take a day off when necessary (e.g. in the event of illness) without negatively affecting the business.

> *"If one of our friends in the group has a problem, we come in and take up her responsibilities until the time she comes back." – Female participant, 64 years-old, Jumbe*

This finding of general satisfaction with the structure of the program was corroborated by the group meetings held in December 2015, at which time the majority of groups reported that they worked together well with equal contributions from all members.

Notably, not every group remained intact for the duration of the project. In a few circumstances, individual group members left the group, usually by choice or due to extenuating circumstances. One woman left her group after moving back to her parent's village following a separation from her husband; in another case, a woman and her family moved to another village for unknown reasons. In three other examples, the group member (a man in two cases and a woman in one case) simply stopped showing up at the EPC to perform their assigned duties, and the remaining members of the group together decided that, in failing to work, they had declared themselves to no longer be part of the group. In all five cases above, the individuals' separation from the group was mutual, amicable, and did not involve any payment to the departing group member. The departing member was sometimes replaced with another individual who had expressed interest in the EPC business, while other groups opted to continue working with the original members less one.

In contrast, two groups (J3 and Mw2) completely failed to work together and were dissolved after only a few months, leaving just one member to manage the EPC for most of the production cycle. The exact details leading to the dissolution of these two groups are unclear; however, in both cases, the group members disagreed about how the labor and decision-making power should be distributed, with some members insufficiently contributing to the business and others attempting to exert excessive control. In both cases, one of the authors (S.E.D.) and COMACO extension staff negotiated a reconciliation in which the individual remaining in control of the EPC compensated the departing group members for the initial time and labor they invested in starting the business (~$10 per person). This solution was satisfactory for all participants and appeared to result in an amicable separation for both groups. After, the remaining member of Mw2 appeared to adequately manage the EPC with her adult sons (although production records are not available to confirm this). In contrast, J3 had very poor productivity and was barely able to break even, suggesting that it was either unable to recover from the poor early management by the group or that the remaining individual in charge was unable to manage the duties of the EPC alone.

These examples emphasize the importance of careful group selection and communication. The three most profitable EPCs were operated by groups where the members were either all related (in the case of M6) or were close friends (N1 and M4) with a history of participating in other groups together (e.g. women's savings groups), the dynamics of these existing relationships may has positively contributed to the success of these groups.

Production and profitability challenges

Despite their broad satisfaction with the program, there were some production challenges that limited profits and the overall success of the program. Fourteen of the twenty EPCs with complete production records indicated at least one death during the very hot months of October and November, with four groups losing approximately 1/3 of their flocks. Although they were not included in the productivity analysis due to lack of data, three of the four groups in Mwanya reported flock losses to predators, including to lions, honey badgers, and a leopard. One group in Jumbe also experienced the theft of about 5 hens.

By far the most widely experienced production limitation was unreliable access to layer mash, reported during our group discussions by all but a few EPCs. During periods without feed, groups were forced to provide only maize bran to the hens, which led to dramatic drops in egg production for up to two weeks. Feed access was reportedly restricted by erratic stocking by COMACO, impassable roads during the rainy season, or groups' inability to secure transportation. Unexpected increases in feed price, which reflected increased production costs, also delayed feed acquisition in some groups who were unprepared for the added expense.

> *"We find it very difficult to buy feed. Our area is very far from COMACO offices where feed is sold, so whenever we want to buy feed, we have to hire a motor bike [… and] buy fuel. […] If it is during the rainy season, we also pay 5 kwacha per bag to people who help to carry feed across the river, because during the rainy season the river becomes very difficult to cross." – Female participant, 52 years-old, Mnkhanya*

> *"Sometimes our chickens go for weeks without feed. If we go to COMACO to buy feed, at times we find that they don't have it in stock. So during such situations we are forced to feed our chickens with maize bran and the chickens stop laying eggs." – Female participant, 42 years-old, Jumbe*

In addition to inconsistent feeding, overall, husbandry practices were suboptimal at the time of the December 2015 inspection. Most groups were using straw litter, which poorly absorbs moisture. Of those using wood shavings, the depth was inadequate (<10cm) in all but three houses. Nearly all groups had lights, but few were following an appropriate artificial lighting schedule to optimize egg production. Less than half of the groups had appropriate nesting boxes that were clean, covered, and dark, and a few had no nesting spaces at all. Few groups had adequate covers for all three windows in the facility, which allowed rain to enter the house and dampen the litter. Some groups left at least one of the covers down at all times, preventing proper ventilation of the facility.

Biosecurity practices were similarly suboptimal. About half of the facilities had designated footwear available for use in the facility, but members were observed to enter those same facilities without using the designated footwear. Only two groups had a jacket to use while in the house. Of the 90 egg producers surveyed in December 2015, 84.9% reported washing their hands before entering the house, but only 19.8% always used soap and 41.7% occasionally used soap. Reported hand washing before work improved to 95.2% by June 2016 (n=85), after a refresher training, but only 50.6% reported always or sometimes using soap.

Finally, because the Zambian kwacha has limited circulating denominations, groups were constrained in their ability to respond to increasing feed costs by adjusting the sale price of eggs. Although coins, called *ngwee* (1 ngwee = K 100), are routinely used by large stores, coins less than 50 ngwee are rarely used by smaller shops or in villages, effectively making it the smallest denomination in many communities. Most eggs were sold in small batches (1 – 3 eggs) to individual households for single meals, and groups set the initial price of eggs at K 1 per egg, matching the price of eggs sold at roadside stalls or shops in Mfuwe. However, as the cost of feed increased from K125/ 50kg bag to K132, K150, K162, and eventually to K182/ bag, they were unable to incrementally adjust egg prices to match increasing production costs. One group was able to successfully increase the sale price of eggs to K 1.50 per egg, while others reverted back to K 1 per egg after unsuccessfully trying to set prices at K 2.5 for two eggs or K 3.5 for three eggs, which customers would reportedly not accept.

Case studies of most and least successful EPCs

In addition to the above analyses, it is useful to examine both positive and negative outliers for common characteristics, which may therefore be important determinants of EPC success or failure. On the basis of total profits, the three most successful EPCs were identified as M4, M6, and N1, while the least successful EPCs were J2 and J3. The Mwanya EPCs were also included in the “least successful” category, despite a lack of production and profits records, based on reports from COMACO extension staff and personal observation (S.E.D.). This evaluation revealed five key categories of characteristics: EPC location, adherence to best management practices, group composition, group cohesion, and community relations (Table 4.5).

Table 4.5. Characteristics of the most and least successful EPCs based on their total profits.

Characteristics	**Most successful: M4, M6, N1**	**Least successful: J3, J2, Mwanya EPCs**
EPC location	• Located <30 km from COMACO farmer support center by road • Accessible year-round by road • Limited to no risk of predation by wildlife	• Located a >40 km from COMACO by road (with exception of J3) • Seasonally inaccessible by road (with exception of J3) • Experienced predation by wildlife (J2, Mwanya)

EPC management practices	• Deep litter, clean/covered nesting boxes, perches • Appropriate use of window covers • Few (M4) or no (M6, N1) early flock losses	• Straw litter with inadequate depth • Dirty, uncovered nesting boxes • Window covers either insufficient (allowing rain in) or left down at all times (preventing ventilation) • EPCs built in direct sunlight with inadequate shade (J2, Mw1) • Very high early flock losses (Mw1, Mw4)
Group composition	• Individuals who are related or are close friends with a history of participating in groups together • Group members had been members of COMACO for an average of ≥ 4 years	• Relationships of group members prior to program unclear • Group members had been members of COMACO for an average of ≤ 2.5 years (J2, J3)
Group cohesion	• Groups were able to divide labor and decision-making responsibilities equitably and to everyone's satisfaction • All original members remained in the group throughout the year	• Groups were unable to successfully negotiate labor and decision-making responsibilities • Experienced high group drop-out (J2, Mw1, Mw3, Mw4) or dissolution of the group all together (J3, Mw2)
Community relations	• Communities had high demand for eggs and appreciated the program • Communities understood that the program required them to purchase eggs	• Very limited local demand for eggs (Mw3) • Neighbors were jealous of the EPC owners and resentful that they had not been selected as members (J2, J3) • Communities misunderstood the program, expecting free eggs (J2)

Discussion

Small-scale, group-operated, semi-intensive EPCs is a livestock development model that can enable rural communities to change their local food environment and enhance access to nutritious, safe, and sustainable ASF. Although the mean productivity and profitability were below industry benchmarks, performance varied dramatically among individual EPCs, and a number of EPCs approached optimal performance under difficult conditions. We identified a number of group characteristics that predicted higher egg production, including female-only groups who are somewhat wealthier than their neighbors on average and have a longer relationship with the implementing organization. We also identified key production challenges that can be addressed during replication or expansion of the project in order to maximize the program's success. Despite a lack of quantifiable impact on their household food security within the first year of the program, egg producers were overwhelmingly satisfied with the program and noted important benefits of their participation, which is key for the long-term sustainability of the program.

Previous research on the use of poultry development interventions to increase children's access to and consumption of eggs in low-income, rural communities has focused exclusively on the promotion of free-range village chickens, and the collective assessment of these programs has been disappointing. The modest impact of village poultry development projects on egg consumption is likely due to a combination of factors. First, village chickens raised in extensive systems experience high flock mortality, with an estimated 53-55% dying within the first four weeks of age due to disease, poor management, or predation (Gueye, 2000; Songolo & Katongo, 2000). In areas with endemic Newcastle disease, which is common throughout sub-Saharan Africa and is the leading cause of death among village chickens in Zambia (Songolo & Katongo, 2000), outbreaks in susceptible flocks result in losses of 50-100% (Alders et al., 2010). 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 (mean egg weight = 30-50 g) (Gueye, 2000; Wong et al., 2017), compared to approximately 300 eggs per year for Isa Brown hens (mean egg weight = 62.9 g; (*Isa Brown Product Guide: Alternative Production Systems*). Finally, as a means of offsetting high flock mortality, smallholder poultry producers have demonstrated a strong preference for allowing eggs from village chickens to hatch rather than consuming them at home (Bagnol, 2001; Dumas et al., 2016; de Bruyn et al., 2017; Gueye, 2000; Halder & Urey, 2003; Lane, 2016; Olney et al., 2013).

Our market-based poultry intervention using layer hens and semi-intensive production practices to increase the availability of eggs in rural communities has numerous advantages over family-based village chicken development project. First, because the hens are raised in a confined system, the program does not risk increasing children's exposure to fecal pathogens or other zoonotic pathogens if proper biosecurity practices are observed. Second, rather than targeting individual households, the program worked with small groups, an arrangement that participants preferred because it required a relatively small time commitment from each individual. This is important because livestock interventions can have the unintended consequence of adding to women's time poverty (Flintan, 2008; Mullins et al., 1996; Valdivia, 2001; Wangui, 2008), which may negatively affect her ability to care for herself and her children. Additionally, working with groups may empower women by enhancing their social capital and status, increasing their access to resources, information, and decision-making power, and allowing them to retain control of project benefits that might otherwise be controlled by their husbands in family-based projects (Quisumbing & Pandolfelli, 2010; Westermann, et al., 2005). Finally, because the intervention is market-driven, it is an economically sustainable way to change the local food environment to the benefit of the entire community, not only the program participants, assuming local demand is high.

Despite these advantages, we identified a number of important production constraints and challenges, some of which can and should be addressed before scaling-up of the program. The biggest constraint to overall productivity and profitability in the program were suboptimal management practices and poor biosecurity, inconsistent feeding, and periods of excessive ambient temperatures. Although we were not able to obtain daily weather data for the year of production, the study area is one of the hottest places in Zambia, and the mean high temperature recorded in Mfuwe from 1961 through 1990 in October and November was 36 °C (97 °F; Appendix 12). Even in the cool season (June and July), average high temperatures approach 30 °C. In contrast, the product guide for raising this breed of hens in an alternative production system recommends an ideal housing temperature of between 18 °C and 22 °C (*Isa Brown Product Guide: Alternative Production Systems*). High ambient temperatures lower feed intake and egg production, but, as demonstrated by the most successful of our EPCs, excellent productivity and profitability can be achieved without investing in environmentally controlled housing. Most EPCs were built in shady areas and had good natural ventilation. To enhance cooling, stocking density was significantly lower than recommended for normal temperature conditions (3.8 birds/m^2 compared to the recommended 7 birds/m^2; *Isa Brown Product Guide: Alternative Production Systems*), and additional water was provided (2 bell drinkers/ 40 birds, compared to recommended 1 bell drinker/ 100 birds). Therefore, despite high temperatures, excellent results are possible in natural housing conditions if the groups follow best practices for management, feeding, and biosecurity and adapt to local conditions, which can be ensured by in-depth trainings and frequent monitoring by extension staff.

In addition to these production constraints, we identified a number of group characteristics that predicted productivity. Although many groups expressed a preference for having a man in their group to aid in the physical labor required of them to establish the EPC, the data indicate that having a man in the group was associated with a mean hen-day percent lay that was 11.5 p.p. lower per week compared to women-only groups. We did not probe the gendered aspects of group dynamics, but the superior performance of female-only groups may reflect their ability to better communicate, divide labor and leadership roles, and work together in the absence of a pre-determined power hierarchy based on prevailing cultural gender norms. An analysis of Heifer International goat projects in Tanzania found that, in contrast to mixed-gendered groups, the groups dominated by women had greater group cohesion, joint engagement, and motivation (de Haan, 2001). In a review of 46 natural resource management groups in 20 countries, Westerman et al. found that women-only groups tended to meet more often, collaborate outside the group more frequently, and had higher capacity to manage conflict than did mixed-gendered or men-only groups (Westermann et al., 2005). In some contexts, mixed-gendered groups may "(re)produce gender discrimination" and "reinforce male dominated power structures" already existing in participating communities (Westermann et al., 2005). Additionally, in backyard poultry systems throughout sub-Saharan African, women are usually responsible for the care of birds, including their feeding, watering, treatments, and cleaning their shelters (Gueye, 2000; Wong et al., 2017). As such, similar tasks in the EPCs may be regarded as "women's work", leading male group members to contribute less time and labor to the day-to-day management of the EPC. Further research to explore the gendered aspects of group dynamics and relative time and labor contributions within the EPCs is warranted during the next stages of the program.

In addition to the gender composition of the groups, we found that productivity was positively associated with higher average baseline household wealth within the group, as measured by an asset index. This may be due to wealthier groups having a greater capacity to invest in their EPCs and protect the business from shocks (e.g. when the COMACO hammer mill was offline and the subsidized feed was not available, wealthier groups were more likely able to buy alternative, more expensive feed and pay for transport to obtain it). Alternatively, wealth may be an indicator of some other unmeasured variable (e.g. business experience) that positively affected production. Counter intuitively, however, higher mean HFIAS at baseline (i.e. groups experiencing greater average food insecurity) was also associated with better productivity. The significance of this finding is unclear. It is possible that the program's relatively modest economic and food benefits are a greater source of extrinsic motivation for more food insecure participants, but further research is needed to explore this hypothesis.

Egg producers noted that the time they dedicated to work in the EPC was manageable; however, the finding that household size was negatively associated with productivity may reflect greater time poverty among women living in larger households. Throughout sub-Saharan Africa, a substantial portion of women's work time is dedicated to family care (of children, elderly, or ill) or household care (cooking, cleaning, fetching water and firewood; Arora, 2015; Blackden & Wodon, 2006), and larger households may markedly increase the demand on women's time, negatively affecting her ability to contribute to EPC labor. Future research to explicitly explore this hypothesis in greater detail is warranted.

Although the coefficient was small, the finding that the EPCs' distance from a paved road was associated with *higher* productivity was unexpected, because the perception on the ground from both COMACO extension staff and egg producers was that the most remote communities experienced the greatest challenges accessing feed and support. Indeed, in our analysis of positive and negative outliers, the least successful EPCs were all located some distance from COMACO and were only seasonally accessible by road. The exclusion of the four EPCs from Mwanya, the most remote chiefdom in the program, due to insufficient data likely biased this finding because three of these four EPCs performed very poorly based on anecdotal reports from the COMACO extension staff. Additionally, it is possible that distance from a paved road is not the most appropriate indicator of "remoteness". For example, some roads that are not paved are graded, are in good condition, and can support rapid travel, while others are only seasonally-accessible at speeds of less than 10 km/hr due to their very poor condition. Similarly, the communities surrounding some of the EPCs are densely populated, with multiple shops, schools, and local markets, while others are no more than a cluster of approximately 30 households surrounded by farmland and bush. Future research should gather more information about participating communities and their access to resources to better operationalize the concept of "remoteness".

Our findings should be interpreted within the context of some limitations. First, the analysis on the determinants of egg productivity is largely exploratory, and the estimates are likely biased by unobservable or unmeasured variables that were not included in the models, including producers' literacy, knowledge about or experience with egg production and business, and motivation. Additionally, data on group and community characteristics were only collected in 20 of the 24 EPCs, and after dropping the four Mwanya EPCs due to insufficient data, only 16 clusters were included in the final analyses examining the determinants of productivity. The Mwanya Chiefdom is the most geographically isolated and culturally distinct of the four chiefdoms in the study area. The EPCs there faced the greatest challenges accessing feed, protecting birds from predators, and marketing eggs, and only one of the four EPCs is likely to continue production in Year 2. The omission of data from this area is therefore not random, biasing our estimates of both overall productivity and profitability as well as the effects of group and community characteristics on productivity.

In summary, small-scale, semi-intensive egg production is a viable, community-based model that can successfully increase community access to eggs in some contexts. Demand from participating communities was high, in some cases far exceeding supply. Although we did not find a significant impact of the program on producers' food security in the first year of the program, producers were overwhelmingly satisfied with the program and intended to continue egg production in subsequent years. The program is not appropriate for all settings, however, and we recommend careful selection of participating communities and group members. In particular, participating communities must have a local demand for eggs, should be able to access layer feed year-round, and should not have a high risk of predation. The gender composition of groups should be determined after an assessment of the prevailing gender norms, with women-only groups being potentially more appropriate in settings with a male-dominated power hierarchy. Groups whose members have a pre-existing relationship with the implementing organization and have demonstrated their willingness and ability to successfully adopt new technologies and practices may also be preferable.

While charitable organizations have implemented egg production programs in sub-Saharan Africa (e.g. Heifer International, International Egg Foundation, One Egg), to our knowledge, this is the first rigorous analysis to examine the productivity, profitability, and acceptability of semi-intensive egg production. Our findings suggest that the EPC model can be successfully scaled-up in appropriate rural communities to provide families with access to reliable and affordable ASF. Future research will examine the program's impact on the diet and nutritional status of women and children in the surrounding communities.

References

Alders, R. G., Bagnol, B., & Young, M. P. (2010). Technically sound and sustainable Newcastle disease control in village chickens: lessons learnt over fifteen years. *World's Poultry Science Journal*, *66*(03), 433–440.

Arora, D. (2015). Gender differences in time-poverty in rural Mozambique. *Review of Social*

Economy, *73*(2), 196–221.

Ayele, Z., & Peacock, C. (2003). Improving access to and consumption of animal source foods in rural households: the experiences of a women-focused goat development program in the highlands of Ethiopia. *The Journal of Nutrition*, *133*(11 Suppl 2), 3981S–3986S.

Bagnol, B. (2001). The social impact of Newcastle disease control. In R. G. Alders & P. B. Spradbrow (Eds.), *SADC Planning Workshop on Newcastle Disease Control in Village Chickens* (pp. 69–75). ACIAR Proceedings, no. 103. Maputo, Mozambique.

Blackden, C. M., & Wodon, Q. (Eds.). (2006). Gender, time use, and poverty in sub-Saharan Africa. Washington, D.C.: The World Bank.

Central Statistical Office (CSO), Ministry of Health (MOH), & ICF International. (2015). Zambia Demographic and Health Survey 2013-14. Rockville, MA, USA: Central Statistical Office, Ministry of Health, and ICF International.

Community Markets for Conservation (COMACO). (2014). *Community Markets for Conservation: Project Description Document for 2014-2018*. Lusaka, Zambia: COMACO.

Darapheak, C., Takano, T., Kizuki, M., Nakamura, K., & Seino, K. (2013). Consumption of animal source foods and dietary diversity reduce stunting in children in Cambodia. *International Archives of Medicine*, *6*(29). http://doi.org/10.1186/1755-7682-6-29

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Maulaga, W., Thomson, P. C., & Alders, R. G. (2017). Characterising infant and young child feeding practices and the consumption of poultry products in rural Tanzania: A mixed methods approach. *Maternal & Child Nutrition*. http://doi.org/10.1111/mcn.12550

de Haan, N. (2001). Of goats and groups: a study on social capital in development projects. *Agriculture and Human Values*, 18(1), 71–84.

Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, *32*(3), 227–243.

Dumas, S. E., Lungu, L., Mulambya, N., Daka, W., McDonald, E., Steubing, E., et al. (2016). Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia. *Food Security*, *8*, 507–520.

Dumas, S. E., Maranga, A., Mbullo, P., Collins, S., Wekesa, P., Onono, M., & Young, S. L. (2017). "Men are in front at eating time, but not when it comes to rearing the chicken": Unpacking the Gendered Benefits and Costs of Livestock Ownership in Kenya. *Food and Nutrition Bulletin:* in press.

Flintan, F. (2008). Women's empowerment in pastoral societies. Nairobi, Kenya: World Initiative for Sustainable Pastoralism, Global Environment Facility, International Union for Conservation of Nature, United Nations Development Programme.

Galiè, A., Mulema, A., Benard, M. A. M., Onzere, S. N., & Colverson, K. E. (2015). Exploring gender perceptions of resource ownership and their implications for food security among rural livestock owners in Tanzania, Ethiopia, and Nicaragua. *Agriculture & Food Security*, *4*(2). https://doi.org/10.1186/s40066-015-0021-9

Gittelsohn, J., & Vastine, A. E. (2003). Sociocultural and household factors impacting on the selection, allocation and consumption of animal source foods: current knowledge and application. *The Journal of Nutrition*, *133*(11), 4036S–4041S.

Government of the Republic of Zambia, United Nations Development Programme (UNDP). (2010). *Adaptation to the effects of drought and climate change in Agro-ecological Regions I and II in Zambia* (No. PIMS No. 3942). United Nations Development Programme.

Grillenberger, M., Neumann, C. G., Murphy, S. P., Bwibo, N. O., van't Veer, P., Hautvast, J., & West, C. E. (2003). Food supplements have a positive impact on weight gain and the addition of animal source foods increases lean body mass of Kenyan schoolchildren. *The Journal of Nutrition*, *133*(11), 3957S–3964S.

Gueye, E. F. (2000). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on Agriculture*, *29*(2), 129–136.

Halder, S., & Urey, I. (2003). Changing food consumption patterns: implications for nutrition and livelihoods. Presented at the "Patterns and Trends in Food Consumption in Poor and Urban and Rural Households" conference in Bangladesh, BRAC Research and Evaluation Division, Dhaka: BRAC.

Headey, D., & Hirvonen, K. (2016). Is exposure to poultry harmful to child nutrition? An observational analysis for rural Ethiopia. *PloS One*, *11*(8), e0160590–16.

Hoorweg, J., Leegwater, P., & Veerman, W. (2000). Nutrition in agricultural development: intensive dairy farming by rural smallholders. *Ecology of Food and Nutrition*, *39*(6), 395–416.

Iannotti, L. L., Lutter, C. K., Bunn, D. A., & Stewart, C. P. (2014). Eggs: the uncracked potential for improving maternal and young child nutrition among the world's poor. *Nutrition Reviews*, *72*(6), 355–368.

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., et al. (2017). Eggs in early complementary feeding and child growth: a randomized controlled trial. *Pediatrics*, e20163459.

Isa Brown Product Guide: Alternative Production Systems. (n.d.). Isa Brown Product Guide: Alternative Production Systems. Boxmeer, The Netherlands: ISA.

Kennedy, G., Ballard, T., & Dop, M. C. (2011). Guidelines for measuring household and individual dietary diversity. Nutritional and Consumer Protection Division. Rome: Food and Agriculture Organization.

Knueppel, D., Cardona, C., Msoffe, P., Demment, M. W., & Kaiser, L. (2010). Impact of vaccination against chicken Newcastle disease on food intake and food security in rural households in Tanzania. *Food and Nutrition Bulletin*, *31*(3), 436–445.

Krasevec, J., An, X., Kumapley, R., Bégin, F., & Frongillo, E. A. (2017). Diet quality and risk of stunting among infants and young children in low- and middle-income countries. *Maternal & Child Nutrition*, *13*(Suppl 3), e12430–11.

Krebs, N. F., Mazariegos, M., Tshefu, A., Bose, C., Sami, N., Chomba, E., et al. (2011). Meat consumption is associated with less stunting among toddlers in four diverse low-income settings. *Food and Nutrition Bulletin*, *32*(3), 185–191.

Lane, J. (2016). Demystifying the pathways of impact of a livestock transfer program on household resilience & food security in Malawi. Presented at "Agriculture for Nutrition and Health Academy Week" in Addis Ababa, June 20.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition*, *137*(10), 2311–2316.

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences*, *108*(34), 13957–13962.

Masset, E., Haddad, L., Cornelius, A., & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *Bmj*, *344*(jan17 1), d8222–d8222.

Mullins, G., Wahome, L., Tsangari, P., & Maarse, L. (1996). Impacts of intensive dairy production on smallholder farm women in coastal Kenya. *Human Ecology*, *24*(2), 231–253.

Neumann, C. G., Bwibo, N. O., Jiang, L., & Weiss, R. E. (2013). School snacks decrease morbidity in Kenyan schoolchildren: a cluster randomized, controlled feeding intervention trial. *Public Health Nutrition*, *16*(09), 1593–1604.

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., et al. (2013). Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *American Journal of Tropical Medicine and Hygiene*, *89*(4), 709–716.

Nielsen, H., Roos, N., & Thilsted, S. H. (2003). The impact of semi-scavenging poultry production on the consumption of animal source foods by women and girls in Bangladesh. *The Journal of Nutrition*, *133*(11 Suppl 2), 4027S–4030S.

Njuki, J. M., Wyatt, A., Baltenweck, I., Yount, K., Null, C., Ramakrishnan, U., et al. (2015). An exploratory study of dairying intensification, women's decision making, and time use and implications for child nutrition in Kenya. *European Journal of Development Research*, *28*(4), 722–740.

North, M. O. (1990). Breeder Management. In M. O. North & D. D. Bell (Eds.), *Commercial Chicken Production Manual* (4 ed.). New York.

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. *Food and Nutrition Bulletin*, *30*(4), 355–369.

Olney, D. K., Vicheka, S., Kro, M., & Chakriya, C. (2013). Using program impact pathways to understand and improve program delivery, utilization, and potential for impact of Helen Keller International's Homestead Food Production Program in Kenya. *Food and Nutrition Bulletin*, *34*(2), 169–184.

Pachon, H., Simondon, K. B., Fall, S. T., Menon, P., Ruel, M. T., Hotz, C., et al. (2007). Constraints on the delivery of animal-source foods to infants and young children: case studies from five countries. *Food and Nutrition Bulletin*, *28*(2), 215–229.

Quisumbing, A. R., & Pandolfelli, L. (2010). Promising approaches to address the needs of poor female farmers: resources, constraints, and interventions. *World Development*, *38*(4), 581–592.

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., & Wydick, B. (2014). Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy*, *44*(C), 202–213.

Songolo, A., & Katongo, J. C. (2000). Country Report: Zambia. In R. G. Alders & P. B. Spradbrow (Eds.), *SADC Planning Workshop on Newcastle Disease Control in Village Chickens* (pp. 43–45). ACIAR Proceedings, no. 103. Maputo, Mozambique.

Talukder, A., Haselow, N. J., Osei, A. K., Villate, E., Reario, D., Kroeun, H., et al. (2010). Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations - lessons learned from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philippines). *Field Actions Science Report*, 1–9. Retrieved from http://factsreports.revues.org/404?file=1

Valdivia, C. (2001). Gender, livestock assets, resource management, and food security: lessons from the SR-CRSP. *Agriculture and Human Values*, *18*(1), 27–39.

Walingo, M. K. (2009). Role of livestock projects in empowering women smallholder farmers for sustainable food security in rural Kenya. *African Journal of Food, Agriculture, Nutrition, and Development*, *9*(7): 1468-1483.

Wangui, E. E. (2008). Development interventions, changing livelihoods, and the making of female Maasai pastoralists. *Agriculture and Human Values*, *25*(3), 365–378.

Webb-Girard, Amy, Self, J. L., McAuliffe, C., & Olude, O. (2012). The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review. *Paediatric and Perinatal Epidemiology*, *26*(s1), 205–222.

Westermann, O., Ashby, J., & Pretty, J. (2005). Gender and social capital: the importance of gender differences for the maturity and effectiveness of natural resource management groups. *World Development*, *33*(11), 1783–1799.

Wong, J. T., de Bruyn, J., Bagnol, B., Grieve, H., Li, M., Pym, R., & Alders, R. G. (2017). Small-scale poultry and food security in resource-poor settings: a review. *Global Food Security*.

Wyatt, A. J., Yount, K. M., Null, C., Ramakrishnan, U., & Webb-Girard, A. (2013). Dairy intensification, mothers and children: an exploration of infant and young child feeding practices among rural dairy farmers in Kenya. *Maternal & Child Nutrition*, *11*(1), 88–103.

CHAPTER 5

Do small-scale egg production centers in rural Zambia enhance maternal and child egg consumption and dietary diversity?

Abstract

Background: Animal source foods can efficiently enhance dietary quality, but they remain inaccessible for many women and young children in remote, low-income communities. In the Luangwa Valley, Zambia, we assessed a novel, market-based intervention in which twenty groups from twenty different rural communities established an egg production center (EPC) in their community.

Methods: In a repeated cross-sectional design, we evaluated program impact on household egg acquisition, egg consumption and dietary diversity among women and young children (6 – 36 mo), and child height-for-age z-score (HAZ), using multi-level linear, logistic, and truncated negative binomial regression techniques.

Results: At midline, households in project areas were significantly more likely to consume eggs than those in control areas (OR 1.49, p=0.010), particularly those located within 250 meters of the EPC (OR 3.54, p<0.001). Similarly, children and women living in project communities were significantly more likely to consume eggs at midline than those in control areas (OR 1.80, p=0.009 and OR 2.29, p=0.010, respectively), though proximity to the EPC did not significantly modify these effects. Among children and women who consumed any eggs, the frequency of egg consumption increased significantly at midline from season-matched baseline values in both project and control areas, and the change was not significantly different between the two groups for either children or women. Although increased over baseline, egg acquisition and consumption decreased by endline, such that the change was not significant, likely due to depressed egg production at the time of the endline survey. There was no apparent effect of the intervention on either children's or women's dietary diversity or on child HAZ.

Conclusions: The EPC program successfully increased the acquisition and consumption of eggs by households, women, and young children in participating communities. The program offers a novel approach to improving access to ASF, and integration with nutrition education and longer follow-up is needed to ensure that egg consumption translates to improved dietary quality, growth, and health.

Introduction

Worldwide, approximately 156 million children under the age of five are stunted as a result of chronic undernutrition (de Onis & Branca, 2016; UNICEF et al., 2016). Stunting, defined as having a length/height-for-age z-score (HAZ) more than 2 standard deviations below the WHO Child Growth Standard median (WHO Multicentre Growth Reference Study Group, 2006), is associated with poor cognitive function and school performance, poor immune function, increased risk of morbidity and mortality, and decreased economic productivity in adulthood (Adair et al., 2013; Black et al., 2013; de Onis & Branca, 2016; Victora et al., 2008). Dietary quality is especially important for young children, for whom both the demand for nutrients to support growth and the burden of infectious diseases are high (Arimond & Ruel, 2004; Black et al., 2008), and dietary diversity is highly predictive of child growth (Arimond & Ruel, 2004; Krasevec et al., 2017; Steyn et al., 2007). A recent WHO conceptual framework on stunting therefore emphasized inadequate complementary feeding of infants and young children as a particularly important cause of stunted growth and development (Stewart et al., 2013).

Animal source foods (ASF), including meat, milk, eggs, and fish, are energy- and lipid-dense foods that provide highly bioavailable amino acids and micronutrients (Allen, 2012;

Murphy & Allen, 2003). Because relatively small amounts of ASF can make large contributions to a child's nutrient intake, ASF are a more efficient mechanism for meeting children's micro- and macronutrient requirements than are plant source foods (Allen, 2003; 2012; Dror & Allen, 2011; Murphy & Allen, 2003; Neumann et al., 2002). Indeed, there is strong evidence that the incorporation of ASF into the regular diets of young children can improve dietary quality, micronutrient intake, and nutrition outcomes (Allen, 1993; Allen et al., 1992; Darapheak et al., 2013; Grillenberger et al., 2006; Herrador et al., 2014; Iannotti et al., 2017; Krasevec et al., 2017; Krebs et al., 2011; Lien et al., 2009; Long et al., 2011; Neumann et al., 2013).

Despite the recognized importance of ASF, the poorest families in low- and lower-middle-income countries often rely on low-quality, plant-based diets consisting primarily of starchy staples that have low protein and micronutrient availability (Allen, 1993; 2012; Arimond & Ruel, 2004; Black et al., 2008). In low-income countries, approximately 8.5% of daily energy intake is consumed as ASF, compared with nearly 18% in the world as a whole (FAOStat Database, 2017). Constraints to regular ASF consumption among children include poor local availability, the relatively high cost of ASF, inequitable intra-household food allocation, cultural or religious food proscriptions, caretaker beliefs and nutritional knowledge, and traditional child feeding practices (Appoh & Krekling, 2005; Gittelsohn & Vastine, 2003; Pachon et al., 2007; Sigman et al., 1991).

In theory, small-scale homestead livestock production can at least partially overcome the physical and economic accessibility barriers to ASF consumption. Backyard poultry production has been promoted as a particularly promising livestock-based approach to increasing ASF consumption for a number of reasons. First, extensive poultry production is already a familiar livelihood activity for most smallholder farmers, kept by 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, and poultry therefore provide many women with an important source of income, offering development practitioners with the opportunity to simultaneously boost homestead food production and empower women (Gueye, 2000a; Gueye, 2000b; Wong et al., 2017). Third, backyard poultry production has a low cost of entry and, because birds are often free-ranging and scavenging, they can be maintained with very low levels of land, labor, and capital inputs (Alders & Pym, 2009; Gueye, 2000a), making it a feasible livelihood activity for even the poorest of rural households (Alders & Pym, 2009; Dolberg, 2003). Finally, because poultry are small, reproduce quickly, and have lower monetary value relative to other types of livestock, they can be more readily slaughtered or sold in times of need (Wong et al., 2017).

Despite the promise of backyard poultry, research evaluating the impact of poultry-based interventions on child ASF consumption, dietary quality, and/or growth and development have yielded mostly disappointing results (Table 5.1). Among the seven studies evaluating the impact of poultry development programs on nutrition outcomes, four are integrated with other nutrition-specific or nutrition-sensitive interventions, making it difficult to attribute impact to the poultry intervention. One study in Bangladesh found no impact on chicken or egg consumption or dietary quality (Nielsen et al., 2003). Another found that a program in Tanzania had a modest impact on egg consumption among women (but not children) that was not sustained beyond one year (Knueppel et al., 2010). In Cambodia, a homestead food production program had a small impact on the proportion of children who consumed eggs (Olney et al., 2009), although the authors later reported that, due to high flock mortalities and the reluctance of beneficiaries to eat eggs from their own chickens, this finding was likely secondary to income generation rather than a direct effect of backyard chicken production (Olney et al., 2013). Two other studies reported a positive impact of the program on chicken, egg, or ASF intake, but the authors did not conduct statistical tests to support their conclusion (Galal et al., 1987; Nielsen, 1996). The impact on child nutritional status was only investigated in four of the studies, each reporting no or limited effect on child morbidity, micronutrient status, or anthropometric measures, and the integrated nature of many of the programs makes it impossible to attribute impact to the poultry component (Galal et al., 1987; MacDonald et al., 2011; Olney et al., 2009; Talukder et al., 2010).

Table 5.1. Summary of the research examining the impact of small-scale poultry interventions on women's and children's animal source food (ASF) consumption and nutritional status

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Galal et al., 1987 (Egypt)	More and Better Food Project promoting 31 different agricultural interventions, including poultry raising (program details not given)	Post-intervention cross-sectional analysis of participants (n= 227) and non-participants (n not given)	• Per capita intakes of protein, animal protein, and Fe were higher in participating HHs[a] • There was no difference in per capita calorie intake[a]	No significant difference in morbidity or WAZ between children <36 mo in program and control HHs (small sample, n=52)[a]
Nielsen, 1996 (Bangladesh)	BRAC program distributing a technical package to support intensive poultry production by very poor women	Post-intervention cross-sectional analysis of participants, randomly selected from purposively selected areas (n= 1000); no comparison group	• Average household intake of eggs increased from 2 to 5 per week[a] • Average household intake of chickens increased from 2 to 5 per year[a] • Meals with fish or meat increased from 10 to 12 per month and from 1 to 2 per month, respectively[a] • Average household intake of dairy increased from 0.8 to 2.5 L per month[a]	NM

Table 5.1 (Continued)

Citation (Location)	Intervention	Design	Key findings: Diet or nutrient intake	Key findings: Nutritional status
Nielsen et al., 2003 (Bangladesh)	Participatory Livestock Development Project, promoting semi-scavenging poultry production by women through loans and technical assistance	Post-intervention cross-sectional analysis of HHs in project (n=35) and control (n=35) villages	• The number of eggs and chickens consumed per month did not differ in project and control HHs • Overall dietary composition among women and young girls did not differ among groups • Per capita consumption of fish was marginally higher among women (+19 g /d, p=0.08) and girls (+11 g/d, p=0.06) in project HHs	NM
Olney et al., 2009 (Cambodia)	HKI's homestead food production program promoting micronutrient-rich foods by providing inputs and technical assistance, including chicken distribution	Pre/post analysis of participating (n=300) and control (n=200) HHs	There was no program impact on HH, maternal, or child consumption of ASF, except a small increase in prevalence of egg consumption among children (+4.2%, p<0.05)	• No difference in child anthropometrics or anemia • No difference in maternal BMI or anemia
Knueppel et al., 2010 (Tanzania)	Newcastle disease vaccination campaign and poultry health training	Repeated cross-sectional surveys of HHs in participating and non-participating villages, 1 and 2 yrs after program initiation (no baseline; n=237)	• There was no difference in maternal or child consumption of chicken meat in participating vs. control HHs • Women in project HHs ate significantly more eggs than in controls 1 yr after the program (but not after 2 yr)	NM

Table 5.1 (Continued)

			Key findings	
Citation (Location)	**Intervention**	**Design**	**Diet or nutrient intake**	**Nutritional status**
Talukder et al., 2010 (Bangladesh, Cambodia, Nepal, and the Philippines)	HKI's homestead food production model, promoting vegetable, fruit, meat, poultry, and egg production and consumption, providing inputs training, and extension services	Pre/post analysis of participating HHs, pooled for Bangladesh and Cambodia (n= 720); control HHs sampled but data not presented for ASF outcomes	• Egg consumption by HHs, women, and children increased in Bangladesh and Cambodia by 3, 0.5, and 1 eggs/wk, respectively ($p<0.05$ for all) • Chicken liver consumption increased from 24% to 46% from baseline to endline in project HHs in Bangladesh and Cambodia[a] • Data from Nepal and the Philippines not presented for ASF outcomes	• Anemia prevalence among children decreased in program areas of all four countries, but it did not significantly differ from the change in control areas • Anemia prevalence among non-pregnant women decreased in project areas in Bangladesh ($p=0.08$) and Nepal ($p<0.01$), but not Cambodia
MacDonald et al., 2011 (Malawi)	Mixed livestock distribution (including chicken and guinea fowl) and training, integrated with nutrition education, Fe supplementation and malaria control (MICAH program)	Pre/post analysis of participating (n= 1930) and non-participating (n= 988) HHs	Significant increase in HHs reporting that consumption of eggs, chicken, goat, and rabbit meat is the primary purpose for keeping animals ($p<0.05$), though increase was not different from change in control areas for eggs and rabbit meat	Significant reduction in anemia prevalence among children <60 mo, pregnant women, and women of reproductive age ($p<0.05$), but change was not different from that in control areas for children

[a] No statistical tests reported.

Abbreviations: ASF, animal source food; BMI, body mass index; BMIZ, body mass index z-score; Fe, iron; HAZ, height-for-age z-score; Hb, hemoglobin; HH, household; HI, high-intensity; MI, medium-intensity; NM, not measured; SD, standard deviation; vit, vitamin; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score

Additionally, there is an emerging concern that free-ranging poultry can negatively affect child nutrition outcomes by exposing women and young children to zoonotic pathogens that cause clinical disease (e.g. diarrhea, avian influenza) or subclinical infections affecting nutritional status (e.g. environmental enteric dysfunction). In a recent meta-analysis, exposure to livestock was consistently associated with diarrheal illness, with a particularly high risk from exposure to poultry (Zambrano et al., 2014). Research in Zimbabwe and Peru revealed that infants frequently consume chicken feces or feces-contaminated dirt during normal exploratory play (Marquis et al., 1990; Ngure et al., 2013), and there is evidence that fecal markers for environmental enteric dysfunction and stunting odds are associated with presence of animal feces in the household compound (Headey & Hirvonen, 2016), geophagy (George et al., 2015b), and corralling poultry in a child's sleep room (George et al., 2015a; Headey & Hirvonen, 2016). None of the studies in Table 5.1 considered the potential unintended consequences of poultry development projects, including increased exposure to poultry fecal pathogens, increases in women's time poverty, or women's loss of control over livestock assets or decision-making power.

Given the inconsistent findings, limited high-quality evidence, and concerns about unintended consequences, backyard poultry production may not be the ideal mechanism through which to deliver ASF to young children in low-income rural communities. We have therefore explored an alternative, market-based poultry intervention to increase the availability of eggs in rural communities in the Luangwa Valley, Zambia. In this project, twenty groups from twenty different communities were provided with the initial resources, training, and extension support to establish an egg production center (EPC) in their community using layer hens managed in a confined system. Each EPC was jointly owned and operated by the egg production group, who, working together, managed egg production and sold eggs to households in the surrounding community.

The objective of this research was to evaluate the impact of the EPC program on egg consumption and dietary diversity among women and young children (6 – 36 months of age) living in participating communities, as well as its impact on child HAZ. In a repeated cross-sectional design, we surveyed approximately 400 households with children 6-36 months of age living in the communities immediately surrounding the twenty EPCs, as well as approximately 400 households in twenty matched control communities without an EPC. To control for seasonal differences in food acquisition and consumption in the area, we repeated the survey at two time points prior to the start of egg production and at two time points during the first year of egg production. We hypothesized that, compared to individuals living in control communities, egg consumption among both women and young children would increase as a result of the program, leading to greater dietary diversity; however, given the short follow-up time, we hypothesized that the program would not have any impact on child HAZ.

Methods

Conceptual framework

This research is guided by a framework (Figure 5.1) that outlines the theoretical pathway from village-level egg production to improved maternal and child nutritional status in the surrounding community. For the business owners and operators, egg production can contribute to improved maternal and child nutritional outcomes by: 1) providing direct access to eggs for home consumption; 2) providing cash income from the sale of eggs; 3) providing manure for fertilizer to increase crop productivity; and 4) providing social or cultural benefits, including enhanced social status in the community and the empowerment of female farmers involved in the business (Herrero et al., 2013; Randolph et al., 2007). However, the EPC program can also contribute to diets and nutritional outcomes for women and children living in the surrounding communities by providing physical access to a high-quality food source that is also economically accessible and culturally acceptable.

The pathway from egg production to improved nutritional status among women and children within a community is mediated through several intermediate outcomes and modified by a number of cultural, household, and individual characteristics. The relationship between egg production and increased egg consumption is likely modified by the price of eggs and household wealth. This is true even in producer households because home consumption of eggs produced by the business results in lost potential income, so egg producers may make choices to reduce their own consumption and favor income generation. Once acquired for household consumption, eggs need to be allocated to and consumed by women and children in that household, which is affected by cultural beliefs about eggs (food prohibitions or prescriptions), individual food preferences, knowledge and opinions about eggs, and method of food service within the household. Individual consumption of eggs will improve dietary quality if eggs do not replace other high-quality components of the diet (e.g. meat or milk). Finally, the relationship between improved individual dietary quality and subsequent improvements in nutritional status is modified by concurrent morbidities (e.g. diarrhea, AIDS), reproductive status, and the household water, sanitation, and hygiene (WASH) environment, which affect the body’s biological utilization of ingested nutrients.

Figure 5.1. Simplified program impact pathway from local egg production to improved maternal and child dietary quality and child linear growth in the surrounding community. Outcomes 1 through 6 were measured for this study, as described below, while local production of eggs in the EPC program was described Chapter 4.

Study setting and population

This research was conducted in rural areas of Zambia's Eastern Province. Zambia is divided into non-administrative, historically-defined areas of traditional leadership called chiefdoms, four of which were purposively selected for this study: Mnkhanya, Jumbe, Nsefu, and Mwanya. Twenty-four communities within these four chiefdoms were purposively selected by the implementing organization, Community Markets for Conservation (COMACO; www.itswild.org) to receive the egg production intervention based on their internal targets. Due to time and resource constraints, twenty of these twenty-four communities were randomly selected to participate in this impact evaluation study ("project areas"). Twenty additional communities were identified by COMACO extension staff as suitable matched controls based on their chiefdom and a subjective assessment of their size, density, and proximity to major roads, schools, markets, and natural resources. Control areas were a median of 5.2 km walking distance from their matched project areas (range 1.6 – 17.5 km) and approximately 1 hour walking (range 26 – 210 minutes; Figure 5.2).

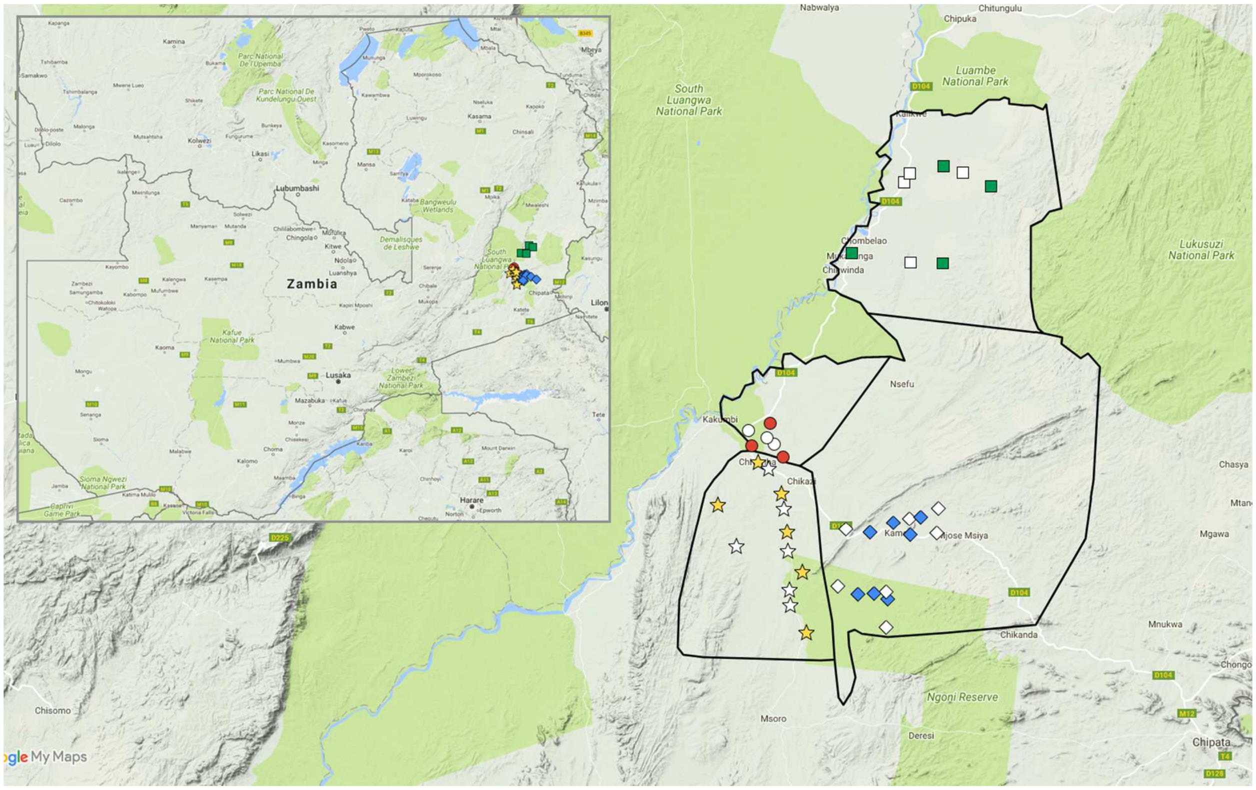


Figure 5.2. Project (colored; n= 20) and control (white; n= 20) study locations in Zambia's Luangwa Valley, in the Chiefdoms of Jumbe (diamonds), Mnkhanya (stars), Mwanya (squares), and Nsefu (circles). Black lines roughly indicate the borders of the four Chiefdoms according to (Dalal-Clayton & Child, 2003) and (K. Baldwin, 2015). Images created in Google maps.

The majority of the people in Nsefu, Mnkhanya, and Jumbe Chiefdoms are of the Kunda ethnic group, and all speak some mutually intelligible dialect of Chinyanja. In Mwanya, the Bisa tribe predominates and Lala-Bisa is the primary language, though Chinyanja is well understood and frequently spoken as a second language. Small-scale agriculture is the chief livelihood activity for the majority of households in the Luangwa Valley, (COMACO, 2014), though crop yields are limited by inconsistent rains (Government of the Republic of Zambia & UNDP, 2010), poor access to agricultural inputs, and suboptimal soil management practices (Hoffine, 2013; Lewis et al., 2011). As a result, chronic food insecurity is pervasive, particularly during the "hungry season" from December to March (Lewis et al., 2011), when grain stores are depleted and crops are not ready for harvest.

Nationally, dietary quality is extremely poor (Central Statistical Office (CSO) et al., 2015) and undernutrition is a significant public health concern: 40% of children under five are stunted, 54% suffer from vitamin A deficiency, and 58% are anemic (CSO et al., 2015). A 12.9% HIV prevalence rate nationally (UNAIDS AIDSinfo, n.d.), combined with endemic malaria, tuberculosis, and other infectious diseases, additionally contribute to Zambia's ranking of 139 out of 188 countries in the world's human development rankings (*Human Development Report 2016: Zambia*, 2017).

Program description

Four to five smallholder farmers from each of the 20 project areas were recruited by COMACO extension staff in June 2014 to be trained as the owners and operators of the EPC in their community, with 80% targeted female participation overall. Farmers were eligible for selection if they were members of a COMACO Poultry Producer group (which promotes production of backyard/village chickens), had a history of successfully adopting recommended agricultural practices, and were vulnerable to food insecurity and poverty in the subjective assessment of COMACO's Area Managers. The EPC design was adapted from a previous pilot project in the area (Dumas et al., 2016) and construction of the 20 EPCs took place from August to November 2014. The egg producer groups were trained in hen health, biosecurity, food safety, and business management by COMACO's Poultry Manager. Each EPC was stocked with 40 layer hens in August 2015 and egg production began in September 2015. During egg production, COMACO extension staff monitored production records and intervened with groups where necessary to resolve disputes or address production concerns; however, the egg producers were the owners and operators of the group business and were ultimately responsible for their own businesses, including marketing eggs, purchasing feed, and maintaining the facility and production records. Additional details about the EPC design, productivity, profitability, and challenges are provided in Chapter 4.

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; Figure 5.3). At each timepoint, data were collected over approximately 3.5 – 4 weeks.

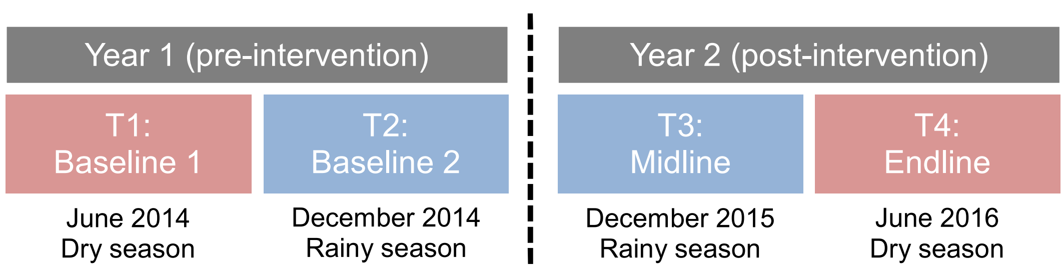


Figure 5.3. Timeline of data collection at four time points (T1, T2, T3, and T4) before the start of egg production (pre-intervention) and during the first year of egg production (post-intervention). To account for the seasonality of food consumption from the dry to rainy season that is typical in the region, data were collected at two time points before and after the intervention.

Because villages in the area are very small, multiple villages were included in most field sites (mean 5.6 villages per field site, 222 villages in total). Each field site was marked with a GPS point representing the approximate center of the multiple communities that made up each field site. For project areas this GPS point also represented the proposed site of the EPC. A sampling frame of eligible households in each of the 40 field sites was created through in-home visits, facilitated by COMACO Lead Farmers and Village Headmen. Inclusion criteria were: 1) there was a child 6-36 months residing in the household, and 2) the dwelling was located within reasonable walking distance (≤1.5 km) from the field site GPS location. Households were excluded from the study if the mother of the eligible child could not comfortably converse in one of the languages of the research staff or if the child was physically disabled or severely ill. The 20 eligible households nearest to the field site GPS location were recruited and enrolled in the study. All eligible children 6-36 months of age living within enrolled households were included in the study. The sampling and enrollment procedures were repeated in the same communities at each of the four time points.

Twelve local staff members were trained in research ethics, interview methods, and anthropometric techniques for one week prior to each survey. The staff was deployed in two teams, each managed by a Team Leader, such that each project site and its matched control site were surveyed on the same day. Questionnaires were administered in pairs in the preferred language of the respondent at his/her home. Responses were recorded either on paper forms (June 2014) or in GPS-enabled tablets using the open-source data collection tool ODK Collect (v.1.4.10, Open Data Kit, https://opendatakit.org; all other time points).

At each enrolled household, the research staff administered three in-home questionnaires in a single sitting. The first questionnaire, administered to the male or female head of household, assessed household composition, asset ownership and dwelling characteristics, crop and livestock production, income generating activities, and food security. The second and third questionnaires, administered to the mother or primary caretaker of the eligible child, assessed her and her child's dietary diversity (24-hr recall), animal source food consumption (7-day recall), child morbidities (14-day recall), child breastfeeding history (WHO, 2010a), and maternal subjective wellbeing (Bjørnskov, 2010). Anthropometric measurements were then taken on both the woman and child (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/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. The entire procedure, including questionnaires and anthropometry, lasted approximately 45 minutes per household. Printed versions of the data collection instruments are in Appendix 4.

Outcome measures

We assessed the impact of the EPC program on six outcomes of interest. First, egg consumption was assessed at three levels: at the level of the household (Outcome 1), by the eligible child (Outcome 2), and by that child's mother or primary female caretaker (Outcome 3). *Household egg acquisition* was operationalized as a dichotomous variable indicating whether or not anyone in the household consumed any chicken eggs in the seven days prior to the survey, as recalled by the woman who was interviewed. Because the typical method of food service is "family style" where everyone (especially the women and children) eats from the same service plate or pot, determining the exact number of eggs consumed by an individual is difficult. Therefore, *individual egg consumption* by women and children was operationalized in a two-step process: first, as a dichotomous variable indicating that he/she did or did not consume any eggs in the seven days prior to the survey, and second, as the number of times that he/she consumed eggs over the past seven days. The second measure does not attempt to quantify the number of eggs consumed by an individual, but rather acknowledges that at each "time", greater than or less than a single egg may have been consumed.

Children's dietary diversity (CDDS; Outcome 4) was assessed by the number of food groups (0 to 7) that the child consumed in the 24 hours preceding the interview, as recalled by their mother or primary caregiver (WHO, 2010a).[2] *Women's dietary diversity* (Outcome 5) was assessed using the Women's Dietary Diversity Score (WDDS; (Arimond et al., 2010; Kennedy, Ballard, & Dop, 2011)), which is the number of food groups (0 to 9) that the woman consumed in the 24 hours preceding the interview[3] and is correlated with micronutrient adequacy in women of reproductive age (Arimond et al., 2010).

Children's nutritional status (Outcome 6) was measured by height-for-age z-score (HAZ), calculated with zscore06 in Stata, where:

$$HAZ = \frac{(measured\ height - median\ height\ for\ a\ child\ of\ that\ age\ and\ gender\ in\ the\ reference\ population)}{Standard\ deviation\ of\ the\ reference\ population}$$

The reference population was based on the WHO Child Growth Standards. Children with HAZ < -2 were classified as stunted and with HAZ < -3 as severely stunted.

Covariates and descriptive variables

At baseline 2, the women's survey included questions about their practices, attitudes, and beliefs around eggs (Appendix 4). These included a multiple-choice question about the

---

[2] The seven food groups for the CDDS were: 1) grains, roots, and tubers; 2) legumes and nuts; 3) dairy products; 4) flesh foods (meat, fish, poultry, and liver/organ meats); 5) eggs; 6) vitamin-A rich fruits and vegetables; 7) other fruits and vegetables.

[3] The nine food groups for the WDDS were: 1) starchy staples; 2) vitamin A-rich fruits and vegetables; 3) leafy greens; 4) other fruits and vegetables; 5) organ meats; 6) other meat and fish; 7) eggs; 8) legumes, nuts, and seeds; and 9) dairy products.

household's primary source of eggs, an open-ended question about travel time to that source, a multiple-choice question about why the family does not consume eggs more often, and questions about the duration of egg storage and how eggs are prepared for consumption. All multiple-choice questions included an "other" option, with space to specify. To understand women's attitudes and beliefs about the social acceptability of eggs for particular individuals, they were asked to indicate their level of agreement with to a series of statements using a five-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"; if so, they were asked to indicate what type of people are not supposed to eat eggs.

Household economic welfare was assessed with an asset index generated using principal components analysis (PCA). PCA is a variable reduction procedure that collapses a large number of observed variables into as single measure of a particular construct (here, long-term wealth). Rather than arbitrarily imposing weights for each observed variable, PCA allows the data to directly determine the most appropriate weight for each variable and then linearly combines these optimally-weighted observed variables into fewer components (Booysen et al., 2008; Filmer & Pritchett, 2001; Sahn & Stifel, 2003). The first component, which is the linear index of the variables that captures the largest amount of information common to all variables, was retained as both a continuous variable and a categorical variable of wealth tertiles (low, medium, high, for descriptive purposes) to create a measure of relative household wealth within the sample across all four time points (Appendix 13).

Household food security was assessed by the Household Food Insecurity Access Scale (HFIAS; (Coates et al., 2007)) and the Household Hunger Scale (HHS; (Ballard et al., 2012)), two experiential measures of food insecurity. The HFIAS is a 9-item questionnaire that captures the frequency of the three universal domains of inadequate household-level food access over the past four weeks: feelings of anxiety or uncertainty about household food supply, perceptions of insufficient food quality, and perceptions of insufficient food quantity. Summation of all 9 items results in a score of 0 (food secure) to 27 (severely food insecure) for the household. For descriptive purposes, the HFIAS was retained as a both continuous variable and as a four-level categorical variable, although these cut-offs have not been validated: food secure (HFIAS=0), mild food insecurity (HFIAS= 1-9), moderate food insecurity (HFIAS= 10-18), and severe food insecurity (HFIAS= 19-27). The HHS was developed and validated for cross-cultural use. It utilizes the last three questions of the HFIAS, which measure the frequency of the most extreme consequences of food insecurity (having no food in the home, going to sleep hungry, and going 24 hours without food), and categorizes households as having experienced "little to no household hunger", "moderate household hunger", or "severe household hunger" over the past four weeks.

Child morbidities were operationalized as dichotomous variables and included having any fever, diarrhea, vomiting, or rapid or difficult breathing with coughing in the past 14 days, as observed and 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 eligible child's breastfeeding and complementary feeding history, with questions and indicators following WHO recommendations (WHO, 2010b).

Distance of the household from the field site's central GPS point or from the EPC was measured using the *near* tool in ArcGIS, which calculates the geodesic distance (i.e. "as the crow flies") between two features on a map. While walking distance would be preferable for our purposes, roads and paths for the region have not been reliably mapped and often change seasonally.

Women's nutritional status was assessed with body mass index (BMI), calculated in the standard manner (BMI = weight (kg)/ height(m)^2). Women's subjective wellbeing, defined as "the valuations people make regarding their lives, the events happening to them, their bodies and minds, and the circumstance in which they lived" was measured using the Cantril "Ladder of Life" scale from the Gallup World Poll (Gallup, 2012). This is a single-item measure that attempts to capture an individual's overall evaluation of their life as a whole, on a scale of 0 (the "worst possible life for you") to 10 (the "best possible life for you"), and is "self-anchored", meaning it is framed relative to the individual's personal aspirations (OECD, 2013). We used a drawing of a ladder with ten numbered rungs (0 at the bottom, 10 at the top) as a visual aid given the low literacy and numeracy in our study population.

Statistical analyses

Data were cleaned and analyzed in Stata (Stata/IC version 14.0, StataCorp, College Station, Texas). Descriptive analyses of all variables at baseline were first performed to better understand the characteristics of the study population and identify baseline differences between the treatment and control groups. Difference were considered significant at $p < 0.05$.

Household egg acquisition

To investigate if the program impacted household acquisition of eggs, the probability that a household consumed any eggs over the past 7 days was modeled using four-level random-intercept logistic regression with random-effects for Chiefdom, matched field site pairs, and field site (i.e. community; Figure 5.4a). Level-1 covariates were included to control for differences in household asset index, education and gender of head of household, household size, COMACO membership status, EPC group membership, chicken or other poultry ownership, household hunger, and sources of off-farm income (Appendix 14). The interaction of time point and group (project vs. control community) was the "treatment effect" and eight pairwise comparisons across the levels of interest were made, where pre-intervention data from the dry season were compared with post-intervention data from the dry season and pre-intervention data from the rainy season were compared with post-intervention data from the rainy season (project vs. control at each of four time points, baseline 1 vs. endline in projects, baseline 1 vs. endline in controls, baseline 2 vs. midline in projects, baseline 2 vs. midline in controls).

Egg consumption by women and children

In histograms of egg consumption by women and children, both outcome variables were highly zero-inflated and right-skewed. Therefore, two-stage models were used to determine the overall impact of the program on individual egg consumption. Two-stage models, also called hurdle models, were developed to cope with zero-inflated outcome data (Afifi et al. 2007; Hu et al., 2011; Rossen et al., 2013). They first model the probability of the outcome occurring at all (yes/no) and then model the intensity of the outcome given that it did occur. In the first stage, we used multilevel random-intercept logistic regression to model the probability of the outcome occurring at all (i.e. any egg consumption in the past 7 days). To account for the survey design, random-effects were included for Chiefdom, matched field site pairs, and field site, and household (Figure 5.4b).

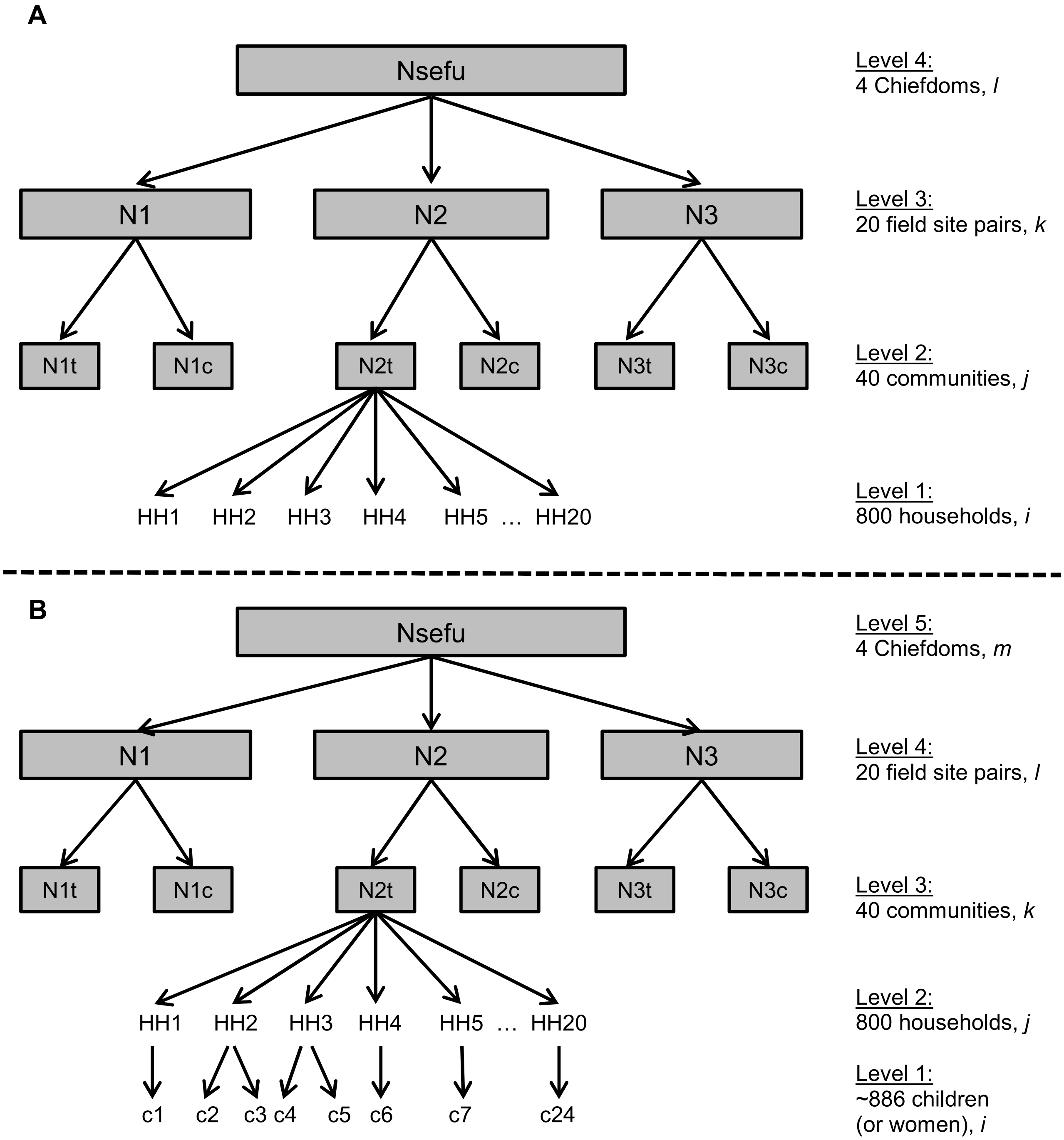


Figure 5.4. Hierarchical structure of four-level data collected on households (panel A, top) and five-level data collected on women and children (panel B, bottom) at each time point.

In the second stage, we conducted zero-truncated negative binomial regression to model the *intensity* of egg consumption (the number of times a woman or child ate eggs in the past 7 days) for the subsample of those individuals who consumed at least some eggs. An extension of the Poisson distribution, the negative binomial distribution allows the mean and variance to be different (Atkins et al., 2013) and is therefore the most appropriate model for our data, which are over-dispersed relative to the Poisson distribution (dispersion= variance/mean= 2.81 [children] and 2.88 [women]). 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 five-level random-intercept logistic regression models 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 to control for differences in household wealth, education, and gender, among other characteristics (Appendix 14).

Women's and children's dietary diversity, and children's HAZ

To examine the impact of the intervention on women's dietary diversity, children's dietary diversity, and children's HAZ, we fit multi-level 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 14). These models assume that, given the covariates, the level-1 residuals and random intercepts at level-2, level-3, level-4, and level-5 have zero expectation, are not correlated with the covariates (exogeneity), and have constant variances (homoskedasticity). The models also assume that, given the covariates, level-1 residuals are uncorrelated across individuals and that random intercepts are uncorrelated for different clusters.

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. Because there are no successful poultry interventions for comparison, a reasonable effect size was extrapolated from research on the effect of dairy cow ownership on child HAZ. The desired effect size was therefore set at 0.33 standard deviations, which is smaller than the magnitude of the effect of a recent dairy interventions (0.54 standard deviations, (Rawlins et al., 2014)) and within the estimated effect size of dairy cow ownership (0.25 – 0.58 standard deviations, (Grosse, 1998; Hoddinott et al., 2015; Nicholson et al., 2003)). It is also approximately half the effect of a recent egg feeding trial, which fed one egg per day to children 6-9 months, on child length-for-age z-score (0.63 standard deviations; (Iannotti et al., 2017)). Sample size was calculated using the formula described by Rutterford et al. for cluster randomized trials (Rutterford et al., 2015). The 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 in the calculation, defined as DE = 1 + ICC(n-1), where ICC = the intra-class correlation for HAZ in rural areas of low-income countries, estimated to be 0.035 (Fenn et al., 2007). The sample size per cluster, n, was set at 20 children aged 6-36 months, which was 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 timepoint and 3240 children across all four time points.

Ethical standards

All procedures, protocols, and research materials underwent an internal review process at COMACO and were approved by the Institutional Review Board at Cornell University (Protocol

ID#: 1402004456). The study was registered at ClinicalTrials.gov (ID#: NCT02516852). In the field, approval was first obtained from Senior Chief Nsefu and Chiefs Mnkhanya, Jumbe, and Mwanya, who granted permission for all field activities in their respective Chiefdoms. We then met individually with key Village Headmen from selected field sites to inform them of our activities and obtain their support. At the time of enrollment, all participants provided individual written informed consent; separate consents were obtained for the household interview, the maternal interview, and parental consent for anthropometric measurements. In the case of an illiterate participant, 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.

Results

Baseline characteristics

At baselines 1 and 2, there were some differences between the children, the mothers, and the households in project and control areas (Table 5.2). Control households were significantly less likely to be COMACO members at both time points (likely a function of the purposive selection of the research sites; $p < 0.001$), but were more likely to own village chickens at baseline 1 ($p = 0.036$) and cattle at baseline 2 ($p=0.023$). Households in project areas were marginally wealthier than those in control areas at baseline 2 ($p=0.063$), which is reflected in the significantly higher proportion of homes built with brick walls ($p=0.021$) and iron roofs ($p=0.036$). Overall experiences of household food insecurity over the past month, as measured by the HFIAS, were not significantly different between the groups at either timepoint. However, control households reported significantly greater experiences of very severe food insecurity at both time points (Figure 5.5), reflected in the HHS status (p= 0.036 and p=0.016). Project households were significantly closer on average to the field site center (p< 0.001), suggesting that control areas were somewhat less densely populated than project areas.

Mothers from both project and control areas reported very high prevalences of morbidities in their children, especially at baseline 1. At baseline 1, children from control areas were significantly more likely to have experienced fever (p= 0.035), diarrhea (p= 0.025), and vomiting (p= 0.043) in the past two weeks, and they were marginally more likely to have been diagnosed with malaria (p= 0.055). Perhaps partially as a result of this high burden of morbidity, children from control areas also had significantly lower WHZ (p= 0.043) and were marginally more likely to be wasted (p= 0.064). However, the mean WHZ for both populations (overall mean= 0.29, SD 1.10) was above the global median for healthy children, indicating that wasting is not a concern in this population. Finally, due to their significantly lower WHZ and slightly (non-significantly) lower HAZ, children from control areas are significantly more likely to be underweight (p= 0.025). At baseline 2, there were no significant differences in burden of morbidity, WHZ, or underweight prevalence between the two groups at the level of 0.05.

The mean number of eggs consumed by households, children, and their mothers did not vary by group at either time point. At baseline 1, children in project areas were marginally (non-significantly) more likely to have consumed eggs in the past 24 hours, while the same was true for women in control areas at baseline 2. In both cases, there was no difference in their likelihood of having consumed eggs in the past week.

Table 5.2. Characteristics of participating households, women, and children in project and control communities in the Luangwa Valley at baseline 1 and 2

	Baseline 1 (dry season)			Baseline 2 (rainy season)		
	Control	Project	p-value	Control	Project	p-value
Household characteristics	***n= 390***	***n= 409***		***n= 399***	***n= 406***	
Household size, mean (± SD)	5.66 (2.00)	5.80 (2.12)	0.336	5.16 (2.14)	5.37 (2.05)	0.172
Number of children under age 5y, mean (± SD)	1.69 (0.72)	1.61 (0.69)	**0.096**	1.41 (0.68)	1.44 (0.68)	0.570
Female headed, %	13.08%	13.94%	0.722	21.05%	20.44%	0.831
Head of household completed primary school, %	56.02%	61.25%	0.138	55.61%	56.47%	0.808
Socioeconomic status (tertiles of asset index)						
Lowest, %	36.24%	34.42%		36.84%	33.99%	
Middle, %	33.86%	33.92%	0.828	34.84%	30.05%	**0.063**
Highest, %	29.89%	31.66%		28.32%	36.95%	
Brick walls on home, %	30.26%	35.45%	0.118	37.09%	45.07%	**0.021***
Iron sheets on home, %	29.64%	31.36%	0.599	31.83%	38.92%	**0.036***
Protected drinking water source [a], %	61.34%	64.62%	0.338	80.95%	77.83%	0.274
Electricity access[b], %	25.38%	25.18%	0.948	27.57%	26.85%	0.818
Private latrine, %	44.36%	41.67%	0.443	46.62%	47.04%	0.903
Owns agricultural land, %	84.36%	79.71%	**0.087**	82.96%	81.03%	0.672
COMACO membership, %	21.85%	40.10%	**<0.001***	23.81%	38.92%	**<0.001***
Livestock ownership, %	67.95%	62.35%	**0.097**	59.65%	66.01%	**0.062**
Chicken, %	64.36%	55.50%	**0.011***	54.14%	58.87%	0.176
Pigs, %	13.85%	11.74%	0.372	7.02%	9.85%	0.148
Guinea fowl, ducks, or pigeons, %	13.85%	11.00%	0.223	10.03%	12.56%	0.256
Goats or sheep, %	11.28%	12.96%	0.468	11.28%	11.82%	0.809
Cattle, %	5.90%	3.42%	**0.096**	8.02%	4.19%	**0.023***
HFIAS, mean (± SD)	10.43 (6.90)	9.94 (6.62)	0.313	8.59 (5.95)	7.84 (5.72)	**0.073**
Food secure (HFIAS= 0), %	7.97%	9.56%		15.54%	14.53%	
Mildly FI (1 ≤ HFIAS ≤ 9), %	37.28%	39.22%	0.731	39.35%	48.03%	**0.090**
Moderately FI (10 ≤ HFIAS ≤ 18), %	41.65%	39.46%		41.10%	34.24%	
Severely FI (19 ≤ HFIAS ≤ 27), %	13.11%	11.76%		4.01%	3.20%	
Household Hunger Scale status						
Little/no hunger, %	64.36%	72.30%		62.66%	70.44%	
Moderate hunger, %	24.62%	20.59%	**0.036***	31.33%	26.85%	**0.016***
Severe hunger, %	11.03%	7.11%		6.02%	2.71%	

Table 5.2 (Continued)

	Baseline 1 (dry season)			Baseline 2 (rainy season)		
	Control	**Project**	**p-value**	**Control**	**Project**	**p-value**
Number of eggs eaten, past 7d, mean (± SD)	2.89 (4.93)	3.31 (5.41)	0.254	2.85 (4.24)	2.72 (4.63)	0.675
Travel time to access eggs, mean minutes (± SD)	12.09 (17.51)	14.42 (23.17)	0.132	8.37 (15.54)	10.80 (17.86)	**0.048***
Primary limitation to eating eggs at home						
Cost, %	49.74%	51.87%		43.07%	43.81%	
Availability, %	47.91%	45.39%	0.630	51.89%	51.73%	0.792
Other, %	2.35%	2.74%		2.77%	2.98%	
Distance from field site (m), mean (± SD)	466.6 (455.6)	326.4 (262.5)	**<0.001***	470.6 (482.9)	364.5 (313.0)	**<0.001***
Women's characteristics/ responses	***n= 396***	***n= 413***		***n= 400***	***n= 409***	
Age (yr), mean (± SD)	27.90 (8.61)	28.05 (7.88)	0.602	27.88 (7.68)	27.69 (7.54)	0.358
Married, %	82.07%	78.93%	0.261	86.00%	84.11%	0.451
Pregnant[c], %	NM	NM	-	4.50%	5.38%	0.564
Lactating[c], %	NM	NM	-	46.50%	46.94%	0.899
Dietary diversity[d], mean (± SD)	4.05 (1.22)	4.15 (1.29)	0.238	3.75 (1.51)	3.78 (1.33)	0.608
Number of meals, past 24h, mean (± SD)	NM	NM	-	2.50 (0.90)	2.69 (1.00)	**0.003***
Meals containing ASF, past 7d, mean (± SD)	4.26 (4.14)	4.33 (4.33)	0.808	5.55 (4.93)	5.41 (4.57)	0.672
Any ASF in past 24h, %	43.18%	45.04%	0.595	83.75%	87.29%	0.153
Number of times eating eggs, past 7d, mean (± SD)	0.87 (1.40)	0.79 (1.44)	0.423	0.77 (1.27)	0.65 (1.24)	0.195
Any eggs in past 24h, %	5.56%	8.47%	0.105	13.00%	9.29%	**0.093**
Any eggs in past 7d, %	40.40%	37.86%	0.460	35.50%	32.27%	0.332
Subjective wellbeing, mean (± SD)	5.40 (2.14)	5.28 (2.09)	0.393	4.92 (1.73)	4.92 (1.85)	0.973
BMI (kg/m^2), mean (± SD)	21.88 (2.77)	21.98 (2.73)	0.616	22.35 (3.06)	22.27 (3.04)	0.699
Underweight, %	8.67%	5.84%	0.121	7.77%	8.33%	0.769
Overweight, %	11.99%	11.68%	0.892	19.30%	15.20%	0.123
Children's characteristics	***n= 426***	***n= 434***		***n= 412***	***n= 426***	
Age (mo), mean (± SD)	20.08 (8.74)	20.30 (8.92)	0.715	21.34 (8.57)	21.09 (8.59)	0.668
Gender, % female	52.82%	51.84%	0.775	54.37%	52.11%	0.513
Dietary diversity[e], mean (± SD)	3.58 (1.28)	3.72 (1.28)	0.131	3.37 (1.57)	3.40 (1.34)	0.748
Minimum dietary diversity met (6-23 mo), %	47.29%	55.60%	**0.052**	35.37%	40.16%	0.269
Meals containing ASF in past 7d, mean (± SD)	3.70 (4.03)	3.73 (4.23)	0.939	5.48 (5.12)	4.90 (4.36)	**0.078**
Any ASF in past 24h, %	35.68%	39.63%	0.232	43.45%	45.31%	0.588
Any fish or meat in past 24h, %	27.23%	29.95%	0.377	37.86%	38.50%	0.850
Any dairy in past 24h, %	11.74%	9.22%	0.227	10.19%	7.75%	0.215

Table 5.2 (Continued)

	Baseline 1 (dry season)			Baseline 2 (rainy season)		
	Control	**Project**	**p-value**	**Control**	**Project**	**p-value**
Any eggs in past 24h, %	6.57%	9.91%	**0.076**	16.02%	13.38%	0.280
Any eggs in past 7d, %	40.14%	37.33%	0.397	37.38%	34.04%	0.313
Number of times eating eggs, past 7d, mean (± SD)	0.83 (1.28)	0.77 (1.33)	0.490	0.84 (1.41)	0.69 (1.27)	0.107
Ever breastfed, %	94.89%	94.01%	0.598	87.86%	88.50%	0.776
Currently breastfeeding, %	50.47%	47.70%	0.416	45.63%	44.84%	0.817
At least 1 morbidity in past 2 weeks, %	91.55%	89.10%	0.225	77.43%	73.47%	0.184
Fever, %	77.41%	71.13%	**0.035***	58.50%	52.47%	**0.080**
Diarrhea, %	56.57%	48.96%	**0.025***	46.60%	43.90%	0.432
Malaria diagnosis, %	54.23%	47.69%	**0.055**	27.43%	21.60%	**0.050**
Dyspnea and coughing, %	51.17%	46.53%	0.173	25.24%	23.47%	0.551
Vomiting, %	41.71%	34.97%	**0.043***	20.87%	15.96%	**0.066**
MUAC (cm), mean (± SD)	14.84 (1.27)	14.89 (1.17)	0.548	14.82 (1.13)	14.92 (1.11)	0.218
HAZ, mean (± SD)	-1.76 (1.21)	-1.72 (1.18)	0.616	-1.70 (1.42)	-1.60 (1.42)	0.328
Stunted (< 2 SD below mean), %	41.77%	39.06%	0.423	41.32%	38.73%	0.445
Severely stunted (< 3SD below mean), %	15.99%	13.88%	0.390	12.96%	14.79%	0.445
WHZ, mean (± SD)	0.21 (1.18)	0.37 (1.02)	**0.043***	0.05 (1.13)	0.15 (1.06)	0.190
Wasted (< 2 SD below mean), %	2.64%	0.95%	**0.064**	3.19%	1.65%	0.148
WAZ, mean (± SD)	-0.77 (1.17)	-0.67 (1.05)	0.224	-0.87 (0.99)	-0.74 (1.06)	**0.069**
Underweight (< 2 SD below mean), %	12.29%	7.69%	**0.025***	12.65%	12.03%	0.784

Notes: P-values are for the comparison of households control and project areas at the same time point. Bolded p-values indicate that the test statistic is approaching significance at p< 0.1. Asterisk (*) indicates p < 0.05. [a]There was a dramatic increase in access to protected water sources throughout the course of the survey due to targeted projects to install boreholes in the area. [b]With the exception of four households, which were connected to the national grid or using a generator, electricity was provided by a solar panel purchased by the household. [c]Reproductive status was not assessed at baseline 1. [d]Ranging from 0 – 9 food groups, based on the Women's Dietary Diversity Score (WDDS) (Arimond et al., 2010; Kennedy et al., 2011) [e]Ranging from 0 – 7 food groups, based on the food groups used by the WHO to calculate the percentage of children eating a minimally diverse diet (World Health Organization (WHO), 2010a)

Abbreviations: ASF, animal source foods; BMI, body mass index; COMACO, Community Markets for Conservation; HAZ, height-for-age z-score; HFIAS, Household Food Insecurity Access Scale; MUAC, mid-upper-arm circumference; NM, not measured; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score

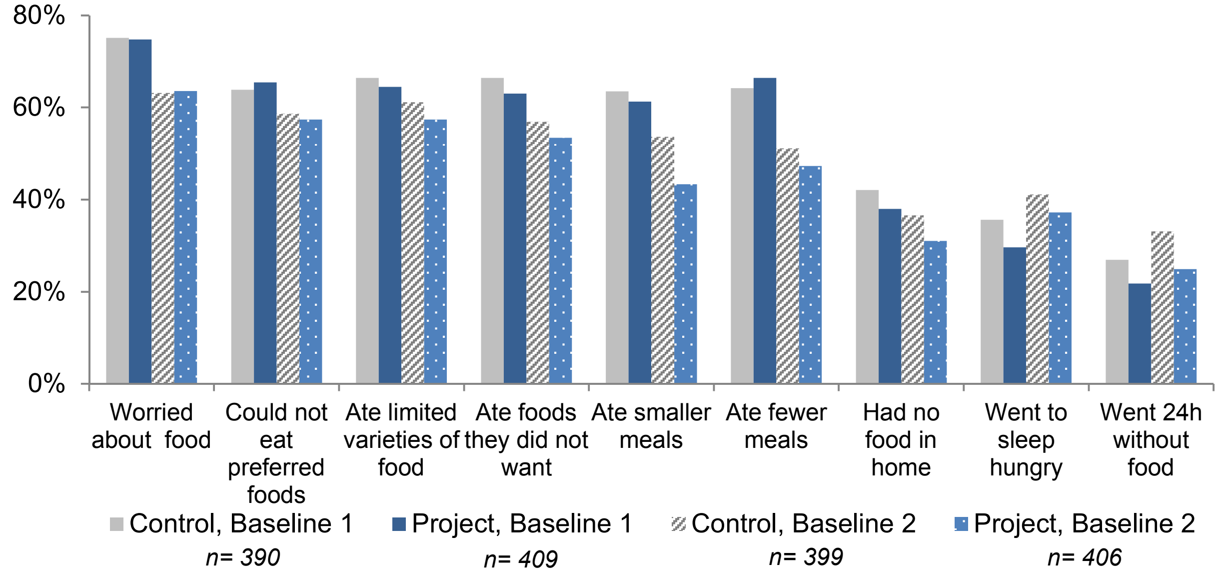


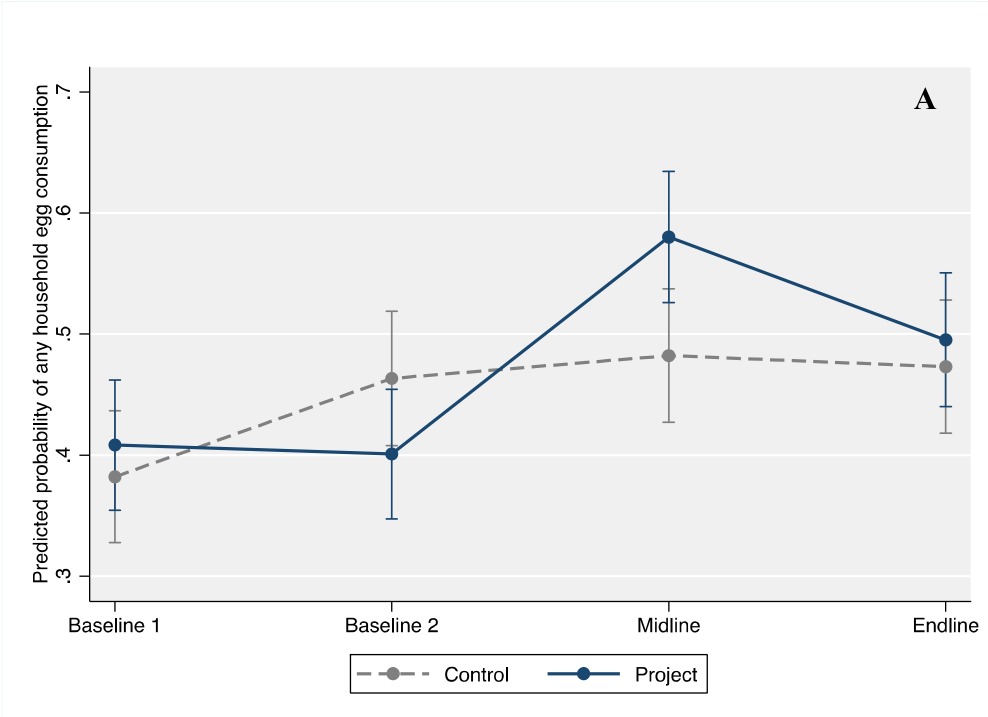
Figure 5.5. Proportion of households reporting that they experienced each of the nine items on the Household Food Insecurity Access Scale (HFIAS) on at least one occasion in the past month in households in control and project areas in the Luangwa Valley at baseline 1 (Jul 2014) and baseline 2 (Dec 2014).

Eggs were mostly commonly sourced from the family's own flock of village chickens (48.0%) or purchased from road-side stalls (31.0%), were not stored in the home for more than one day (93.5%), and were primarily served fried (69.7%) or hardboiled (25.6%). Women from both project and control groups reported typical travel times of 8 to 14 minutes to get eggs (where travel time=0 for those primarily sourcing eggs from their own flock). Despite high prevalence of village chicken ownership, women cited cost and physical availability as the primary barriers to routine consumption of eggs in their household. The majority of women responded that they liked eating eggs (94.%), 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). Just a handful of women said they believed in egg taboos for people with seizure disorders (n=5), infants or young children (n=3), any women (n=2), breastfeeding women (n=1), or elderly people (n=1).

Outcome 1: Did households access more eggs as a result of the program?

In project communities, the estimated conditional odds that a household consumed any eggs in the 7 days prior to the survey increased dramatically from baseline 2 to midline (OR 2.09, 95% CI 1.56-2.79, $p<0.001$), after production began in the EPCs (Figure 5.6a). By endline, ten months after egg production began, the odds of a household consuming any eggs had decreased, but remained significantly higher compared to the same season of the previous year at baseline 1 (OR 1.43, 95% CI 1.07-1.91, $p<0.015$). In contrast, in control communities, the odds that a household consumed any eggs in the 7 days prior to the survey did not change after egg production began ($p=0.598$ between baseline 2 and midline, $p=0.629$ between baseline 1 and endline). At midline, households in project areas were significantly more likely to have consumed eggs than in control areas (OR 1.49, 95% CI 1.10-2.03, $p=0.010$), but there was no difference between the two groups by endline ($p=0.556$), likely due to depressed egg production at the time of the endline survey (Appendix 15). At endline, 34.6% of respondents in the project areas indicated that low production was the main reason they hadn't bought eggs from the EPC recently; in contrast, at midline, this number was only 16.0%.

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 5.6b). Households located within 250 meters of the EPC were significantly more likely to consume any eggs at midline relative to baseline 2 (OR 3.54, 95% CI 2.21-5.70, $p<0.001$), while the odds ratio was smaller, yet still significant, for households located greater than 250 meters from the EPC (OR 1.49, 95% CI 1.03-2.16, p=0.034). There was no difference in the odds of egg consumption between baseline 1 and endline for households located within 250 meters (p=0.250) or beyond 250 meters (p=0.050). 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), while households located within project communities but greater than 250 meters from the EPC were not (p=0.183). By endline, however, there was no difference between either group and control areas (p=0.994 for households <250 meters; p=0.424 for households >250 meters).



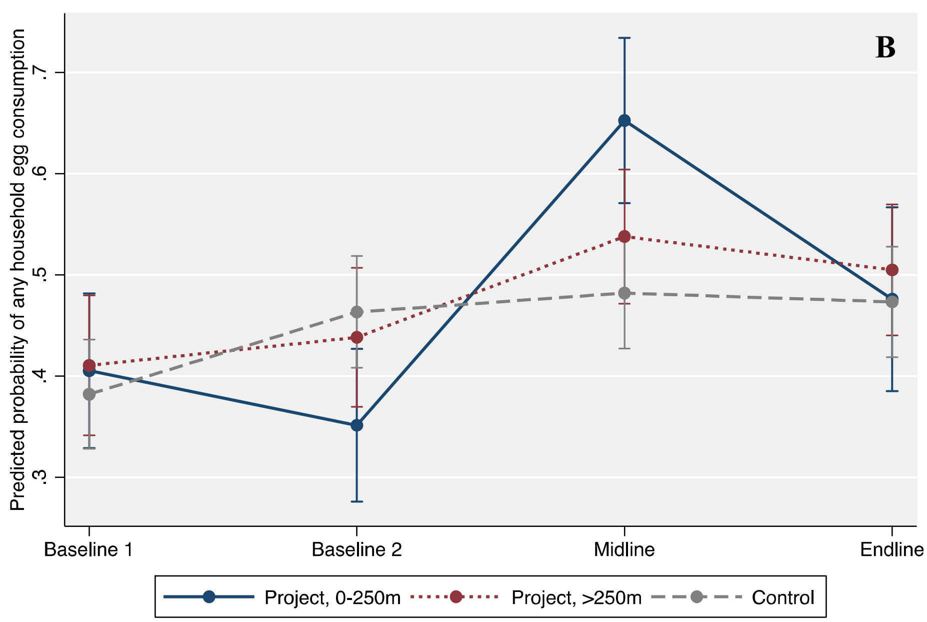


Figure 5.6. (a) Predicted probability and 95% confidence intervals of any household egg consumption in the 7 days prior to the survey in project (solid navy) and control (dashed gray) communities. (b) Predicted probability and 95% confidence intervals of any household egg consumption in the 7 days prior to the survey in households in project communities within 250 meters of an EPC (solid navy), in households in project communities greater than 250 meters from an EPC (dotted maroon), and control (dashed gray) communities with no EPC.

Outcomes 2 and 4: Did children eat more eggs and improve their dietary diversity as a result of the program?

In project communities, but not control communities, the estimated conditional odds that a child consumed any eggs increased significantly from baseline 2 to midline (OR 5.53, 95% CI 2.90-10.58, $p<0.001$) after the start of the egg production program (Figure 5.7a). There was no significant difference in the odds of egg consumption among children at endline relative to baseline 1 in either control ($p= 0.092$) or project ($p= 0.238$) communities. At midline, children living in project communities were significantly more likely to have consumed eggs than those in control areas (OR 2.29, 95% CI 1.22-4.29, $p=0.010$), but there was no difference between the groups at endline ($p=0.115$). Within project communities, the odds of egg consumption did not significantly differ by proximity of the household to the EPC at midline ($p= 0.525$) or endline ($p=0.582$; data not shown).

In truncated negative binomial regression models, among children consuming any eggs, the frequency of egg consumption in the past 7 days increased from baseline 2 to midline in both project ($\beta= 0.59$, 95% CI 0.31-0.87, $p<0.001$) and control ($\beta= 0.37$, 95% CI 0.02-0.71, $p=0.039$) communities (Figure 5.7b). There was no significant change from baseline 1 to endline in either project ($p=0.137$) or control ($p=0.087$) areas. The number of times children consumed eggs was not different among those living in project or control communities at midline ($p=0.870$) or endline ($p=0.165$). Within project communities, the proximity of a child's home did not affect the number of times they ate eggs at midline ($p=0.592$) or endline ($p=324$; data not shown).

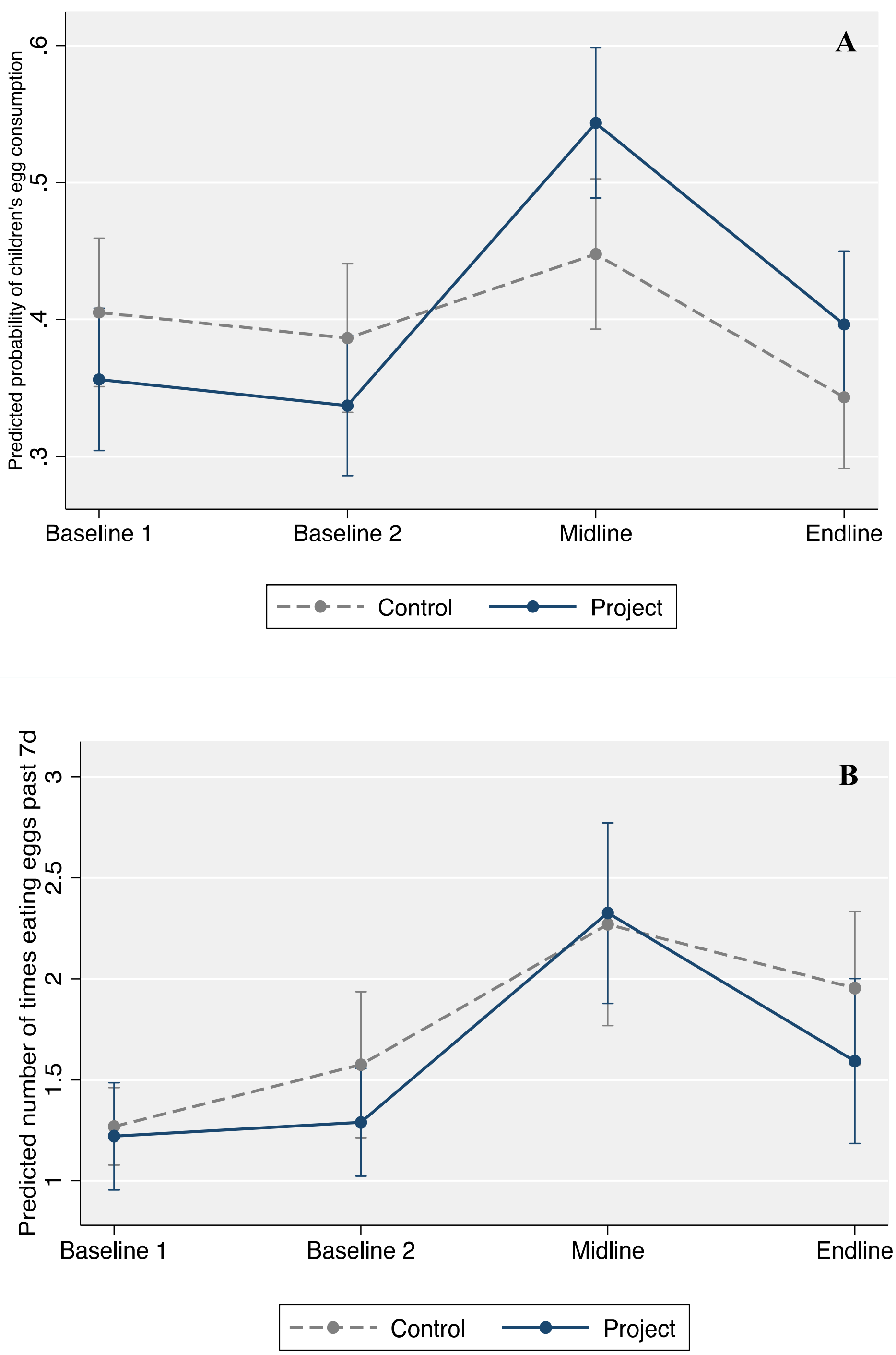


Figure 5.7. (a) Predicted probability and 95% confidence intervals of any child egg consumption in the 7 days prior to the survey in project (solid navy) and control (dashed gray) communities. (b) Among those consuming any eggs, predicted number of times children consumed eggs in the 7 days prior to the survey, in project and control communities.

Despite increased egg consumption, there was no difference in child dietary diversity between those living in project versus control communities at any of the four timepoints (p= 0.221, p= 0.882, p= 0.894, and p=0.890, consecutively). Overall dietary diversity among children declined significantly from baseline 1 to endline in both project (β= -0.63, p<0.001) and control communities (β= -0.49, p<0.001; Figure 5.8). There was no significant decline in dietary diversity from baseline 2 to midline in either project (p=0.150) or control (p=0.273) areas.

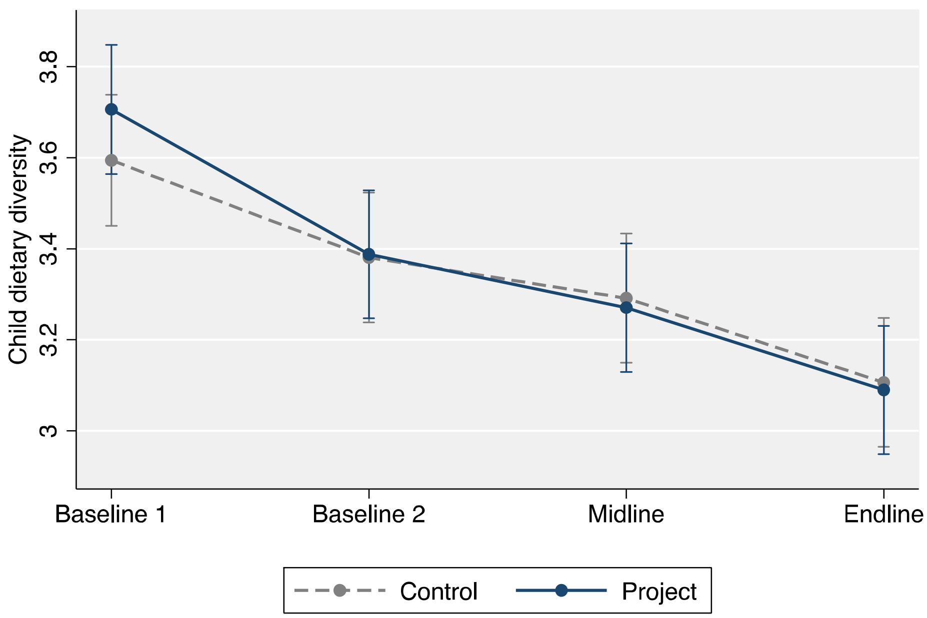


Figure 5.8. Predicted child dietary diversity and 95% confidence intervals in the 24 hours prior to the survey, in project (solid navy) and control (dashed gray) communities.

To investigate the source of this decline in dietary diversity, we ran seven additional models for each of the seven food groups in the children's dietary diversity score, controlling for clustering within communities. The results (Appendix 16) indicate dramatic changes in daily diets for children from both project and control areas over the four time points, with a net decrease in the probability that children consumed legumes or nuts, flesh foods, diary products, and other fruits and vegetables.

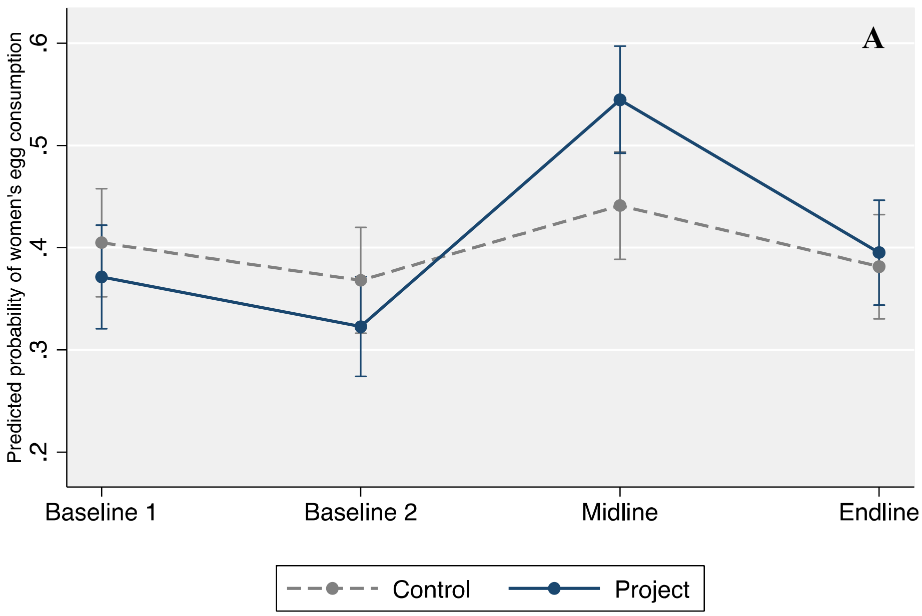
Outcomes 3 and 5: Did women eat more eggs and improve their dietary diversity as a result of the program?

In project communities, the estimated conditional odds that a woman consumed any eggs increased significantly from baseline 2 to midline (OR 3.18, 95% CI 1.87-5.41, $p<0.001$) after the start of the egg production program, but there was no significant change in control communities ($p=0.051$; Figure 5.9a). There was no significant difference in the odds of egg consumption among women at endline relative to baseline 1 in either control ($p= 0.509$) or project ($p= 0.478$) communities. Women living in project communities were significantly more likely to have consumed eggs at midline (OR 1.70, 95% CI 1.13-2.54, $p=0.011$), but there was no difference between the groups at endline ($p=0.701$). Within project communities, the odds of egg consumption did not significantly differ by proximity of the household to the EPC at midline ($p= 0.119$) or endline ($p=0.722$; data not shown).

In the truncated negative binomial regression model, among women consuming any eggs, the frequency of egg consumption in the past 7 days increased from baseline 2 to midline in both project ($\beta= 0.50$, 95% CI 0.11-0.90, $p=0.012$) and control ($\beta= 0.45$, 95% CI 0.17-0.73, $p=0.002$) communities (Figure 5.9b). Although the frequency of egg consumption declined by endline, it remained significantly higher than at baseline 1 in project areas ($\beta= 0.37$, 95% CI 0.01-0.72, $p=0.043$), but not control areas ($p=0.184$). The number of times women consumed eggs was not different among those living in project or control communities at midline ($p=0.460$) or endline ($p=0.919$).

Within project communities, the proximity of a woman's home to the EPCs did affect the frequency of egg consumption, which increased from baseline 2 to midline among those living within 250 m of the EPC ($\beta= 0.78$, 95% CI 0.34-1.23, $p=0.001$) but did not change among those living greater than 250 m away ($p=0.239$; data not shown). At midline, the frequency of egg consumption was higher among women living within 250 m of the EPC than among those living farther away ($\beta= 0.28$, 95% CI 0.01-0.55, $p=0.039$), but this difference was no longer apparent at endline ($p=0.847$).

As among children, there was no difference in women's dietary diversity between those living in project versus control communities at any timepoint ($p=0.595$, $p=0.964$, $p= 0.758$, $p=0.557$, consecutively). Overall dietary diversity among women declined significantly from baseline 1 to endline in both project ($\beta= -0.83$, $p<0.001$) and control communities ($\beta= -0.72$, $p<0.001$; Figure 5.10). There was a slight, non-significant increase in women's dietary diversity from baseline 2 to midline in project ($p=0.095$) and control (0.051) areas.



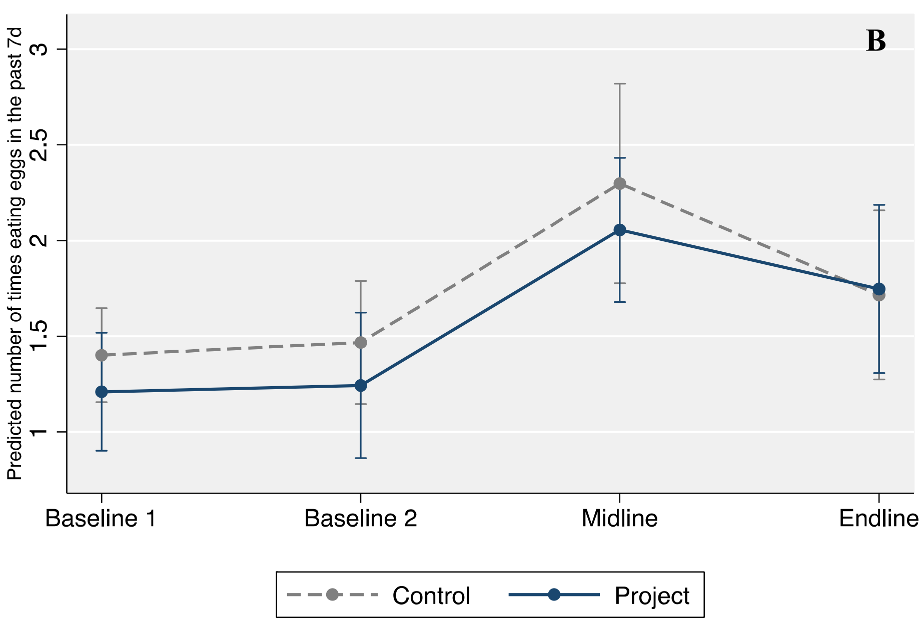


Figure 5.9. (a) Predicted probability and 95% confidence intervals of any egg consumption among women in the 7 days prior to the survey in project (solid navy) and control (dashed gray) communities. (b) Among those consuming any eggs, predicted number of times women consumed eggs in the 7 days prior to the survey, in project and control communities.

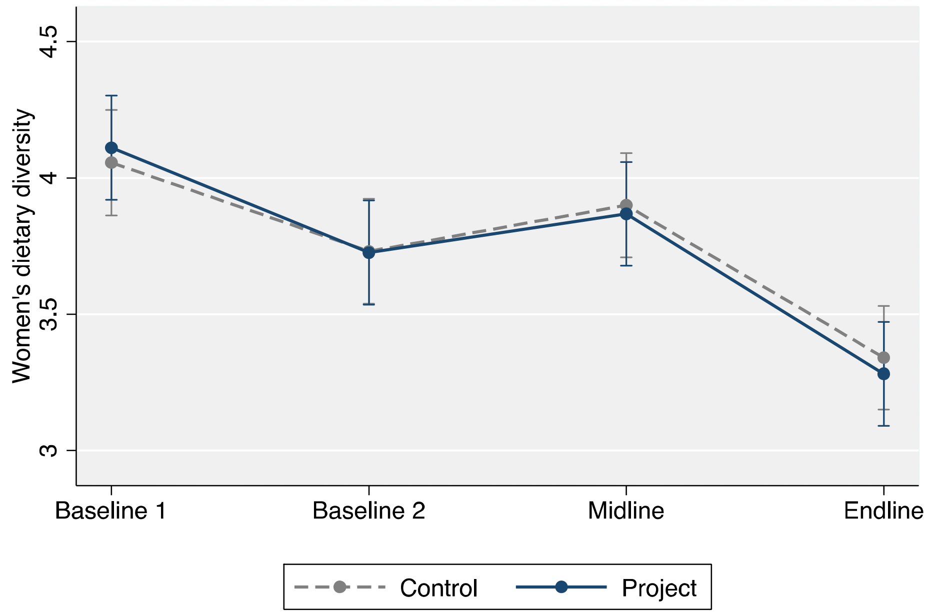


Figure 5.10. Predicted women's dietary diversity and 95% confidence intervals in the 24 hours prior to the survey, in project (solid navy) and control (dashed gray) communities.

Outcome 6: Did the program 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 (p= 0.906, p= 0.827, p= 0.565, and p= 0.241, consecutively; Figure 5.11). Children's HAZ was not significantly different in either project or control areas from baseline 2 to midline (p= 0.069 project and p= 0.375 control). HAZ increased significantly from baseline 1 to endline in control areas (β= 0.20, 95% CI 0.02-0.38, p=0.027), but the change was not significantly different from that in project areas. There was no significant change in HAZ from baseline 1 to endline in project areas (p=0.439).

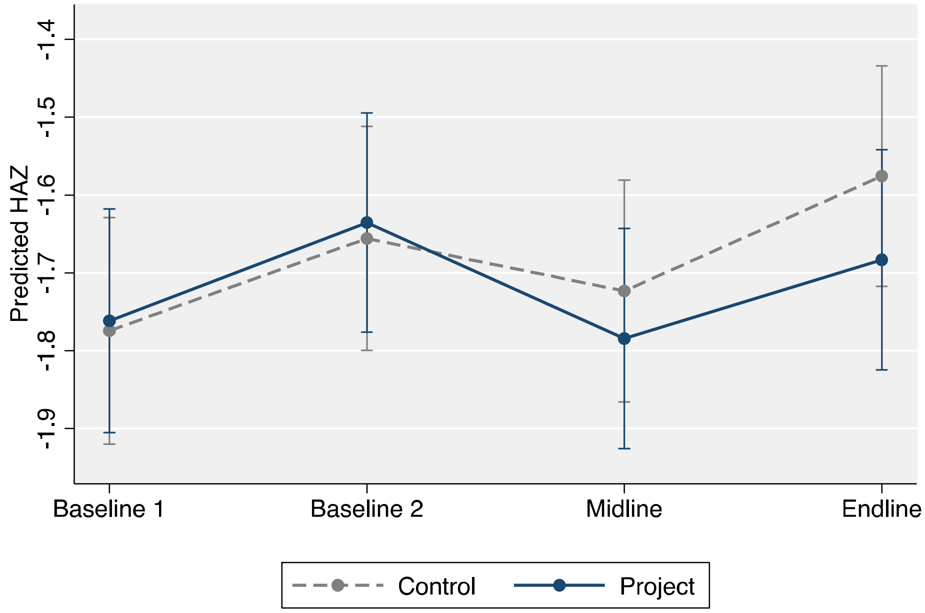


Figure 5.11. Predicted child height-for-age z-scores (HAZ) for children 6-36 months living in project (solid navy) and control (dashed gray) communities. HAZ did not differ between groups at any time point, and there was no significant effect of the project on HAZ in either group (comparing baseline 2 to midline, and baseline 1 to endline).

Discussion

In summary, the market-based EPC program in rural Zambia successfully increased the acquisition and consumption of eggs by households, women, and young children in the surrounding communities, though the impact was attenuated at endline due to declining production in the EPCs. At the household level, those located within 250 m of an EPC were most likely to benefit from the program; however, distance of the home from the EPC did not modify the impact of the program on women's and children's individual odds of egg consumption. Interestingly, while the program successfully increased the *odds* of egg consumption among women and children, the *number of times* they ate eggs increased in both project and control communities after the start of the program, making it difficult to attribute the change in the intensity of egg consumption to the program. Increased egg consumption by women and children did not translate into greater individual dietary diversity, however, and, as predicted, no evidence was found for program impact on child HAZ (Table 5.3).

Table 5.3. Key findings and implications for future programming and research

<table>
<tr><th>Key findings:</th><th>Programmatic implications and recommendations for further research:</th></tr>
<tr><td>Household acquisition of eggs increased significantly as a result of the program, particularly among households located very close to the EPCs and when egg production was high</td><td rowspan="2">• Address production limitations in low-performing EPCs
• Reassess program impact on egg acquisition and consumption within highest-performing EPC areas (or in subsequent years, after optimal performance has been achieved) to better understand potential impact
• Conduct market research to analyze customer demand, market size, and buyer behavior (e.g. distance people will travel to buy eggs at an EPC, willingness to pay, ideal frequency of egg consumption)
• During scaling-up, build and stock EPCs based on market research to optimally serve and meet demand within the target market</td></tr>
<tr><td>Women and children were significantly more likely to eat eggs as a result of the program, but only when egg production within the EPCs was high</td></tr>
<tr><td>It is unclear if women and children consumed more eggs as a result of the program</td><td>• Investigate local intra-household food allocation practices and potential barriers to individual ASF consumption among women and children
• Integrate the EPC program with nutrition-specific interventions (counseling on optimal maternal, infant, and young child feeding practices)
• Consider integration with a voucher program to subsidize egg consumption by pregnant/lactating women, infants, and young children to eliminate inability to pay as a barrier to egg consumption</td></tr>
<tr><td>Despite increased odds of egg consumption, overall dietary diversity among women and children decreased over time, likely as a result of poor harvests compared to in the baseline year</td><td rowspan="2">• Longer follow-up time (at least 1000 days of exposure, from conception to 2 years of age), with evaluations focused on children less than 24 months of age
• Closer examination of local agricultural conditions, crop yields, and household food expenditures
• Assess program impact on alternative measures of dietary quality, including micronutrient adequacy</td></tr>
<tr><td>There was no impact on child HAZ in the first year of the program</td></tr>
</table>

Although these analyses revealed a significant positive effect of the program on egg acquisition and consumption at midline, the impact was dramatically attenuated by endline. Anecdotally, demand for eggs in the participating communities remained high, and the most likely cause of diminished egg acquisition and consumption was poor production in the EPCs at the time of the endline survey (Appendix 15). From the time of the midline survey in December 2015 to the endline survey in June 2016, mean egg production dropped 46% across all EPCs, from an average of 800.6 eggs/ EPC/ month to just 425.6 eggs/ EPC/ month (Appendix 15). Decreased egg production over time is expected as hens age, but in most EPCs, production was below industry standards throughout the year, especially by June 2016. Production challenges included inconsistent feeding, suboptimal husbandry and biosecurity practices, and adverse weather conditions (see Chapter 4). Nonetheless, some EPCs performed extraordinarily well, meeting industry benchmarks for performance despite difficult conditions (Chapter 4). As such, we recommend further examination of the program's impact on egg acquisition and consumption within a subset of the highest performing EPC areas in order to better quantify the program's potential to improve community diets when program delivery and performance is optimized. Additionally, prior to scaling up, market research is needed to analyze demand, market size, and buyer behaviors (e.g. distance people will travel to buy eggs at an EPC, ideal frequency of egg consumption) such that EPCs can be built and stocked appropriately to meet the demand of the target market.

The finding that proximity of the household to the EPC modified the odds of household egg acquisition but not egg consumption by women and children is notable. Previous reviews of livestock development interventions have suggested that programs integrated with nutrition education have had the greatest impact on dietary intake and nutritional status (Leroy & Frongillo, 2007; Randolph et al., 2007). Although behavior change communication was not delivered by COMACO as a program input, EPC group members were encouraged to promote the health benefits of eggs for young children and women of reproductive age as part of their marketing strategy. Their efforts, combined with incidental transfer of knowledge during the recruitment process for the survey, may have incentivized individuals to travel a greater distance in order to provide eggs specifically to women and young children in their households. In contrast, homes located very close to the EPC may have been motivated partially by convenience to buy eggs for the entire family. A better understanding of the pathway from ASF availability to household ASF acquisition, intra-household allocation, and individual consumption of ASF in this context, as well as food consumption surveys that include households without young children, is needed to explore this hypothesis.

Although the program successfully increased the odds of egg consumption by women and children living in intervention areas relative to those in control areas, it was interesting that the number of eggs they consumed increased in both project and control areas equally. Put another way, in project areas, a greater proportion of individuals were consuming eggs and they were also consuming eggs more frequently after the program began. In control areas, in contrast, the proportion of individuals who ate eggs did not change, but among those who consumed any eggs, each individual ate eggs more often after the start of the program. There is anecdotal evidence that, although located an average of 5 km from their homes, some people from control areas purchased eggs at the EPCs, suggesting contamination of the control group. Most likely, this contamination was selective, meaning that only a subset of households in the control area purchased eggs at the EPCs. Indeed, at endline, 38.4% of respondents in the project areas indicated that they bought eggs from their community EPC "often" or "sometimes", while just 5.1% of respondents in control areas said the same. This selective contamination may have been driven by strong personal food preferences or high demand within a subset of households in the control areas. Before the EPC program, these households may have gone to great lengths to find eggs, and the intervention may have allowed them to consume eggs even more frequently or purchase them in bulk. Alternatively, selective contamination could be the result of a few households passing through the project communities frequently (e.g. en route to their fields or work place, to visit family), meaning those households had essentially the same physical access to eggs produced by the EPC as those living in the project communities. There may also be a ceiling effect for how many times an individual is able to or wants to consume eggs in a single week. This could be driven by the small size of the EPCs (which only produced a maximum of 40 eggs per day at peak production), low productivity in some EPCs, personal preference, cultural norms, or one's financial ability to pay.

Due to resource and time constraints, the follow up time for the impact evaluation was just one year. Unfortunately, this short time frame for evaluation does not match the lengthy pathway from program implementation to improved nutritional status and growth that is expected in nutrition sensitive programs, which likely requires at least 1000 days of program exposure to achieve full impact (Leroy et al., 2016; Miller et al., 2016). It is therefore not surprising that we were unable to measure an impact of the EPC program on child HAZ. However, it was unexpected that we were unable to establish a link between increased odds of egg consumption in the previous seven days and improved dietary diversity scores in the previous 24 hours. In part, this may be due to differing recall times; indeed, the probability that a child consumed any ASF in the previous seven days increased nearly 10 percentage points (from 81.9% to 91.6% of children) from baseline 2 to midline, a change entirely due to greater egg consumption in these areas (Appendix 17). Alternatively, eggs may have partially replaced other high-quality components of the diet, such as meat, fish, dairy, or legumes, resulting in an attenuated or even net-zero effect of the program on dietary quality. There was some evidence that the probability of meat and dairy consumption decreased at midline and endline, while consumption of legumes and nuts dropped dramatically at baseline 2 and midline before partially rebounding at endline (Appendices 16 and 17).

As a whole, Zambia experienced record maize production in the 2013-2014 season (harvest April – June 2014; [*Zambia Corn Production by Year*, 2017]). Given that maize is the primary crop grown in the Luangwa Valley, this likely translated into higher than expected incomes for most households in our sample, subsequently affecting their food expenditures and consumption habits throughout 2014. In contrast, in 2015, maize harvest decreased 22% over the previous year (*Zambia Corn Production by Year*, 2017), which could explain the lower consumption of meat, legumes and nuts, and dairy in December 2015 compared to December 2014. This might additionally explain the high consumption of vitamin A rich fruits and vegetable at midline relative to baseline 2, which included a 45% increase in the proportion of children consuming mangoes, which are readily harvested from the wild, and a 17% increase in the proportion of children consuming leafy greens, which can be both readily harvested from the wild or very inexpensively purchased. A closer examination of local agricultural conditions (e.g. local rainfall, temperatures, pests, destruction of crops by wildlife or fire), crop yields, and food expenditures is needed to better understand the cause of the intra-seasonal variation in food group consumption documented here.

If increased consumption of eggs did indeed come at the expense of meat consumption, this finding might also suggest that the EPC program could be an effective complement to conservation efforts if it limits the incentive to engage in wildlife hunting and unsustainable fishing practices. Some observational research has found that consumption of wildlife is associated with decreased availability of alternative ASF from fisheries and livestock production

(Brashares et al., 2004; Loibooki et al., 2002; Rentsch & Damon, 2013; Van Vliet, 2011). Developing alternative ASF sources to replace bushmeat has proved challenging, however (Cawthorn & Hoffman, 2015), and to our knowledge, there is no research directly evaluating the impact of a livestock development program on local wildlife consumption. Further research should explore how demand, prices, sources, and consumption patterns of different types of ASF change in the context of the EPC program to better understand the program's potential to curb unsustainable wildlife harvesting practices.

Although this study has many strengths in its design, including controlling for season and analyzing intermediate outcomes, there are some limitations that should be considered. First, a cluster randomized controlled trial is the gold standard for impact evaluations, because it reasonably ensures that the control group is a valid counterfactual for the intervention group (Leroy et al., 2016). Here, due to COMACO's internal program goals and resource availability and allocation targets, randomization was not possible, and a quasi-experimental approach with repeated cross-sectional surveys was instead taken. 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 (see Table 5.2). 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, such as community density and size, proximity to wildlife resources or markets, and access to or participation in other agriculture, health, or nutrition programs.

Second, although there is strong evidence that conception to 24 months is the key window of opportunity for maximizing the impact of nutrition interventions, children up to 36 month were enrolled in the study due to the small size of villages in the study area. Although safe for young children (Iannotti et al., 2014), the probability of egg consumption in this sample was significantly lower for children 6-12 months compared to older children (data not shown), and a secondary analysis of how age modified the program's impact is justified.

A third limitation to this analysis is that the evaluation was conducted in the first year of the program, during which time only 40 hens were placed in each EPC and egg production was at times below expected levels due to problems with feed production, biosecurity, and management (see Chapter 4). As a result, there were fewer eggs available in project communities and demand often exceeded supply. Anecdotally, the most common complaint from community members about the program was that the EPCs were too often sold out of eggs by the time they went to purchase them, and EPC owners reported that there were often "waiting lists" for eggs that had not yet been produced. By the endline survey, when egg production was particularly low, 34.6% of respondents in the project areas indicated that low production was the main reason they had not bought eggs from the EPC recently. As a result, the program likely did not achieve optimal impact in its first year, and a repeated evaluation after the program has reached its highest level of quality/production is warranted.

Despite the promising theoretical links between poultry production and improved maternal and child nutritional outcomes, there is limited high-quality research to support these links in practice (Table 5.1). The EPC program investigated here adds to the empirical evidence, in part by addressing some of the pitfalls of previous livestock interventions: it avoided contributing to women's time poverty by distributing inputs to groups of farmers rather than households; it limited children's exposure to zoonotic pathogens by designing a confined poultry system and training EPC members in proper hygiene practices; and it was integrated with extension support that provided program beneficiaries with access to feed, vaccination and veterinary services, and ongoing support to maximize productivity. Additionally, an important and unique element of the EPC program is that it aims to improve the local food environment and therefore benefit the entire community. Previous research has focused exclusively on the impact of *homestead*-based poultry programs on consumption of ASF *by the program 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 – women and children living in the surrounding community who were not necessarily direct beneficiaries of the program (i.e. they did not receive any training or inputs). Finally, women represented >80% of program beneficiaries, and although not investigated here, previous research has suggested that targeting women to receive livestock interventions may confer additional social good by empowering women with skills, knowledge, and assets, delivering long-term impact on their and their children's wellbeing (Leroy & Frongillo, 2007; Randolph et al., 2007). Given the positive short-term impact of the program on egg consumption among women and children, we encourage continued evaluation of the program at a larger scale, ideally integrated with a comprehensive nutrition education program, to investigate the program's long-term impacts on dietary quality, micronutrient adequacy, women's empowerment, and child growth and development.

References

Adair, L. S., Fall, C. H., Osmond, C., Stein, A. D., Martorell, R., Ramirez-Zea, M., et al. (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: Findings from five birth cohort studies. *The Lancet*, *382*(9891), 525–534.

Afifi, A. A., Kotlerman, J. B., Ettner, S. L., & Cowan, M. (2007). Methods for improving regression analysis for skewed continuous or counted responses. *Annual Review of Public*

Health, *28*(1), 95–111.

AIDSinfo. (2017, September 13). *Country Factsheets, Zambia 2015*. UNAIDS. Retrieved from http://aidsinfo.unaids.org/

Alders, R. G., & Pym, R. (2009). Village poultry: Still important to millions, eight thousand years after domestication. *World's Poultry Science Journal*, *65*(02), 181–190.

Allen, L. H. (1993). The Nutrition CRSP: What is marginal malnutrition, and does it affect human function? *Nutrition Reviews*, *51*(9), 255–267.

Allen, L. H. (2003). Interventions for micronutrient deficiency control in developing countries: Past, present and future. *The Journal of Nutrition*, *133*(11), 3875S–3878S.

Allen, L. H. (2012). Global dietary patterns and diets in childhood: Implications for health outcomes. *Annals of Nutrition and Metabolism*, *61*(s1), 29–37.

Allen, L. H., Backstrand, J. R., & Stanek, E. J. (1992). The interactive effects of dietary quality on the growth and attained size of young Mexican children. *The American Journal of Clinical Nutrition*, *56*, 353–364.

Appoh, L. Y., & Krekling, S. (2005). Maternal nutritional knowledge and child nutritional status in the Volta region of Ghana. *Maternal & Child Nutrition*, *1*(2), 100–110.

Arimond, M., & Ruel, M. T. (2004). Dietary diversity is associated with child nutritional status: Evidence from 11 Demographic and Health Surveys. *The Journal of Nutrition*, *134*(10), 2579–2585.

Arimond, M., Wiesmann, D., Becquey, E., Carriquiry, A., Daniels, M. C., Deitchler, M., et al. (2010). Simple food group diversity indicators predict micronutrient adequacy of women's diets in 5 diverse, resource-poor settings. *The Journal of Nutrition*, *140*(11), 2059S–2069S.

Atkins, D. C., Baldwin, S. A., Zheng, C., Gallop, R. J., & Neighbors, C. (2013). A tutorial on count regression and zero-altered count models for longitudinal substance use data. *Psychology of Addictive Behaviors*, *27*(1), 166–177.

Baldwin, K. (2015). *The paradox of traditional chiefs in democratic Africa*. Cambridge, England: Cambridge University Press.

Ballard, T., Coates, J., Swindale, A., & Deitchler, M. (2012). *Household Hunger Scale: Indicator definition and measurement guide.* Washington, D.C.: FHI360 and Food and Nutrition Technical Assistance Project (FANTA).

Bjørnskov, C. (2010). How comparable are the Gallup World Poll life satisfaction data? *Journal of Happiness Studies*, *11*(1), 41–60.

Black, R. E., Allen, L. H., Bhutta, Z. A., Caulfield, L. E., de Onis, M., Ezzati, M., et al. (2008). Maternal and child undernutrition: Global and regional exposures and health consequences. *The Lancet*, *371*, 243–260.

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet*, *382*(9890), 427–451.

Booysen, F., van der Berg, S., Burger, R., Maltitz, M. V., & Rand, G. D. (2008). Using an asset index to assess trends in poverty in seven sub-Saharan African countries. *World Development*, *36*(6), 1113–1130. doi:10.1016/j.worlddev.2007.10.008

Brashares, J. S., Arcese, P., Sam, M. K., Coppolillo, P. B., Sinclair, A. R. E., & Balmford, A. (2004). Bushmeat hunting, wildlife declines, and fish supply in West Africa. *Science*, *306*(5699), 1180–1183. doi:10.1126/science.1102425

Cawthorn, D. M., & Hoffman, L. C. (2015). The bushmeat and food security nexus: A global account of the contributions, conundrums and ethical collisions. *Food Research International*, *76*(P4), 906–925. doi:10.1016/j.foodres.2015.03.025

Central Statistical Office (CSO), Ministry of Health (MOH), ICF International. (2015). Zambia Demographic and Health Survey 2013-14. Rockville, MA, USA: CSO, MOH, and ICF International.

Central Statistical Office (CSO), Ministry of Health (MOH), Tropical Diseases Research Centre (TDRC), University of Zambia, Macro International Inc. (2009). Zambia Demographic and Health Survey 2007. Calverton, Maryland: CSO and Macro International Inc.

Coates, J., Swindale, A., & Bilinsky, P. (2007). *Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide (v. 3)*. Washington D.C.: FHI360 and FANTA.

Cogill, B. (2003). *Anthropometric Indicators Measurement Guide.* Washington D.C.: Food and Nutrition Technical Assistance Project (FANTA), Academy for Educational Development.

Community Markets for Conservation (COMACO). (2014). *Community Markets for Conservation: Project Description Document for 2014-2018*. Lusaka, Zambia: COMACO.

Dalal-Clayton, B., & Child, B. (2003). *Lessons from Luangwa: The story of the Luangwa integrated resource development project, Zambia.* London: International Institute for Environment and Development (IIED).

Darapheak, C., Takano, T., Kizuki, M., Nakamura, K., & Seino, K. (2013). Consumption of animal source foods and dietary diversity reduce stunting in children in Cambodia. *International Archives of Medicine*, *6*(1), 1–1. doi:10.1186/1755-7682-6-29

de Onis, M., & Branca, F. (2016). Childhood stunting: a global perspective. *Maternal & Child Nutrition*, *12*(S1), 12–26. doi:10.1111/mcn.12231

Dolberg, F. (2003). Review of household poultry production as a tool in poverty reduction with focus on Bangladesh and India. *FAO Pro-Poor Livestock Policy Initiative* (Working Paper No. 6). Retrieved from http://ageconsearch.umn.edu/bitstream/23762/1/wp030006.pdf

Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, *32*(3), 227–243.

Dumas, S. E., Lungu, L., Mulambya, N., Daka, W., McDonald, E., Steubing, E., et al. (2016). Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia. *Food Security*, *8*, 507–520. doi:10.1007/s12571-016-0579-5

Fenn, B., Morris, S. S., & Frost, C. (2007). Do childhood growth indicators in developing countries cluster? Implications for intervention strategies. *Public Health Nutrition*, *7*(07), 829–834. doi:10.1079/PHN2004632

Filmer, D., & Pritchett, L. H. (2001). Estimating wealth effects without expenditure data - or tears: An application to educational enrollments in states of India. *Demography*, *38*(1), 115–132.

FAO, IFAD, and WFP. (2015). *The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress.* Rome: FAO.

FAOSTAT Database. (2017, August 4). Retrieved from http://faostat3.fao.org/home/E

Galal, O. M., Harrison, G. G., Abdou, A. I., & Abedin, El, A. Z. (1987). The impact of a small-scale agricultural intervention on socio-economic and health status. *Food and Nutrition*, *13*(1), 35–43.

Gallup. (2012). *Global states of mind: New metrics for world leaders.* Retrieved from http://www.gallup.com/services/176381/global-states-mind-new-metrics-world-leaders.aspx

George, C. M., Oldja, L., Biswas, S. K., Perin, J., Lee, G. O., Ahmed, S., et al. (2015a). Fecal markers of environmental enteropathy are associated with animal exposure and caregiver hygiene in Bangladesh. *American Journal of Tropical Medicine and Hygiene*, *93*(2), 269–275. doi:10.4269/ajtmh.14-0694

George, C. M., Oldja, L., Biswas, S., Perin, J., Lee, G. O., Kosek, M., et al. (2015b). Geophagy is associated with environmental enteropathy and stunting in children in rural Bangladesh. *American Journal of Tropical Medicine and Hygiene*, *92*(6), 1117–1124. doi:10.4269/ajtmh.14-0672

Gittelsohn, J., & Vastine, A. E. (2003). Sociocultural and household factors impacting on the selection, allocation and consumption of animal source foods: Current knowledge and application. *The Journal of Nutrition*, *133*(11), 4036S–4041S.

Government of the Republic of Zambia, United Nations Development Programme (UNDP). (2010). *Adaptation to the effects of drought and climate change in Agro-ecological Regions I and II in Zambia* (No. PIMS No. 3942). Lusaka, Zambia: United Nations Development Programme.

Grillenberger, M., Neumann, C. G., Murphy, S. P., Bwibo, N. O., Weiss, R. E., Jiang, L., et al. (2006). Intake of micronutrients high in animal-source foods is associated with better growth in rural Kenyan school children. *British Journal of Nutrition*, *95*(02), 379–390. doi:10.1079/BJN20051641

Grosse, S. D. (1999). Farm animals and children's nutritional status in rural Rwanda. Presented at Symposium on Human Nutrition and Livestock in the Developing World, 1998, October 14, (pp. 190–200). Little Rock, AR: Heifer Project International.

Gueye, E. F. (2000a). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on Agriculture*, *29*(2), 129–136.

Gueye, E. F. (2000b). Women and family poultry production in rural Africa. *Development in Practice*, *10*(1), 98–102. doi:10.1080/09614520052565

Headey, D., & Hirvonen, K. (2016). Is exposure to poultry harmful to child nutrition? An observational analysis for rural Ethiopia. *PloS One*, *11*(8), e0160590–16. doi:10.1371/journal.pone.0160590

Herrador, Z., Sordo, L., Gadisa, E., Moreno, J., Nieto, J., Benito, A., et al. (2014). Cross-sectional study of malnutrition and associated factors among school aged children in rural and urban settings of Fogera and Libo Kemkem Districts, Ethiopia. *PloS One*, *9*(9), e105880–11. doi:10.1371/journal.pone.0105880

Herrero, M., Grace, D., Njuki, J. M., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. *Animal*, *7*(s1), 3–18. doi:10.1017/S1751731112001954

Hoddinott, J., Headey, D., & Dereje, M. (2015). Cows, missing milk markets, and nutrition in rural Ethiopia. *Journal of Development Studies*, *51*(8), 958–975. doi:10.1080/00220388.2015.1018903

Hoffine, T. (2013). *Zambia Food Security Brief.* USAID Famine Early Warning Systems Network (FEWS NET). Retrieved from http://www.fews.net/southern-africa/zambia/food-security-brief/march-2014

Hu, M. C., Pavlicova, M., & Nunes, E. V. (2011). Zero-inflated and hurdle models of count data with extra zeros: Examples from an HIV-risk reduction intervention trial. *The American Journal of Drug and Alcohol Abuse*, *37*(5), 367–375. doi:10.3109/00952990.2011.597280

Human Development Report 2016: Zambia. (2017). *Human Development Report 2016: Zambia.* New York: United Nations Development Programme (UNDP).

Iannotti, L. L., Lutter, C. K., Bunn, D. A., & Stewart, C. P. (2014). Eggs: The uncracked potential for improving maternal and young child nutrition among the world's poor. *Nutrition Reviews*, *72*(6), 355–368. doi:10.1111/nure.12107

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., et al. (2017). Eggs in early complementary feeding and child growth: A randomized controlled trial. *Pediatrics*, e20163459. doi:10.1542/peds.2016-3459

Kennedy, G., Ballard, T., & Dop, M. C. (2011). *Guidelines for measuring household and individual dietary diversity.* FAO. Retrieved from http://www.fao.org/3/a-i1983e.pdf

Knueppel, D., Cardona, C., Msoffe, P., Demment, M. W., & Kaiser, L. (2010). Impact of vaccination against chicken Newcastle disease on food intake and food security in rural households in Tanzania. *Food and Nutrition Bulletin*, *31*(3), 436–445.

Krasevec, J., An, X., Kumapley, R., Bégin, F., & Frongillo, E. A. (2017). Diet quality and risk of stunting among infants and young children in low- and middle-income countries. *Maternal & Child Nutrition*, *13*(Suppl 3), e12430–11.

Krebs, N. F., Mazariegos, M., Tshefu, A., Bose, C., Sami, N., Chomba, E., et al. (2011). Meat consumption is associated with less stunting among toddlers in four diverse low-income settings. *Food and Nutrition Bulletin*, *32*(3), 185–191.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition*, *137*(10), 2311–2316.

Leroy, J. L., Olney, D. K., & Ruel, M. T. (2016). Evaluating nutrition-sensitive programs: Challenges, methods, and opportunities. In N. Covic & S. L. Hendriks (Eds.), *Achieving a Nutrition Revolution for Africa The Road to Healthier Diets and Optimal Nutrition* (pp. 130–146). ReSAKSS Annual Trends and Outlook Report 2015. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences*, *108*(34), 13957–13962. doi:10.1073/pnas.1011538108

Lien, D. T. K., Nhung, B. T., Khan, N. C., Hop, L. T., Nga, N. T. Q., Hung, N. T., et al. (2009). Impact of milk consumption on performance and health of primary school children in rural Vietnam. *Asia Pacific Journal of Clinical Nutrition*, *18*(3), 326–334.

Loibooki, M., Hofer, H., Campbell, K. L. I., & East, M. L. (2002). Bushmeat hunting by communities adjacent to the Serengeti National Park, Tanzania: The importance of livestock ownership and alternative sources of protein and income. *Environmental Conservation*, *29*(3), 391–398. doi:10.1017/S0376892902000279

Long, J. K., Murphy, S. P., Weiss, R. E., Nyerere, S., Bwibo, N. O., & Neumann, C. G. (2011). Meat and milk intakes and toddler growth: a comparison feeding intervention of animal-source foods in rural Kenya. *Public Health Nutrition*, *15*(06), 1100–1107.

MacDonald, A. C., Main, B. J., Namarika, R. H., Yiannakis, M. E., & Mildon, A. M. (2011). Small-animal revolving funds: an innovative programming model to increase access to and consumption of animal-source foods by rural households in Malawi. In B. Thompson & L. Amoroso (Eds.), *Combating Micronutrient Deficiencies: Food-based Approaches* (pp. 137–149). Rome: FAO and CAB International.

Marquis, G. S., Ventura, G., Gilman, R. H., Porras, E., Miranda, E., Carbajal, L., & Pentafiel, M. (1990). Fecal contamination of shanty town toddlers in households with non-corralled poultry, Lima, Peru. *American Journal of Public Health*, *80*(2), 146–149.

Miller, L. C., Joshi, N., Lohani, M., Rogers, B., Kershaw, M., Houser, R., et al. (2016). Duration of programme exposure is associated with improved outcomes in nutrition and health: the case for longer project cycles from intervention experience in rural Nepal. *Journal of Development Effectiveness*, *9*(1), 101–119. http://doi.org/10.1080/19439342.2016.1231706

Murphy, S. P., & Allen, L. H. (2003). Nutritional importance of animal source foods. *The Journal of Nutrition*, *133*(11), 3932S–3935S.

Neumann, C. G., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research*, *22*(1-2), 193–220. doi:10.1016/s0271-5317(01)00374-8

Neumann, C. G., Jiang, L., Weiss, R. E., Grillenberger, M., Gewa, C. A., Siekmann, J. H., et al. (2013). Meat supplementation increases arm muscle area in Kenyan schoolchildren. *British Journal of Nutrition*, *109*(07), 1230–1240. doi:10.1017/S0007114512003121

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., et al. (2013). Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to fecal bacteria. *American Journal of Tropical Medicine and Hygiene*, *89*(4), 709–716. doi:10.4269/ajtmh.12-0568

Nicholson, C. F., Mwangi, L., Staal, S. J., & Thornton, P. K. (2003). Dairy cow ownership and child nutritional status in Kenya. Presented at the AAEA Annual Meetings, Montreal, Quebec, Canada, July 27-30.

Nielsen, H. (1996). Socio-economic impact of smallholder livestock development project, Bangladesh (pp. 64–70). Presented at the Integrated Farming in Human Development Workshop Report. Danish Agricultural and Rural Development Advisers Forum, Tune Landboskole, Denmark.

Nielsen, H., Roos, N., & Thilsted, S. H. (2003). The impact of semi-scavenging poultry production on the consumption of animal source foods by women and girls in Bangladesh. *The Journal of Nutrition*, *133*(11 Suppl 2), 4027S–4030S.

OECD. (2013). OECD guidelines on measuring subjective well-being. Paris: OECD Publishing. Retrieved from http://dx.doi.org/10.1787/9789264191655-en

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. *Food and Nutrition Bulletin*, *30*(4), 355–369.

Olney, D. K., Vicheka, S., Kro, M., & Chakriya, C. (2013). Using program impact pathways to understand and improve program delivery, utilization, and potential for impact of Helen

Keller International's Homestead Food Production Program in Cambodia. *Food and Nutrition Bulletin*, *34*(2), 169–184.

Pachon, H., Simondon, K. B., Fall, S. T., Menon, P., Ruel, M. T., Hotz, C., et al. (2007). Constraints on the delivery of animal-source foods to infants and young children: Case studies from five countries. *Food and Nutrition Bulletin*, *28*(2), 215–229.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., et al. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800. doi:10.2527/jas.2007-0467

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., & Wydick, B. (2014). Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy*, *44*(C), 202–213. doi:10.1016/j.foodpol.2013.12.003

Rentsch, D., & Damon, A. (2013). Prices, poaching, and protein alternatives: An analysis of bushmeat consumption around Serengeti National Park, Tanzania. *Ecological Economics*, *91*(C), 1–9. doi:10.1016/j.ecolecon.2013.03.021

Rossen, L. M., Khan, D., & Warner, M. (2013). Trends and geographic patterns in drug-poisoning death rates in the U.S., 1999–2009. *American Journal of Preventive Medicine*, *45*(6), e19–e25. doi:10.1016/j.amepre.2013.07.012

Rutterford, C., Copas, A., & Eldridge, S. (2015). Methods for sample size determination in cluster randomized trials. *International Journal of Epidemiology*, *44*(3), 1051–1067. http://doi.org/10.1093/ije/dyv113

Sahn, D. E., & Stifel, D. (2003). Exploring alternative measures of welfare in the absence of expenditure data. *Review of Income and Wealth*, *49*(4), 463–489. doi:10.1111/j.0034-6586.2003.00100.x

Sigman, M., McDonald, M. A., Neumann, C. G., & Bwibo, N. (1991). Prediction of cognitive competence in Kenyan children from toddler nutrition, family characteristics and abilities. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *32*(2), 307–320.

Stewart, C. P., Iannotti, L. L., Dewey, K. G., Michaelsen, K. F., & Onyango, A. W. (2013). Contextualising complementary feeding in a broader framework for stunting prevention. *Maternal & Child Nutrition*, *9*(4), 27–45. doi:10.1111/mcn.12088

Steyn, N. P., Nel, J. H., Nantel, G., Kennedy, G., & Labadarios, D. (2007). Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? *Public Health Nutrition*, *9*(05), 156–7. http://doi.org/10.1079/PHN2005912

Talukder, A., Haselow, N. J., Osei, A. K., Villate, E., Reario, D., Kroeun, H., et al. (2010). Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations: Lessons learned from scaling-up programs in Asia (Bangladesh, Cambodia, Nepal and Philippines). *Field Actions Science Report*, 1–9. Retrieved from http://factsreports.revues.org/404?file=1

UNICEF, World Health Organization (WHO), The World Bank. (2016). *Levels and trends in child malnutrition: Joint child malnutrition estimates.* New York: UNICEF, WHO and World Bank Group.

Van Vliet, N. (2011). Livelihood alternatives for the unsustainable use of bushmeat. Report prepared for the CBD Bushmeat Liaison Group. Technical Series No. 60. Montreal, Canada: Secretariat of the Convention on Biological Diversity.

Victora, C. G., Adair, L., Fall, C., Hallal, P. C., Martorell, R., Richter, L., & Sachdev, H. S. (2008). Maternal and child undernutrition: Consequences for adult health and human capital. *The Lancet*, *371*(9609), 340–357. doi:10.1016/S0140-6736(07)61692-4

WHO Multicentre Growth Reference Study Group. (2006). Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. *Acta Pædiatrica*, (Suppl 450), 56–65. doi:10.1080/08035320500495514

Wong, J. T., de Bruyn, J., Bagnol, B., Grieve, H., Li, M., Pym, R., & Alders, R. G. (2017). Small-scale poultry and food security in resource-poor settings: A review. *Global Food Security*. doi:10.1016/j.gfs.2017.04.003

World Health Organization (WHO). (2010). *Indicators for assessing infant and young child feeding practices: Measurement.* Geneva: WHO.

Zambia Corn Production by Year. (2017, October 9). Retrieved from https://www.indexmundi.com/agriculture/?country=zm&commodity=corn&graph=production

Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: A systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *108*(6), 313–325. doi:10.1093/trstmh/tru056

CHAPTER 6

Conclusion

Nutrition-sensitive livestock interventions have strong theoretical potential to improve maternal and child nutrition outcomes, addressing the underlying determinants of undernutrition by enhancing access to animal source foods (ASF), income and savings, crop production yields, and women's empowerment (Figure 3.1; (Randolph et al., 2007)). Poultry production has been promoted as a particularly promising livestock-based approach to increasing ASF consumption because it is a common livelihood activity among the rural poor and is often controlled by women.

Development programs for rural, smallholder poultry can generally be categorized as 1) interventions for extensive "backyard" poultry production, or 2) programs promoting semi-intensive production of either broilers or layers (Figure 6.1). Semi-intensive production programs are often introducing a new production system to the participants, and typically involve some combination of training, access to services and inputs, and either credit for purchasing improved breeds or the distribution of birds (Kryger et al., 2010). In contrast, interventions targeting extensive poultry systems are generally building off of existing systems with which the intended beneficiaries have previous experience, using indigenous or improved breeds adapted to local conditions. These programs usually aim to improve husbandry and management practices, housing, supplementary feeding, flock genetics, and disease prevention practices (e.g. Newcastle Disease vaccination; Kryger et al., 2010). Both extensive and semi-intensive interventions may be rolled out as stand-alone programs or integrated with other agricultural or nutrition interventions. Although groups are often formed in the initial phases of these programs, individual members typically retain full ownership and control over their productive resources, with the groups functioning primarily for the dissemination of information, training, and credit.

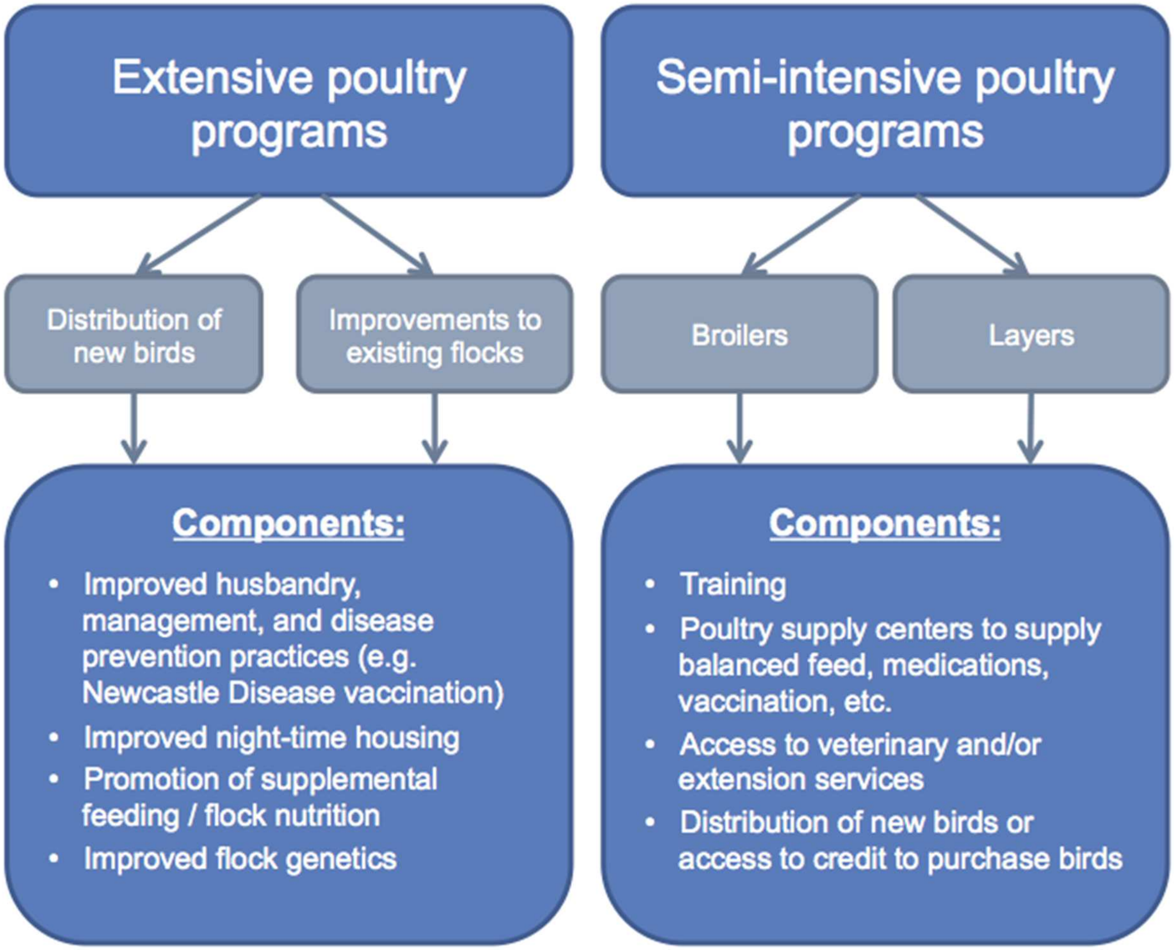


Figure 6.1. Common types of poultry interventions and their components.

There are numerous examples of poultry development projects that have successfully increased poultry production outputs (e.g. flock size, eggs produced, profits) and even household incomes, including the “Bangladesh Poultry Model” supported by BRAC (Dolberg, 2003; Islam & Jabbar, 2003; Nielsen, 1996; Riise et al., 2005), the AusAID Southern Africa Newcastle Disease Control Project (Alders et al., 2010; Harun et al., 2009), and the Fowls for Africa Program in South Africa (Clarke, 2004). However, evidence for the real-world effectiveness of livestock interventions to improve maternal and child nutrition remains inconclusive in some livestock systems and study settings (Table 1.4; Leroy & Frongillo, 2007), especially for poultry programs (Table 5.1). In part, the lack of high quality evidence is due to the combined effect of programmatic constraints (e.g. the complexity of implementing nutrition-sensitive programs in resource-poor settings, the disparity between long impact pathways and short time frames imposed by donors, resource constraints) and methodological limitations (e.g. participant and non-participant comparison without baseline, before-and-after comparison without a control, inappropriate statistical methods or reporting of statistics, lack of control for confounding factors, poorly defined counterfactual; Leroy & Frongillo, 2007; Masset et al., 2012).

Additionally, there are concerns that livestock interventions may inadvertently negatively affect care, feeding, and health of infants and young children, offsetting the benefits of livestock ownership. First, while livestock interventions can theoretically empower women, there is little empirical evidence to support this. Livestock programs could instead add to the already heavy demands on women's time and labor (Mullins et al., 1996; Tangka et al., 1999; Wangui, 2008), negatively affecting their capacity to care for themselves and their children, and efforts to "modernize" the livestock sector may inadvertently transfer women's existing control over livestock assets or decision-making power to men (Kristjanson et al., 2014; Njuki et al., 2011; Njuki et al., 2015; Wangui, 2008). Second, there is mounting evidence that children's exposure to livestock, particularly poultry, increases their risk of disease (Grace et al., 2012; Zambrano et al., 2014) and environmental enteric dysfunction (George et al., 2015; Headey & Hirvonen, 2016); therefore, any positive effect of livestock on child health and growth through increased incomes and ASF consumption may be curtailed by poorer nutrient utilization.

In light of this, we aimed to design and implement an alternative, market-based, gender-sensitive poultry intervention in rural communities in the Luangwa Valley, Zambia and evaluate its impact using an appropriate methodological design and analytical approach. We began with formative research assessing the impact of interventions targeting village chickens on household resilience in the area, which aimed to increase flock size, poultry profits, and ASF consumption within participating households. We then conducted a cross-sectional study investigating the association between traditional livestock ownership and dietary diversity, ASF consumption, and anthropometric indicators among children using a novel hierarchical livestock typology measure. Building off the lessons from these studies, we then designed and implemented an egg production center (EPC) program in 24 rural communities, evaluating their productivity and profitability, documenting participant experiences with the program, and identifying key programmatic challenges for improvement. Finally, we evaluated the impact of the EPC program on egg consumption and dietary diversity among women and young children living in the surrounding community.

As described in detail below, the EPC model includes many of the same components of previous semi-intensive poultry programs (Figure 6.1); however, it additionally has a number of unique characteristics that make it a particularly promising approach for sustainably providing vulnerable households with access to ASF. First, rather than seeking to change the diets of individual households, the EPC model aimed to provide benefits to entire communities by using a market-based approach wherein the primary consumers are those living around the EPC. Second, program inputs were delivered to groups, rather than to individuals, and were collectively owned and managed by them to avoid contributing to women's time poverty. Third, in contrast to extensive poultry programs, this model maintains the birds in total confinement, which avoids concerns that children's exposure to poultry feces might be intensified as a result of the intervention. Fourth, the program was implemented by a local non-profit with strong ties to the community and experience delivering agricultural interventions to smallholder farmers there, giving them the ability to respond quickly to participants' needs and concerns.

Synthesis of research findings

Improvements to the village poultry system

The most common targets for poultry development interventions are the extensive "backyard chicken" systems prevalent through rural areas of low-income countries. This is a logical approach because it is already a familiar livelihood activity for most smallholder farmers (Gueye, 2000a), has a low cost of entry, and can be managed with very low levels of land, labor, and capital inputs (Alders & Pym, 2009; Gueye, 2000a), making it an feasible livelihood activity for even the poorest of rural households (Alders & Pym, 2009; Dolberg, 2003). Additionally, while many women have limited ownership rights, decision-making power, and control over the income and ASF from most livestock species (Curry, 1996; Dumas et al., 2017; Galiè et al., 2015; Njuki et al., 2011; Njuki & Sanginga, 2013; Tangka et al., 2000), an estimated 70% of chicken owners are women (Gueye, 2000a), providing an avenue for empowering women and maximizing the social impact (Gueye, 2000a; Gueye, 2000b; Wong et al., 2017).

In Chapter 2, we investigated the impact of targeted interventions promoting village poultry production on the resilience of the household poultry system and family welfare in the Luangwa Valley, evaluating the program's impact on three key parameters: (1) household flock size; (2) household poultry profits; and (3) family consumption of chicken meat and eggs. We reported a significant effect of the program on flock size (roughly 135% increase, from 10.9 to 25.7 birds per household in project areas, compared to no change in control areas, $p<0.001$) and poultry profits (138% increase in project households, from \$16.89 to \$40.25, compared to 65%

increase in controls). However, despite increased flock sizes, there was no change in household consumption of chicken eggs or meat, and focus groups revealed that program participants preferred to sell birds rather than eat them or their eggs at home. These results are consistent with evaluations of similar projects in Bangladesh (Nielsen et al., 2003) and Tanzania (Knueppel et al., 2010), and the preference of smallholders to allow the eggs of village chickens to hatch as a means of offsetting high flock mortality has been documented before (Bagnol, 2001; de Bruyn et al., 2017; Dumas et al., 2016; Gueye, 2000a; Halder & Urey, 2003; Lane, 2016; Olney et al., 2013). Therefore, despite the promise of backyard poultry, we considered the idea that backyard poultry production may not be the ideal mechanism through which to provide young children in the Luangwa Valley with access to ASF.

Traditional livestock ownership and children's nutrition

Building off this finding, in Chapter 3 we expanded the scope of our inquiry and evaluated the association between ownership of all livestock managed in traditional systems in the Luangwa Valley and child diets and anthropometrics. Recent research on the impact of livestock managed in traditional extensive systems in sub-Saharan Africa on child stunting has yielded mixed findings (Appendix 3), suggesting that the link is complex and context specific. Households were categorized into five hierarchical typologies based on the types and numbers of animals owned, ranging from no livestock to large numbers of mixed livestock, an approach that allowed for an efficient and a more in-depth examination of the differential impact of livestock ownership patterns compared to typical binary or count measures of livestock ownership. No measure of livestock ownership was significantly associated with children's odds of ASF consumption, child HAZ, or stunting odds. Interestingly, having a small number of poultry was associated with decreased child dietary diversity (β= -0.477; $p<0.01$) relative to owning no livestock, an unexpected finding that diverges from traditional livestock development thinking. This research revealed the complex association between traditional livestock ownership and child nutrition outcomes in the Luangwa Valley, suggesting that ownership of livestock alone is not necessarily associated with greater ASF consumption, dietary diversity, or growth among children. This finding helped to lay the groundwork for the design of the EPC program, confirming the view that a novel livestock development program was needed to optimize the impact of livestock on child diets.

The EPC model and participant experiences

Given the formative research findings, in Chapter 4 we explored the EPC model as an alternative livestock development intervention to enhance community access to ASF and women's and children's consumption of ASF. In order to better understand program implementation and delivery, we measured key intermediate outcomes of the EPC program (egg productivity and profitability) and participant experiences with the program. Overall, twenty EPCs with sufficient data produced 156,188 eggs, with 50.8% of hens laying an egg on any given day and total average profits of 3261 kwacha (US$ 313). Although the mean productivity was below industry benchmarks, there was dramatic variation among individual EPCs, and some approached optimal performance. There was no significant impact of the program on the household food security of participants, but they were overwhelmingly satisfied with the program, noted important benefits of their participation for their families, and intended to continue the egg production business the following year. These findings suggest that the EPC model is acceptable, appropriate, and can be feasibly implemented in rural communities. Given that egg production is the necessary intermediate outcome along the impact pathways from the EPC program to improved child nutrition outcomes, the finding that eggs were successfully produced and sold by the EPCs suggests that the hypothesized impact is plausible, setting the stage for impact evaluation.

Impact evaluation of the EPC program on maternal and child diets

Following our finding that the EPC program can successfully make eggs available in rural communities in the Luangwa Valley, in Chapter 5 we examined the more distal outcomes in the program impact pathway: egg acquisition by nearby households, egg consumption by women and young children in those households, contribution to the quality of their diets, and impact on child HAZ. We found that the EPC program successfully increased the acquisition and consumption of eggs by households, women, and young children in the surrounding communities. Households located within 250 m of an EPC were most likely to consume eggs, but distance did not modify the impact of the program on women's and children's individual consumption of eggs. Interestingly, while the program successfully increased the *odds* of egg consumption among women and children, the *number of times* they ate eggs increased in both intervention and control communities after the start of the program, making it difficult to attribute the change in the intensity of egg consumption to the program. Increased egg consumption by women and children did not translate into greater individual dietary diversity, however, and, as predicted, no evidence was found for program impact on child HAZ within the short follow-up time.

Contributions to livestock development research and impact evaluations

Created a novel measure of "livestock ownership"

A review of 12 studies investigating the impact of livestock managed in traditional extensive systems in sub-Saharan Africa on child stunting has yielded mixed findings. There is some fairly consistent evidence that the ownership of dairy cows or goats has a positive impact on child nutrition outcomes (Fierstein et al., 2017; Grosse, 1998; Hoddinott et al., 2015; Nicholson et al., 2003; Okike et al., 2005). However, other research has found no association between livestock ownership and stunting (Azzarri et al., 2015; Iannotti & Lesorogol, 2014; Mosites et al., 2016), a modest relationship depending on how "livestock ownership" was operationalized (Jin & Iannotti, 2014; Mosites et al., 2015), or even a negative effect in some situations (Good, 2008; Headey & Hirvonen, 2016). One important limitation to this body of research is the lack of consensus on how to appropriately operationalize the concept of "livestock ownership". The most commonly employed measures have clear limitations: a binary indicator of livestock ownership assumes that ownership of one animal has an equal effect on child nutrition as ownership of many animals, while an absolute count of animals assumes that all species and breeds have an equal effect on child nutrition. The Tropical Livestock Unit (TLU; (Mosites et al., 2015; Okike et al., 2005)) score attempts to capture the differential effects of various types and numbers of livestock, but it undervalues small animals and overvalue large animals, which may not be appropriate for assessing the impact on child nutrition outcomes given that small animals can be more readily bartered, sold, or slaughtered to provide food or income on an as-needed basis than can larger, more valuable animals.

To overcome the limitations of existing measures, we have developed a novel method that combines the total number of animals a household owns with a weighted index of the animal's value to create five hierarchical typologies of livestock ownership, ranging from no animals of any kind to large numbers of mixed livestock. This approach allowed for an in-depth examination of the differential impact of livestock ownership patterns compared to typical binary or count measures of livestock ownership. The typologies measure proved more efficient than an approach testing multiple measures of livestock ownership individually, while avoiding potential concerns of multicollinearity, which would prevent counts of multiple species from being considered in a single regression. In areas that are not dominated by holdings of a single particular species, our new methodology combining metrics might prove more informative and adaptive to different study sites, in which different typologies might need to be defined to reflect local environmental and cultural contexts.

Highlighted the importance of program impact pathways in evaluating livestock programs

There is a tendency in evaluations of livestock development programs to measure outcomes that are far upstream from the impact of interest (e.g. ownership of livestock, increased milk production) and rely on numerous assumptions to imply that these distal outcomes will necessarily translate into impact. While it is highly plausible that livestock ownership is linked to improved maternal and child health and nutrition outcomes through a number of pathways (Figure 3.1; (Randolph et al., 2007)), the linkages in this pathway are dependent on a number of factors. These include the primary use of various livestock types, their perceived or actual value, prevailing gender norms and roles, and access to markets and inputs, among other influences, many of which are highly context specific. Theory linking livestock to improved nutrition outcomes also often ignores the potential negative effects of livestock ownership (e.g. disease exposure, maternal time poverty), or assumes they are outweighed by the positive effects. The findings presented in Chapter 3 emphasize the importance of these considerations: simply *owning livestock* does not necessarily lead to greater ASF consumption, dietary diversity, or growth among children in the Luangwa Valley. Furthermore, as presented in Chapter 2, the successful delivery and uptake of an intervention to improve village poultry program resulted in increased poultry profits but, unexpectedly, no change in ASF consumption. Here, our *a priori* assumptions and expectations likely did not align with the actual way in which the program beneficiaries utilized and valued village chickens. In fact, the multi-purpose utility of livestock requires a daily cost-benefit analysis on the part of livestock owners, who must weigh the many demands of their households against their limited resources (Pell & Kristjanson, 2017). As a result, livestock-owning families in many smallholder systems do not necessarily consume animal products at home on a routine basis (Randolph et al., 2007), even within the context of livestock development programs (Knueppel et al., 2010; Kumar & Quisumbing, 2010; Leroy & Frongillo, 2007; Olney et al., 2013; Olney et al., 2009), a concept highlighted by this research.

Our research further confirms the importance of considering an entire impact pathway, from exposure to impact, and measuring the key intermediate outcomes along that pathway. The implementation of nutrition-sensitive agricultural programs is a complex process requiring coordination across sectors, and the implementation process can vary in quality or success at numerous steps along the pathway from conception to delivery, to adoption, and eventually, to sustainable impact. Previous assessments of a poultry distribution program in Cambodia identified key obstacles in the delivery, uptake, and utilization of production outputs that undermined the hypothesized impact of the program (Olney et al., 2009; 2013). One of the biggest obstacles is high flock mortality caused by disease, predators, and poor management practices (Wong et al., 2017), especially when commercial or exotic breeds that are not adapted to local conditions are introduced by poultry improvement programs (Alders & Pym, 2009; Kitalyi, 1997). Understanding the impact pathway allowed us to test the underlying assumptions associated with each linkage point, identify problems with program delivery and fidelity, and define how impact can be optimized during subsequent phases and scaling up of the program.

Developed a feasible and acceptable model for local egg production with high potential for community-level impact

A recent randomized controlled trial in Ecuador provided infants 6 – 9 months with one egg per day for nine months and found dramatic improvements in linear growth and weight gain compared to controls (Iannotti et al., 2017). In light of their results, the authors called for "effectiveness studies to identify scalable strategies to increase egg availability and access to vulnerable households" to make eggs an affordable and sustainable tool for improving diets and preventing undernutrition. Although charitable organizations have previously funded and implemented egg production programs in low-income communities (e.g. the OneEgg project in Rwanda [www.oneegg.org]; International Egg Foundation in Southern Africa [www.internationaleggfoundation.com]; Bridges International Development in Kenya [www.bridgesid.org/economic-development/chickens/]; various Peace Corps projects around the world), to our knowledge, this is the among the first projects to fully describe the inputs and processes and rigorously evaluate the outputs and impact. Research on a similar egg production project, which is just one component in a much larger integrated nutrition program in Ghana, is currently being evaluated by researchers at McGill University in partnership with World Vision and Heifer Ghana (Atuobi-Yeboah et al., 2016). While there is room for improvement, we found that the market-based EPC program successfully increased the acquisition and consumption of eggs by households, women, and young children in the surrounding communities. Importantly, we also found that eggs were in high demand and that the EPC program was an acceptable, appropriate, and feasible approach to meeting that demand.

The EPC program developed and described here has a number of unique characteristics that make it a particularly promising model for sustainably providing vulnerable households with access to eggs. First, while many livestock development programs operate at the household level, the EPC program sought to change the local food environment, providing benefits to entire communities despite having direct contact with, and providing inputs to, only a small number of individuals. Unlike most nutrition-sensitive agriculture program evaluations, we therefore examined its impact on women and children living in the surrounding community who were not directly receiving any inputs from the program and would therefore not be traditionally defined as the intended “program beneficiaries”.

Second, the model was designed with careful consideration of women’s time poverty and their tenuous intra-household control over livestock assets and income. Although women were the primary recipients of the program, inputs were delivered to groups rather than to individuals. As a result, each individual allocated only a small amount of her time and labor to the program, and because women’s savings groups are common in the region, participants were able to maintain a reasonable degree of control over the resulting income. Although the EPC model – in which the production resources were jointly owned and collectively managed – was a new experience for them, all participants felt that operating the EPC as a group was preferable to doing so alone, because the time burden for each individual was minimal.

Third, because the program model utilizes a confined production system, it avoided concerns that children’s exposure to poultry or poultry feces might be intensified as an unintended consequence of the intervention. During training, to minimize the risk that participants might outsource some of the labor to their children, it was emphasized that only the

EPC members should enter the facility or handle the chickens to prevent the introduction of disease into flocks. Training in other biosecurity practices, such as hand-washing with soap and using only designated slippers when inside the facility, limits the risk of participants contaminating the homestead with pathogens from their hands, shoes, or other fomites. Finally, the program was implemented by a local non-profit, Community Markets for Conservation (COMACO), that has strong ties to the beneficiary communities and is experienced in delivering and monitoring agriculture interventions. This allowed them to provide extension support and provided program beneficiaries with access to feed, vaccination and veterinary services, and ongoing training and advice to maximize productivity.

Future research directions

Our findings highlight several considerations that warrant further research in order to better understand and optimize the impact of the EPC model. First, despite the strengths of our methodological approach, a cluster randomized controlled trial with clear criteria for community inclusion will provide a more valid counterfactual for the intervention group and, thus, higher quality evidence linking the program to nutrition outcomes. Although experimental designs are more complicated from a logistical and practical perspective, we believe that, if funding can be secured, a stepped-wedge design that staggers community enrollment over time would be both feasible and acceptable to participating communities and implementing partners. Second, a longer follow-up time of two to three years is necessary to measure the impact of the EPCs on child growth and development. This longer follow-up time will have the added benefit of allowing for assessment of the long-term sustainability of the EPC model over multiple production cycles where hens must be sold and replaced every 12-18 months. Third, our results are specific to the context and population of the Luangwa Valley, Zambia, and may not be generalizable to other contexts. It is therefore crucial that the EPC model be adapted and tested in diverse settings to better understand its acceptability, appropriateness, feasibility, and sustainability outside of the Luangwa Valley. During this progression, the program inputs, delivery, and processes can be adjusted and improved to optimize the potential for impact in a given setting.

Beyond the methodological considerations, there are additional questions about the EPC model that should be investigated. First, future research should extend the assessment of the EPC program to other potential beneficiaries. Although women and young children have the greatest potential to benefit from increased consumption of eggs, other members of the household (adult men, older children, the elderly) are also likely to benefit, as are households within the community who do not have young children. None of these benefits were captured in our assessment, which focused exclusively on women and children 6-36 months of age. Second, there are additional intermediate outcomes on the pathway from the egg production to maternal and child health and nutrition that were not measured in this evaluation, including through income, women's empowerment, and social status. Previous research has suggested that targeting women as beneficiaries of livestock interventions may confer additional social good by empowering women with skills, knowledge, and assets, delivering long-term impact on their and their children's wellbeing (Leroy & Frongillo, 2007; Randolph et al., 2007). Third, time and resource constraints prohibited the integration of the EPC program with nutrition-specific interventions; however, COMACO has a good network on the ground as well as a popular radio program which could be used for the delivery of a nutrition education program. Previous research suggests these may enhance effectiveness of the intervention (Leroy & Frongillo, 2007;

Randolph et al., 2007). Future research should investigate the effectiveness of the EPC program with and without nutrition education to test this hypothesis and potentially optimize program impact. Finally, with limited domestic livestock production, the Luangwa Valley relies heavily on wildlife for ASF, and developing alternative ASF sources to replace bushmeat has proved challenging (Cawthorn & Hoffman, 2015). To our knowledge, there is no research directly evaluating the impact of a livestock development program on local wildlife consumption. Further research should explore how demand, prices, sources, and consumption patterns of different types of ASF change in the context of the EPC program to better understand the program's potential to curb unsustainable wildlife harvesting practices.

Conclusions

In this dissertation we have implemented and evaluated an intervention to sustainably enhance the production and consumption of eggs using a rigorous evaluation of a theory-based program impact pathway. Our findings suggest that the EPC program may be a viable model for successfully increasing the acquisition and consumption of eggs by households, women, and young children in remote, resource-poor communities. The EPC program could therefore function as one component of a large-scale, multisectoral, integrated nutrition intervention in some contexts to enhance access to, and consumption of, high-quality ASF in vulnerable households. Our results additionally point to a new approach for livestock interventions that focuses on program impact at the community-level, rather than within recipient households alone and contribute to the growing evidence of the association between livestock and child nutrition.

In the 2013 *Lancet* Series on Maternal and Child Undernutrition, Bhutta et al. estimated that scaling up the ten most effective nutrition-specific interventions to 90% coverage in the 34 countries with the highest burden of undernutrition would reduce total deaths in children under 5 can by 15% and the global stunting by 20% (Bhutta et al., 2013). Filling this "impact gap" and enhancing the impact of nutrition-specific interventions requires developing and evaluating novel, contextually appropriate, acceptable, affordable, and scalable strategies to build healthy food systems in low-income communities. The EPC program offers one such strategy.

References

Alders, R. G., & Pym, R. (2009). Village poultry: still important to millions, eight thousand years after domestication. *World's Poultry Science Journal*, *65*(02), 181–190.

Alders, R. G., Bagnol, B., & Young, M. P. (2010). Technically sound and sustainable Newcastle disease control in village chickens: lessons learnt over fifteen years. *World's Poultry Science Journal*, *66*(03), 433–440.

Atuobi-Yeboah, A., Marquis, G. S., Colecraft, E., Kanlisi, R., Aryeetey, R., & Klevor, M. (2016). An integrated nutrition-sensitive health and agriculture intervention to increase egg consumption among infants and young children in Upper Manya Krobo, Ghana. *The FASEB Journal*, *30*(1 Supplement), 274.5–274.5.

Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does livestock ownership affect animal source foods consumption and child nutritional status? Evidence from rural Uganda. *Journal of Development Studies*, *51*(8), 1034–1059.

Bagnol, B. (2001). The social impact of Newcastle disease control. In R. G. Alders & P. B. Spradbrow (Eds.), *SADC Planning Workshop on Newcastle Disease Control in Village Chickens* (pp. 69–75). Maputo, Mozambique: Proceedings of an International Workshop. ACIAR Proceedings, no. 103.

Bhutta, Z. A., Das, J. K., Rizvi, A., Gaffey, M. F., Walker, N., Horton, S., et al. (2013). Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? *Lancet*, *382*(9890), 452–477.

Cawthorn, D. M., & Hoffman, L. C. (2015). The bushmeat and food security nexus: A global account of the contributions, conundrums and ethical collisions. *Frin*, *76*(P4), 906–925.

Clarke, B. (2004). Poultry for profit and pleasure (pp. 1–51). Rome, Italy: Food and Agriculture Organization (FAO) of the United Nations.

Curry, J. (1996). Gender and livestock in African production systems: an introduction. *Human Ecology*, *24*(2), 149–160.

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Maulaga, W., Thomson, P. C., & Alders, R. G. (2017). Characterising infant and young child feeding practices and the consumption of poultry products in rural Tanzania: A mixed methods approach. *Maternal & Child Nutrition*. http://doi.org/10.1111/mcn.12550

Dolberg, F. (2003). Review of household poultry production as a tool in poverty reduction with focus on Bangladesh and India. *FAO Pro-Poor Livestock Policy Initiative Working Paper No. 6*.

Dumas, S. E., Lungu, L., Mulambya, N., Daka, W., McDonald, E., Steubing, E., et al. (2016). Sustainable smallholder poultry interventions to promote food security and social, agricultural, and ecological resilience in the Luangwa Valley, Zambia. *Food Security*, *8*, 507–520.

Dumas, S. E., Maranga, A., Mbullo, P., Collins, S., Wekesa, P., Onono, M., & Young, S. L. (2017). "Men are in front at eating time, but not when it comes to rearing the chicken": Unpacking the Gendered Benefits and Costs of Livestock Ownership in Kenya. In press, *Food and Nutrition Bulletin*.

Fierstein, J. L., Eliasziw, M., Rogers, B. L., & Forrester, J. E. (2017). Nonnative cattle ownership, diet, and child height-for-age: evidence from the 2011 Uganda Demographic and Health Survey. *American Journal of Tropical Medicine and Hygiene*, *96*(1), 74–82.

Galiè, A., Mulema, A., Benard, M. A. M., Onzere, S. N., & Colverson, K. E. (2015). Exploring gender perceptions of resource ownership and their implications for food security among rural livestock owners in Tanzania, Ethiopia, and Nicaragua. *Agriculture & Food Security*, *4*(1), 2.

George, C. M., Oldja, L., Biswas, S. K., Perin, J., Lee, G. O., Ahmed, S., et al. (2015). Fecal markers of environmental enteropathy are associated with animal exposure and caregiver hygiene in Bangladesh. *American Journal of Tropical Medicine and Hygiene*, *93*(2), 269–275.

Good, S. (2009). Animal source foods and nutrition during early life: an evaluation of the possible link between livestock keeping, food intake and nutritional status of young children in Ethiopia (doctoral dissertation). ETH Zurich, Zurich, Switzerland.

Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L., et al. (2012). Mapping of poverty and likely zoonoses hotspots. International Livestock Research Institute (ILRI).

Grosse, S. D. (1999). Farm animals and children's nutritional status in rural Rwanda. Presented at Symposium on Human Nutrition and Livestock in the Developing World, 1998, October 14, (pp. 190–200). Little Rock, AR: Heifer Project International.

Gueye, E. F. (2000a). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on Agriculture*, *29*(2), 129–136.

Gueye, E. H. F. (2000b). Women and family poultry production in rural Africa. *Development in Practice*, *10*(1), 98–102.

Halder, S., & Urey, I. (2003). Changing food consumption patterns: implications for nutrition and livelihoods. Dhaka: BRAC.

Harun, M., Alders, R. G., Sprowles, L., Bagnol, B., Cambaza, A. B., Msami, H. M., & Mgomezulu, R. A. (2009). Southern Africa Newcastle Disease Control Project impact studies: baseline and participatory rural appraisal results. In R. G. Alders, P. B. Spradbrow, & M. P. Young (Eds.), *Village chickens, poverty alleviation and the sustainable control of Newcastle Disease: Proceedings of an international conference* (pp. 96–101). Dar es Salaam, Tanzania: ACIAR.

Headey, D., & Hirvonen, K. (2016). Is exposure to poultry harmful to child nutrition? An observational analysis for rural Ethiopia. *PloS One*, *11*(8), e0160590–16.

Hoddinott, J., Headey, D., & Dereje, M. (2015). Cows, missing milk markets, and nutrition in rural Ethiopia. *Journal of Development Studies*, *51*(8), 958–975.

Iannotti, L. L., & Lesorogol, C. (2014). Animal milk sustains micronutrient nutrition and child anthropometry among pastoralists in Samburu, Kenya. *American Journal of Physical Anthropology*, *155*(1), 66–76.

Iannotti, L. L., Lutter, C. K., Stewart, C. P., Gallegos Riofrío, C. A., Malo, C., Reinhart, G., et al. (2017). Eggs in early complementary feeding and child growth: a randomized controlled trial. *Pediatrics*, e20163459.

Islam, S. M. F., & Jabbar, M. A. (2003). Scavenging Poultry for Poverty Alleviation: A review of experiences with a focus on Bangladesh. Nairobi, Kenya: ILRI.

Jin, M., & Iannotti, L. L. (2014). Livestock production, animal source food intake, and young child growth: The role of gender for ensuring nutrition impacts. *Social Science & Medicine*, *105*, 16–21.

Kitalyi, A. J. (1997). Village chicken production systems in developing countries: what does the future hold? *World Animal Review*, 48–53.

Knueppel, D., Cardona, C., Msoffe, P., Demment, M. W., & Kaiser, L. (2010). Impact of vaccination against chicken Newcastle disease on food intake and food security in rural households in Tanzania. *Food and Nutrition Bulletin*, *31*(3), 436–445.

Kristjanson, P., Waters-Bayer, A., Johnson, N., Tipilda, A., Njuki, J. M., Baltenweck, I., et al. (2014). Livestock and Women's Livelihoods. In Quisumbing, A. R. et al. (eds), *Gender in Agriculture: Closing the Knowledge Gap* (pp. 209–233). Dordrecht, Netherlands: Springer.

Kryger, K. N., Thomsen, K. A., Whyte, M. A., & Dissing, M. (2010). Smallholder poultry production - livelihoods, food security, and sociocultural significance. Rome: Food and Agriculture Organization (FAO) of the United Nations.

Kumar, N., & Quisumbing, A. R. (2010). *Access, Adoption, and Diffusion: Understanding the Long-Term Impacts of Improved Vegetable and Fish Technologies in Bangladesh*. *IFRPI Discussion Paper*. Washington, DC: IFPRI (International Food Policy Research Institute).

Lane, J. (2016). Demystifying the pathways of impact of a livestock transfer program on household resilience & food security in Malawi. Presented at "Agriculture for Nutrition and Health Academy Week" in Addis Ababa, June 20.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition*, *137*(10), 2311–2316.

Masset, E., Haddad, L., Cornelius, A., & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *BMJ*, *344*, d8222–d8222.

Mosites, E. M., Rabinowitz, P. M., Thumbi, S. M., Montgomery, J. M., Palmer, G. H., May, S., et al. (2015). The relationship between livestock ownership and child stunting in three countries in Eastern Africa using national survey data. *PloS One*, *10*(9), e0136686–10.

Mosites, E., Thumbi, S. M., Otiang, E., McElwain, T. F., Njenga, M. K., Rabinowitz, P. M., et al. (2016). Relations between household livestock ownership, livestock ddisease, and young child growth. *The Journal of Nutrition*, (146), 1118–1124.

Mullins, G., Wahome, L., Tsangari, P., & Maarse, L. (1996). Impacts of intensive dairy production on smallholder farm women in coastal Kenya. *Human Ecology*, *24*(2), 231–253.

Nicholson, C. F., Mwangi, L., Staal, S. J., & Thornton, P. K. (2003). Dairy cow ownership and child nutritional status in Kenya. Presented at the AAEA Annual Meetings, Montreal, Quebec, Canada.

Nielsen, H. (1996). Socio-economic impact of smallholder livestock development project, Bangladesh (pp. 64–70). Presented at the Integrated Farming in Human Development Workshop Report. Danish Agricultural and Rural Development Advisers Forum, Tune Landboskole, Denmark.

Nielsen, H., Roos, N., & Thilsted, S. H. (2003). The impact of semi-scavenging poultry production on the consumption of animal source foods by women and girls in Bangladesh. *The Journal of Nutrition*, *133*(11 Suppl 2), 4027S–4030S.

Njuki, J. M., & Sanginga, P. C. (Eds.). (2013). Women, livestock ownership and markets: Bridging the gender gap in eastern and southern Africa. Abingdon, Oxon, UK: Routledge.

Njuki, J. M., Kaaria, S., Chamunorwa, A., & Chiuri, W. (2011). Linking smallholder Farmers to markets, gender and intra-household dynamics: does the choice of commodity matter? *European Journal of Development Research*, *23*(3), 426–443.

Njuki, J. M., Wyatt, A., Baltenweck, I., Yount, K., Null, C., Ramakrishnan, U., et al. (2015). An exploratory study of dairying intensification, women's decision making, and time use and implications for child nutrition in Kenya. *European Journal of Development Research*, *28*(4), 722–740.

Okike, I., Jabbar, M. A., Abate, G., & Ketema, L. (2005). Household and environmental factors influencing anthropometric outcomes in preschool children in a rural Ethiopian community. *Ecology of Food and Nutrition*, *44*(3), 167–187.

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. *Food and Nutrition Bulletin*, *30*(4), 355–369.

Olney, D. K., Vicheka, S., Kro, M., & Chakriya, C. (2013). Using program impact pathways to understand and improve program delivery, utilization, and potential for impact of Helen Keller International's Homestead Food Production Program in Kenya. *Food and Nutrition Bulletin*, *34*(2), 169–184.

Pell, A. N., & Kristjanson, P. (2010). Livestock development projects that make a difference: what works, what doesn't and why. In Swanepoel et al. (eds), *The Role of Livestock in Developing Communities: Enhancing Multifunctionality* (pp. 10-29). Bloemfontein, South Africa: UFS and CTA.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., et al. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800.

Riise, J. C., Kryger, K. N., Seeberg, D. S., & Chistensen, P. F. (2005). Impact of Smallholder Poultry Production in Bangladesh – 12 years Experience with Danida supported livestock projects in Bangladesh. Copenhagen: Danida / Ministry of Foreign Affairs.

Ruel, M. T., Alderman, H., The Maternal and Child Nutrition Study Group. (2013). Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *The Lancet*, *382*(9891), 536–551.

Tangka, F. K., Jabbar, M. A., & Shapiro, B. I. (2000). Gender roles and child nutrition in livestock production systems in developing countries: A critical review. *Socioeconomics and*

Policy Research Working Paper, (27).

Tangka, F., Ouma, E. A., & Staal, S. J. (1999). Women and the sustainable development of market-oriented dairying: evidence from the highlands of East Africa. Nairobi, Kenya: ILRI.

Wangui, E. E. (2008). Development interventions, changing livelihoods, and the making of female Maasai pastoralists. *Agriculture and Human Values*, *25*(3), 365–378.

Wong, J. T., de Bruyn, J., Bagnol, B., Grieve, H., Li, M., Pym, R., & Alders, R. G. (2017). Small-scale poultry and food security in resource-poor settings: A review. *Global Food Security*.

Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *108*(6), 313–325.

APPENDIX 1

Regional vulnerabilities in the Luangwa Valley, Zambia

Agricultural production in Zambia is dominated by smallholder subsistence or semi-commercial farmers (Aregheore, 2009), 78% of whom are living below the national poverty line and are particularly vulnerable to stressors and shocks (World Bank Group, 2014). Nearly half of Zambia's rural population is unable to meet their basic nutritional demands (FAO, 2014), and chronic undernutrition is a significant public health concern: 49.5% of children under five are stunted, 54% suffer from vitamin A deficiency, and 58% are anemic (Central Statistical Office (CSO) et al., 2009). The long-term consequences of undernutrition – including poor physical growth, mental development, and immune function – contribute to decreased overall health, wellbeing, and economic productivity. A 14.3% HIV prevalence rate in the country (Central Statistical Office (CSO) et al., 2009), combined with endemic malaria, TB, and other infectious diseases, further depletes the workforce and contributes to its low human development (ranking 163 out of 187 countries in the 2012 Human Development Index (UNDP, 2013), despite a rapidly growing economy.

With a highly inconsistent, unimodal rainy season, the Luangwa Valley in Zambia's Eastern Province is prone to frequent droughts and floods (Albrecht, 1973; Dodds & Patton, 1968), and the vulnerability of the area's predominantly rain-fed agricultural system is expected to increase even further with climate change (Thurlow, Zhu, & Diao, 2009). Agricultural productivity in the Valley is additionally constrained by historically suboptimal farming and soil management practices leading to poor nutrient cycling, as well as a lack of access to improved seed varieties and other agricultural inputs. Endemic trypanosomiasis in the Valley historically restricts the keeping of cattle, limiting most smallholders to plots of land that they can prepare by hand. As a result, chronic food insecurity is pervasive in the Luangwa Valley, particularly during the ‘hungry season’ from approximately September to March (Lewis et al., 2011), during which time household grain stores have been depleted and newly planted crops are not yet ready for harvest.

Additionally, with minimal non-agricultural employment opportunities and low levels of educational attainment, people in the Valley rely heavily on resources within the Game Management Areas in which they live, as well as several nearby national parks and protected forest reserves. These resources – including fish, wildlife, timber, and non-timber forest products – are variously used to provide food and income on a routine basis, on a seasonal basis, and/or to cope with increasingly intense and frequent shocks such as crop loss, market failure, or family illness. Previous rural development projects in the area promoting the cultivation of cash crops, particularly cotton, over food crops have unintentionally encouraged extremely high rates of local deforestation and have increased farmer vulnerability to global market fluctuations (Lewis et al., 2011). These short-term coping strategies have put unsustainable pressure on the region’s natural resources, threatening the resilience of the ecosystem and the availability of these resources in the long-term (Lewis et al., 2011; Lindsey et al., 2013).

References

Albrecht, R. W. (1973). Luangwa Valley Conservation and Development Project, Zambia: Land use development proposals for the mid and upper Luangwa watershed. No. FO:DP/ZAM/68/510. Working Doc. No. 3. Rome: UNDP/FAO.

Aregheore, E. M. (2009). Country Pasture/Forage Resource Profiles, Zambia. Rome: Food and Agriculture Organization of the United Nations (FAO).

Central Statistical Office (CSO), Ministry of Health (MOH), Tropical Diseases Research Centre (TDRC), University of Zambia, Macro International Inc. (2009). Zambia Demographic and Health Survey 2007. Calverton, Maryland, USA: CSO and Macro International Inc.

Dodds, D. G., & Patton, D. R. (1968). Wildlife and Land-Use Survey of the Luangwa Valley (Rep TA2591). Rome: FAO.

Food and Agriculture Organization (FAO). (2014). FAOSTAT Database Country Indicators. Retrieved from http://www.fao.org/faostat/en/#country/251

International Food Policy Research Institute (IFPRI). (2016). 2014 Global Nutrition Report Dataset.

Appendix 1 (Continued)

Lewis, D., Bell, S. D., Fay, J., Bothi, K. L., Gatere, L., Kabila, M., et al. (2011). Community Markets for Conservation (COMACO) links biodiversity conservation with sustainable improvements in livelihoods and food production. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(34), 13957–13962.

Lindsey, P., Nyirenda, V., Barnes, J., Becker, M., Tambling, C., Taylor, A., & Watson, F. (2013). Zambian Game Management Areas. Wildlife Producers Association of Zambia (WPAZ). Retrieved from http://landforlions.org/data/documents/ Lindsey-et-al-GMA-REPORT.pdf

Thurlow, J., Zhu, T., & Diao, X. (2009). The Impact of Climate Variability and Change on Economic Growth and Poverty in Zambia.

UNDP*Human Development Report 2013: The Rise of the South*. (2013). *Human Development Report 2013: The Rise of the South*. New York: UNDP. Retrieved from http://hdr.undp.org/en/2013-report

World Bank Group. (2014). World Development Indicators Database. Retrieved from http://data.worldbank.org/country/zambia?view=chart

APPENDIX 2

Details of the various sources of data for assessing the impact of improvements in extensive village poultry production and semi-intensive egg production pilot

	Data source	Year(s)	Description	Locations surveyed	Households sampled (n)
Extensive poultry system (village chickens)					
1	Newcastle Disease Vaccination Project, Household Vaccination Form (primary data)	2007 - 2011	Repeated count by community vaccinators of the number of birds vaccinated at each HH during the Newcastle Disease vaccination campaign, average HH flock size, and flock losses	Mambwe district (Chiefdoms of Nsefu, Mwanya, Malama, Sandwe, Mnkhanya, Kakumbi, and Msoro) and Lundazi district (Chiefdoms of Chitungulu and Chifunda)	All HHs participating in vaccination program
2	Baseline study on rural community household livelihoods, gender, and social change - Luangwa Valley Ecosystem Integrated Conservation and Livelihood Project (secondary analysis of Ngumayo 2011, unpublished data)	2009-2010	Cross-sectional data of HH income earned from poultry activities in COMACO and non-COMACO HH in the Luangwa Valley, based on respondent recall	Districts of Chama (10 Chiefdoms), Lundazi (3 Chiefdoms), and Mambwe (8 Chiefdoms)	893
3	Poultry housing survey (primary data)	Jul 2011	Cross-sectional survey of husbandry practices, flock size, and cause-specific mortality in a convenience sample of participating HHs using a structured survey instrument	Chiefdoms of Mnkhanya, Nsefu, and Kakumbi in Mambwe district	59
4	COMACO Monitoring and Evaluation (secondary analysis of COMACO M&E data)	2011	Continuous evaluation of the number of poultry groups formed and number of farmers participating, as reported by COMACO Area Extension Officer	Mambwe district, all participating Chiefdoms	Mean 340 (range 280 – 420)
5	Off-take dynamics monitoring form (primary data)	2011-2012	Longitudinal survey conducted monthly on flock size and composition, bird and egg consumption and sales, and flock losses and additions in participating HHs	Chiefdoms of Mnkhanya, Nsefu, Kakumbi, and Msoro in Mambwe district	130

Appendix 2 (Continued)

6	Neighbor baseline nutritional survey (primary data)	Feb 2012	Cross-sectional data on animal-source food consumption, including eggs, poultry meat, and other meat, using a structured survey instrument	Chiefdoms of Mnkhanya, Nsefu, and Kakumbi in Mambwe district around 5 sites proposed for future egg production	121
7	Poultry producers focus groups survey (primary data)	Jan/Feb 2012	Focus group discussion about poultry feeding, housing and vaccination practices, the determinants and barriers to optimal husbandry practices, and determinants and barriers to home consumption of poultry meat and eggs	6 village area groups within the Chiefdom of Mnkhanya	62 women and 4 men
Semi-intensive egg production					
8	Layer facility daily production and sales record (primary data)	2010-2011	Data from daily records maintained by the producer on the total number of eggs collected, number of eggs consumed by the family, number of eggs sold and price of each egg, and the amount and cost of feed purchased	At one facility in each of Mnkhanya, Nsefu, and Kakumbi	3
9	Individual interviews with egg producers (primary data)	Jun 2011	Qualitative individual semi-structured interview with producers about their motivations for raising layers, the benefits and difficulties of the business, use of added income, and the impact of the business on their HH	At one facility in each of Mnkhanya, Nsefu, and Kakumbi	3
10	Layer facilities – Neighbors and producers nutritional survey (primary data)	Jun 2011	Cross-sectional data of household egg sources, egg and meat consumption patterns, and determinants and barriers to egg consumptions	Chiefdoms of Mnkhanya, Nsefu, and Kakumbi in Mambwe district, around each of the 3 layer facilities and in 3 matched control areas	120

Abbreviations: HH, household

APPENDIX 3

Summary of previous observational research on the link between livestock ownership and child nutrition outcomes in sub-Saharan Africa.

Authors (Year), Country	Population age (n)	Measure of livestock	Outcomes	Findings
Fierstein et al. (2017), Uganda	0 – 5 yr (n= 2214)	• Binary measures of individual species (native cattle, nonnative cattle, equines, goats, sheep, pigs, and chickens)	HAZ	• Nonnative cattle ownership was positively associated with HAZ in rural children 0 – 5, *not* mediated by child dairy consumption • Sheep ownership was positively associated with HAZ in rural children 2 – 5 yr • Goat ownership was positively associated with HAZ in rural children 0 – 2 yr • In urban areas, only nonnative cattle ownership was associated with HAZ, and only in children 2 – 5 yr
Grosse (1999), Rwanda	24 – 59 mo (n= 542)	• 3-level hierarchical index of dairy livestock (none, goats only, cows +/- goats) • Binary measure of poultry	HAZ	• Dairy animal ownership, but not poultry ownership, is associated with child HAZ
Hoddinott et al. (2015), Ethiopia	6 – 60 mo (n= 4479)	• Binary measure of any cattle ownership	• Dairy product consumption (past 7d) • HAZ and stunting	• Cattle ownership increases likelihood and frequency of dairy consumption • Cattle ownership increases HAZ and reduced likelihood of stunting, with the greatest effect among children 12-18mo

Appendix 3 (Continued)

Authors (Year), Country	Population age (n)	Measure of livestock	Outcomes	Findings
Nicholson et al. (2003), Kenya	0 – 72 mo (n= 152)	• Binary measure of any cattle ownership • Count of dairy cows	• HAZ and WHZ	• Any cattle ownership (binary) is positively associated with HAZ, but not WHZ • The number of dairy cows owned is positively associated with HAZ, but not WHZ, and only in one of two regions
Okike et al. (2005), Ethiopia	0 – 60 mo (n= 170)	• Tropical Livestock Units (TLU) • Count of cattle owned	• Child morbidities (past 14d) • HAZ	• TLU and number of cows are positively associated with child morbidity • Number of cows is positively associated with HAZ (association with TLU not reported)
Azzarri et al. (2015), Uganda	0 – 60 mo (n= 3803)	• Individual count of livestock species	• Household ASF consumption • Probability of stunting, wasting, and underweight	• The numbers of poultry and large ruminants are positively associated with per capita household chicken and dairy consumption, respectively • Livestock ownership is not associated with stunting • Ownership of small ruminants is associated with a decreased probability of being wasted or underweight in children 2-5y; for underweight, this effect is partially countered by ownership of large ruminants
Iannotti & Lesorogol (2014), Kenya	0 – 18 yr (n= 229)	• Individual counts of cattle, goats, and sheep owned	• Milk intake (24hr recall) HAZ, WAZ, and BMIZ	• Goat and cattle, but not sheep, ownership increased household milk consumption • Milk consumption was not predictive of any anthropometric measure • Cattle ownership increased WAZ, but not HAZ, among children < 5y

Appendix 3 (Continued)

Authors (Year), Country	Population age (n)	Measure of livestock	Outcomes	Findings
Mosites et al. (2016), Kenya	1 – 60 mo (n= 838)	• Total livestock count • Livestock count by species	• HAZ and WHZ • Annualized growth rate	Livestock ownership was not associated with HAZ, WHZ, or annualized growth rate
Jin and Iannotti (2014), Kenya	6 – 60 mo (n= 183)	• Self-reported value of livestock by gender of owner	• ASF intake (7d recall) • HAZ, WAZ, and WHZ • Stunting, underweight, and wasting	• Co-/female-owned, but not male-owned, livestock was significantly associated with child ASF intake, HAZ, and WAZ • Child ASF intake mediated 25% of the effect from co/female-owned livestock on WAZ
Mosites et al. (2015), Ethiopia, Kenya, and Uganda	0 – 5 yr (n, Ethiopia = 8079; n, Kenya = 3903; n, Uganda = 1645)	• Count of all animals • Individual counts of livestock species TLU score	Stunting prevalence	• Total animal count was associated with slightly lower stunting prevalences in Ethiopia and Uganda, but not Kenya • TLU was not significantly associated with stunting prevalence in any country • Individual counts of cattle, goats, sheep, or chickens were not associated with stunting prevalence in any country • ASF intake did not modify effect between livestock and stunting prevalence
Good (2009), Ethiopia	6 – 18 mo (n= 297)	• Any small livestock production (sheep, goats, or chickens)	• ASF intake (60d recall) • Stunting, wasting, and underweight	• Children in households with small livestock consumed more eggs, but less cow's milk, than those without • Children in households with small livestock were more likely to be stunted and underweight

Appendix 3 (Continued)

Authors (Year), Country	Population age (n)	Measure of livestock	Outcomes	Findings
Headey and Hirvonen (2016), Ethiopia	0 – 59 mo (n= 3494)	• Binary measure of any poultry • Binary measure of other livestock	• HAZ • Egg and meat consumption (past 24 hr)	• Poultry ownership is positively associated with HAZ, but effect is negated by practice of corralling poultry in family home overnight • Other livestock ownership was not associated with HAZ • Poultry ownership is associated with increased egg, but not meat, consumption

Abbreviations: ASF, animal source food; BMIZ, body mass index z-score; HAZ; height-for-age z-score; TLU, tropical livestock units; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score

APPENDIX 4

Data collection instruments – Example

Associated Field Site code: ___________________________ HH code: __________________________

Household Food Security and Wealth Survey, Form 1 **DEC 2014**
Administered to head of household

Section 1. Household demographics

A. Location details

1.1 *Date: ____/ _____/______ Start time: _______________*

1.2 *Interviewer: ______________________________________*

1.3 *Chiefdom: ___________________________* **1.4** *GPS of HH:* ______________________________

1.5 *VAG:*___________________________ **1.6** Village: ________________________________

1.7	Is anyone in this household (HH) a member of COMACO? *(0= no; 1= yes)*	
1.8	Is any member of this HH involved in the operation of the egg layer facility? *(0= no; 1= yes; 88= NA, not applicable if in control site)*	

B. Household details

1.11 Is the head of household a man or woman? *(1= male, 2= female)* ________

1.12 Now I want to ask you about the people living in your household. By 'household', I mean people who live together with you and with whom you share meals at least 4 days per week. This may include your spouse, children, adopted children, parents and in-laws, other extended family, and servants. Do not count children away at school or living elsewhere. Please give first names only.

Note:* *For children 5 years or less, month and year of birth must be recorded and exact age in months must be calculated! *For anyone over 5 years, only one of YEAR BORN or AGE needs to be completed for each individual, not both. Use whichever method respondent prefers. For adults, their 'best guess' is acceptable, or enter 'DK' for 'don't know'. DK cannot be used for children. Use comments box for additional people if more than 12 people reside in this HH.*

a) First, what is the first name of the head of household? What is your age, or, if it is easier, what year where you born? Did you ever attend school? What is the highest year of education that you completed?
b) Are you married? What is the name of the first wife who is living in this household? What is (SPOUSE)'s age, or the year of her birth? Did she ever attend school? What is the highest year of education that she completed? *Continue for all spouses residing in this HH.*
c) What is the name of your oldest child that lives in this HH? Is (CHILD) a boy or a girl? What is (CHILD)'s age or year of birth? *If less than 5 years:* What is the month and year of (CHILD)'s birth? Is (CHILD) in school? *If yes*: What grade is (CHILD) in? *If no:* Has (CHILD) ever been in school? What is the highest year of education that (CHILD) completed? *Continue for all children residing in HH.*
d) Is there anyone else that lives in this household and with whom you share meals? *If yes:* What is this person's name? Is (NAME) a male or female? What is (NAME)'s relation to you? What is the year of (NAME)'s birth, or (NAME)'s age? Is (NAME) in school? What is (his/her) current grade or the highest year of education completed? *Continue for all people in household.*
e) So there are (NUMBER OF PEOPLE) living in this household. Is that correct? Is there anyone else who lives and eats meals in this HH?

Note:* *Circle all children ages 6-36 months who are eligible for Form 3 and Form 4.

Appendix 4 (Continued)

[Individual Code] Name	Relation to HH head *(options below)*	Month / Year born (*MM/YYYY*)	***OR*** Age *(circle mos or yrs)*	Sex (*1=male, 2=female)*	Education *(codes below)* In school?	Current or highest education
[1]	Head of HH	/	yrs mos		a)	b)
[2]		/	yrs mos		a)	b)
[3]		/	yrs mos		a)	b)
[4]		/	yrs mos		a)	b)
[5]		/	yrs mos		a)	b)
[6]		/	yrs mos		a)	b)
[7]		/	yrs mos		a)	b)
[8]		/	yrs mos		a)	b)
[9]		/	yrs mos		a)	b)
[10]		/	yrs mos		a)	b)
[11]		/	yrs mos		a)	b)
[12]		/	yrs mos		a)	b)

Relation to HH head: *spouse (married or cohabitating), son/daughter, son/daughter-in-law, grandchild, mother/father, mother/father-in-law, brother/sister, brother/sister-in-law, uncle/aunt, nephew/niece, step/foster/adopted child, other family, not related*

Codes, education: *a) In school: 0=no; 1= yes; 88=NA, less than 5 years; b) Current or highest level of education: 0= none; 1= some primary, less than grade 4; 2= some primary, completed at least grade 4; 3= completed primary; 4= some secondary; 5= completed secondary; 6= beyond secondary; 88= NA, less than 5 years; 99= don't know*

Section 2. Household wealth proxies

C. House

2.1	What type of material are (most of) the walls of the house made from? (*1= reeds/ straw/ grass/ bamboo; 2= mud/ soil; 3= wood; 4= iron/metal; 5= bricks/ concrete; 77= other, specify)*	
2.2	What type of material is (most of) the roof of the house made from? (*1= thatch; 2= wooden; 3= iron/metal; 4= tiles; 77= other, specify)*	
2.3	What type of material is (most of) the floor of the house made from? (*1= earth/ mud/ soil; 2= concrete/ cement; 3= tiles/ vinyl; 77= other, specify)*	
2.4	How many total rooms are in the house? *(enter number of rooms)*	
2.5	What is the household's main method of cooking food? *(1= fire; 2= charcoal cooker; 3= high-efficiency cook stove; 4= solar cooker; 5= electric or gas stove; 77= other, specify)*	
2.6	Does your household have access to any type of electricity, including solar power? (*0= none; 1= solar panel; 2= connected to grid; 3= battery (non-solar); 77= other, specify)*	

D. Water and sanitation

2.7	What is the main source of drinking water for the household? (*1= open source/ surface water; 2= unprotected dug well; 3= protected dug well; 4= borehole; 5= public tap/ standpipe; 6= private piped water; 77=other source, specify*)	
2.8	What type of toilet does the family use? (*1= no toilet/ open/ bush; 2= bucket; 3= shared pit toilet/latrine; 4= private pit toilet/latrine; 5= flush/pour toilet; 77= other, specify*)	

Appendix 4 (Continued)

Associated Field Site code: ______________________________ HH code: ______________________________

E. **Assets:** Does any member of the household own (ITEM NAME)?

Item		NO= 0; YES= 1	Item		NO= 0; YES= 1
2.9	TV		**2.21**	Wooden cart or wheelbarrow	
2.10	Radio		**2.22**	Gun	
2.11	Cassette/ CD/ VHS/ DVD player		**2.23**	Snare, for hunting	
2.12	Refrigerator/ freezer		**2.24**	Bed	
2.13	Car/ truck		**2.25**	Sofa	
2.14	Motorcycle		**2.26**	Table	
2.15	Bicycle		**2.27**	Treadle water pump	
2.16	Mobile phone *(see Q 1.8)*		**2.28**	Solar panel	
2.17	Boat		**2.29**	Invertor or battery	
2.18	Plough		**2.30**	Clock/ Watch	
2.19	Mattress		**2.31**	A bank or savings account	
2.20	Agricultural land that is worked by members of your household?		**2.32**	Other item worth more than K160, specify: _____________	

F. **Hired labor**

2.31	Is there anyone who works in your household for money or food, but is unrelated to any member of the family? *(0=no; 1= yes)*	

Section 3. Household income sources

G. **Income from crops and livestock**

3.1	Do any members of this household own or rent any agricultural land, including small gardens, or bee-hives/ apiaries? *(0= no, SKIP to Q 3.3; 1= yes)*	

3.2 What types of crops do you grow? ***Note:*** *Create a list of the crops farmed by the household. Then, for each crop, ask parts (a), (b) and (c). Probe for honey production and garden vegetables.*

Crop Type	(a) Does your household eat the (CROP TYPE) that you grow? (*0= no; 1= yes; 88= NA*)	(b) Do you ever sell, barter or trade the (CROP TYPE) that you grow for cash or other goods? (*0=no; 1= yes, sometimes; 2=yes, regularly*)

Appendix 4 (Continued)

3.3	Does any member of this household own livestock of any kind, including cattle, goats, pigs, chickens, farmed fish, or other types of livestock? *(0= no, SKIP to Q 3.5; 1= yes)*	

3.4 What types of livestock do you own? ***Note:*** *Create a list of livestock types. Then, for each type, ask parts (a) and (b). Probe for poultry, farmed fish, and other livestock types listed in your manual.*

Livestock Type	(a) What is the main reason that your household raises (LIVESTOCK TYPE)? (*See codes below; use up to two codes for each livestock type)*		(b) Do you ever sell, barter or trade the (LIVESTOCK TYPE) or its products for cash or other goods? *(0= never; 1= sometimes; 2= regularly)*	(c) How many of this (LIVESTOCK TYPE) does the household have at this moment?

Codes (a): *1= family consumption of animals; 2= family consumption of animal products (milk or eggs); 3= consumption on special occasions (to serve to visitors, celebration, holiday); 4= to sell animals; 5= to sell animal products (milk or eggs); 6= for fertilizer; 7= to prepare land; 77= other, specify*

H. Income from natural resources: Does anyone in this household sell (ITEM NAME)?

3.5	Timber, firewood, or charcoal? *(0=no; 1= yes)*	
3.6	Wild-caught (non-farmed) fish? *(0=no; 1= yes)*	
3.7	Other wild products including wild nuts, seeds, berries, mushrooms, game animals, wild honey, and/or medicinal plants? *(0=no; 1= yes)*	

I. Compensation and wages

3.8	Has any member of the HH had paid work over the past 6 months, including during the planting or harvesting season, such as piece-work or casual labor? Paid work may include working for compensation in kind (i.e. for meali meal). This does not include income from a business that this household owns. *(0= no, SKIP to Q 3.11; 1= yes)*	
3.9	Has any member of the household had paid work over the past 30 days, such as piece-work or casual labor? Paid work may include working for compensation in kind (i.e. for meali meal). This does not include income from a business that this household owns. *(0= no, SKIP to Q 3.11; 1= yes)*	

3.10 What type of work has (he/she) done? How many days over the past 30 days did (he/she) do this work? *Probe:* Any other paid work in the HH? ***Note:*** *One person can be listed more than once for different jobs.*

HH member (using individual code from 1.12)	**Type of work**	**Days worked in past 30 days**

J. Income from non-agriculture business

3.11	Has anyone in this household received income from his/her own business over the past 30 days, not including the sources of income already mentioned above? *(0= no, SKIP to Q 3.13; 1= yes)*	

Associated Field Site code: ____________________________ HH code: ____________________________

3.12 What type of business does (he/she) have? *Probe:* Any other business income in the household?
***Note**: Confirm that business has not already been listed in parts G, H, and I before listing it here.*

HH member (using individual code from 1.12)	**Type of business**

K. Other income sources (*use as many codes as applies)*

3.13 Are there any other sources of income received by the household over the past 3 months?						

***Codes:** 0= no other sources of income; 1= regular income from a family member living and working elsewhere; 2= gifts or financial support from relatives or friends; 3= cash support from government, church, or other organization; 4= pension; 5= payment for renting out land; 77= other, specify*

Section 4. Household food security

L. Household Food Insecurity Access Scale (HFIAS): The next set of questions is about your household's access to food over the past 4 weeks. ***Note:** "Rarely"= once or twice in the past 4 weeks; "Sometimes" = 3 to 10 times in the past 4 weeks; "Often"= more than 10 times in the past 4 weeks*

Question	**Response options**	**Code**
4.1 In the past 4 weeks, was there ever a time that you were worried that your household would not have enough food?	*0= No (SKIP to Q 4.3)* *1= Yes*	
4.2 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.3 In the past 4 weeks, was there ever a time that you or any household member were not able to eat the kinds of foods you preferred because of a lack of resources?	*0= No (SKIP to Q 4.5)* *1= Yes*	
4.4 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.5 In the past 4 weeks, was there ever a time that you or any household member had to eat a limited variety of foods due to a lack of resources?	*0= No (SKIP to Q 4.7)* *1= Yes*	
4.6 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.7 In the past 4 weeks, was there ever a time that you or any household member had to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?	*0= No (SKIP to Q 4.9)* *1= Yes*	
4.8 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.9 In the past 4 weeks, was there ever a time that you or any household member had to eat a smaller meal than you felt you needed because there was not enough food?	*0= No (SKIP to Q 4.11)* *1= Yes*	
4.10 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.11 In the past 4 weeks, was there ever a time that you or any household member had to eat fewer meals in a day because there was not enough food?	*0= No (SKIP to Q 4.13)* *1= Yes*	
4.12 How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	

Appendix 4 (Continued)

4.13	In the past 4 weeks, was there ever at time when there was no food to eat of any kind in your household because of lack of resources to get food?	*0= No (SKIP to Q 4.15)* *1= Yes*	
4.14	How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.15	In the past 4 weeks, was there ever a time that you or any household member went to sleep at night hungry because there was not enough food?	*0= No (SKIP to Q 4.17)* *1= Yes*	
4.16	How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
4.17	In the past 4 weeks, was there ever a time you or any household member went a whole day and night without eating anything because there was not enough food?	*0= No (SKIP to Part M)* *1= Yes*	
4.18	How often did this happen?	*1= Rarely; 2= Sometimes; 3= Often*	
		Total HFIAS Score (Range 0 – 27):	

M. Coping Strategies Index (CSI): These last questions ask you about the things that you did when your household did not have enough food or money to buy food in the past 7 days.

Note: *Ask part (a) first. If the answer is "yes", probe with part (b). If the answer is "no", write 0 in (b).*

a) In the past 7 days, when you did not have enough food or money to buy food, has your household ever had to (ROW ITEM)?		b) In the past 7 days, how many days did this happen? *(enter 0 - 7)*
4.19	Rely on less preferred and less expensive foods	
4.20	Borrow food or money, or rely on help from a friend or relative	
4.21	Purchase food on credit	
4.22	Gather wild plants for food	
4.23	Hunt with a gun or snare	
4.24	Harvest immature crops	
4.25	Consume seed stock being held for next season	
4.26	Send household members to eat elsewhere	
4.27	Send household members to beg	
4.28	Limit portion size at mealtimes	
4.29	Cook differently in order to spread the meal among more people	
4.30	Decrease your own meal size in order for children to eat	
4.31	Limit food for non-working members of the household to feed working members	
4.32	Replace a meal with tea, water or porridge	
4.33	Reduce number of meals eaten in a day	
4.34	Go entire days without eating	

N. Months of Adequate Household Food Provisioning (MAHFP)

5.1	Think back over the past 12 months, all the way to December/January of last year. Were there months, in the past 12 months, when you did not have enough food to meet your family's needs? *(0= no; 1= yes)*	
5.2	*If yes:* Which were the months in the past 12 months during which you did not have enough food to meet your family's needs? [ ] January [ ] February [ ] March [ ] April [ ] May [ ] June [ ] July [ ] August [ ] September [ ] October [ ] November [ ] December	
5.3	Total number of months with inadequate foods: _______	

Finish time: ________________

Form 1, Page 6 of 6

Appendix 4 (Continued)

Associated Field Site code: ____________________ HH code: ______________________

Women's Nutrition and Wellbeing Survey, Form 2 **DEC 2014**

Administered to woman 15-49 years old

Section 1. Interview details

1.1 *Date:* ____ / _____ /______ *Start time:* ________________

1.2 *Interviewer:* ____

1.3 Woman's first name: _________________________	**1.4** *Code (Q1.12, Form 1):*_________	
1.5 Are you currently pregnant? *(0= no, 1= yes, 99= don't know)*		
1.6 *If yes:* What trimester in your pregnancy are you in? *(1= first; 2= second; 3= third, 88= NA, not pregnant; 99= don't know)*		
1.7 Are you currently breastfeeding? *(0= no, 1= yes)*		
1.8 How old is the child you are breastfeeding? *(enter in months)*		
1.9 What is your marital status? *(1= married or living with a man as if married; 2= single; 3= separated; 4= widowed; 5= divorced; 6= have a boyfriend who lives separately)*		
1.10 *If married or cohabitating:* Including yourself, how many wives or partners does your husband have?		
1.11 *If >1 wife*: Are you the first, second, third, …, wife? *(enter rank)*		

Section 2. Women's Dietary Diversity Score (WDDS)

2.1 How many meals did you eat yesterday during the day or night? ___________

Please describe all foods, meals, and snacks that you ate or drank yesterday during the day and night. Start with the first food or drink of the morning. ***Note:*** *Write down all foods and drinks mentioned. When mixed dishes are mentioned, ask for a list of ingredients and list them.*

Morning	Afternoon	Evening

- *When the recall is complete, circle each food that is mentioned in the 'Example Items' column below and place a '1' in each row if any items from that food group were mentioned*
- *If the food mentioned is not listed below, circle it above and discuss with supervisor.*
- *Ignore any foods eaten in small amounts (< 1 tablespoon), like seasoning*
- *For any food group not mentioned, probe:* (Yesterday/ 2 days ago) during the day or night, did you eat any (FOOD GROUP), such as (EXAMPLE ITEMS)?

	Food groups	**Example items**	**NO= 0 YES= 1**
2.2	Starchy staples (cereals, roots, tubers)	Maize, rice, wheat, sorghum, millet, other grains or foods made from grains (nshima, bread, buns, fritters, noodles, porridge); Irish potatoes, white yam, white sweet potatoes, cassava, manioc, other foods made from roots	
2.3	Dark green leafy vegetables	Kale, rape, amaranth, cassava leaves, Chinese rape, cowpea leaves, spinach, collard greens, pumpkin leaves (chiwawa), sweet potato leaves, other leafy greens, including wild forms	
2.4	Vitamin A rich fruits and veggies	Pumpkin, butternut, carrot, squash, red or yellow yams, orange, red or yellow sweet potato, red sweet pepper; mango, cantaloupe, apricot, papaya (paw paw), peach	

Appendix 4 (Continued)

2.5	Other fruits and vegetables	Other vegetables not included above (tomato, onion, eggplant, cabbage, mushrooms, green peppers, okra, cucumber); other fruits not mentioned above (wild fruit, bananas, oranges, guava, grapes, masau, watermelon, baobab, cashew nut fruit, nchenja, African horned melon (kiwano, orange spiky cucumber))	
2.6	Organ meat	Liver, kidney, heart or other organ meats (offal)	
2.7	Meat and fish	Beef, pork, lamb, goat, rabbit, bushmeat, nyama, field mice, chicken, duck, other birds, insects or grubs, caterpillars, fresh or dried fish, kapenta	
2.8	Eggs	Eggs from chicken, duck, guinea fowl, or any other egg	
2.9	Legumes, nuts and seeds	Beans, soybeans, cowpeas, green gram (kankhoma), pigeon peas, peas, lentils, groundnuts, sunflower seeds, sesame, other nuts, seeds or foods made from these (e.g. peanut butter, soy milk, Soya pieces)	
2.10	Milk products	Milk, cheese, yogurt, or other milk products from animal source	
		Total WDDS (add 2.2 through 2.10; range 0–9):	

2.11	In the past 30 days, have you eaten anything that is not food because you have cravings (or strong desire) for it, like earth/soil, clay, stones, ash, charcoal, or uncooked rice, uncooked flour, or uncooked potatoes? *(0=no; 1=yes)*	

In the past 7 days, how many times did you eat (ROW ITEM)?		**No. of times**
2.12	Meat of any kind (e.g. beef, pork, nyama/bushmeat, lamb, goat, chicken, duck, guinea fowl), but not including fish or kapenta	
2.13	Fish	
2.14	Kapenta	
2.15	Milk, cheese, yogurt, or other milk products from animal source	
2.16	Eggs from chicken	
2.17	Eggs from other birds, like duck, guinea fowl, or any other non-chicken poultry	
	Total ASF Score (add 2.12 through 2.17):	

What is the main reason that you don't eat more:		**Code** *(see below)*
2.18	Meat of any kind, but not fish or kapenta	
2.19	Fish	
2.20	Kapenta	
2.21	Milk	
2.22	Eggs of any kind	

Codes: *1= cost, it is too expensive; 2= lack of availability, it is difficult to find; 3= I don't like or prefer not to eat it; 4= I'm allergic; 5= religion/ traditional beliefs; 6= someone else in the HH does not eat it; 77= other, explain; 88= NA, we eat as much as we want and need*

When you do eat (ITEM), where do you mostly get it from?		**Code** *(see below)*
2.23	Meat of any kind, but not fish or kapenta	
2.24	Fish	
2.25	Kapenta	
2.26	Milk	

Codes: *1= livestock raised at home; 2= purchased from market or road-side stalls; 3= purchased from family or neighbors; 4= borrowed/gifted from family or neighbors; 5= hunting/fishing from wild; 77= other, explain; 88= NA, we don't eat it*

Section 3. Food decisions and perceptions

3.1.	Who is usually served first at meals in your household? *(1= Woman herself; 2= spouse; 3= children; 4= other adult men (not husband); 5= other adult women (not woman herself); 6= all served at the same time, SKIP next two questions; 77= other, specify*	
3.2.	Who is usually served second at meals in your household? *(1= Woman herself; 2= spouse; 3= children; 4= other adult men (not husband); 5= other adult women (not woman herself); 6= all served at the same time; 77= other, specify*	
3.3.	Who is usually served last at meals in your household? *(1= Woman herself; 2= spouse; 3= children; 4= other adult men (not husband); 5= other adult women (not woman herself); 6= all served at the same time; 77= other, specify*	

Appendix 4 (Continued)

Associated Field Site code: ______________________		HH code: __________
3.4.	Who <u>usually</u> decides what types of foods the family will eat? *(1= woman herself; 2= husband; 3= husband and wife are equally responsible for deciding; 4= mother or father; 77= other, specify)*	

Egg preference and consumption

3.5	Do you like eggs? *(0= no; 1= yes)*	
3.6	What are the main reasons that you and your family eat eggs? (*1= easy/quick; 2= low cost; 3= taste/ we like them; 4= nutritious; 5= change the diet; 77= other, specify)*	
3.7	In the past <u>7 days</u>, how many <u>chicken eggs</u> did this HH eat in total?	
3.8	In the past <u>7 days</u>, how many <u>eggs from other birds</u> did this HH eat in total?	

Egg handling

3.9	After bringing eggs into the HH, how long do you <u>usually</u> store them before you eat them? (*0= eat them immediately, otherwise enter number of days)*	
3.10	Before cooking eggs, do you wash the outside of them? (*0= no; 1= yes)*	
3.11	Do you <u>usually</u> buy eggs raw or already cooked (hardboiled)? (*1= raw; 2= already cooked (hardboiled))*	
3.12	There are many ways to cook eggs. How do you <u>usually</u> cook eggs? (*1= scrambled; 2= hardboiled; 3= fried; 4= mixed with other relish; 5= in a baked food (e.g. cake); 77= other, specify ______________)*	

Perception about egg safety and social acceptability

Show Image 1, the 5 point scale of agreement level. For the next set of questions, I will read you some about eggs. You can choose to strongly disagree, mildly disagree, neither agree nor disagree, mildly agree, or strongly agree. You can see in the pictures of this woman's face are meant to represent each of these feelings, each associated with a number. For each statement, choose a number or point to a face that most closely matches how you feel about the statement. <u>Remember, there is no right answer!</u>

3.13	Eggs are safe to eat.	1= strongly disagree to 5= strongly agree	
3.14	Raw or undercooked eggs can make me sick.	1= strongly disagree to 5= strongly agree	
3.15	Eggs that are too old are more likely to make me sick than eggs that are fresh.	1= strongly disagree to 5= strongly agree	
3.16	I should wash my hands after handling raw eggs.	1= strongly disagree to 5= strongly agree	
3.17	There is more risk of getting sick from eating Soya Pieces or vegetables than from eating eggs.	1= strongly disagree to 5= strongly agree	
3.18	The eggs that are available to buy in this area are fresh and safe to eat.	1= strongly disagree to 5= strongly agree	
3.19	Eggs available to buy at the shop or at road-side stalls are not as safe as eggs taken directly from a hen.	1= strongly disagree to 5= strongly agree	
3.20	Eggs taken directly from the hen have more nutrients than eggs bought at the shop or road-side stalls.	1= strongly disagree to 5= strongly agree	
3.21	Eggs should be stored in a cool place to keep them fresh and safe.	1= strongly disagree to 5= strongly agree	
3.22	Eggs are good for small babies (under 12 months) to eat.	1= strongly disagree to 5= strongly agree	
3.23	Eggs are good for toddlers (12 months to 3 years) to eat.	1= strongly disagree to 5= strongly agree	
3.24	Eggs are good for school age children to eat.	1= strongly disagree to 5= strongly agree	
3.25	Eggs are good for pregnant women to eat.	1= strongly disagree to 5= strongly agree	

Appendix 4 (Continued)

3.26	Eggs are good for breastfeeding women to eat.	1= strongly disagree to 5= strongly agree	

3.27	Are there any people who are not supposed to eat eggs because of traditional or cultural reasons? *(0= no, SKIP to 3.21; 1= yes)*	
3.28	Who is not supposed to eat eggs? *(1= babies, 2= young children, 3= pregnant women, 4= breastfeeding women, 5= any women, 77= other, specify)*	

Physical accessibility of eggs

3.29	Where does the HH get most of the eggs that it eats? (*1= own village hens; 2= road-side stalls; 3= store; 4= own layer hens/ production facility; 5= nearby egg production facility; 6= neighbor's village hens; 77= other, specify)*	
3.30	How long do you usually travel to get eggs? *(enter number of minutes)*	

Section 4. Women's health and wellbeing

Subjective wellbeing. *Show respondent Image 2, "The Ladder"*

4.1	Please imagine a ladder with steps numbered from 1 at the bottom to 10 at the top, like the one in this picture. The top of the ladder represents the best possible life for you (10) and the bottom of the ladder represents the worst possible life for you (0). Please point to the step of the ladder that you personally feel that you stand at this time?	
4.2	Using your best guess, what step do you think you stood on in the past, around 2009?	
4.3	Using your best guess, what step do you think you will stand on in the future, say in 2019?	

Physical and emotional health. Let's look at the ladder again. This time, for each question I will tell you what the lowest and highest steps on the ladder mean, and you can point to any step or tell me any number from 0 to 10 that represents how you would like to answer the question. Please feel free to ask for clarifications as we go. ***Note:*** *As you define the steps, point to the lowest step as you read (0) and the highest step as you read (10).*

		Step definitions	**Code**
4.4	Overall, how would you rate your health during the past 4 weeks?	0= very poor health 10= excellent health	
4.5	During the past 4 weeks, did you have any difficulty doing your daily work, either at home or away from home, because of physical health problems?	0= no (enter '10' for Q4.6 and SKIP to Q4.7) 1= yes (go to Q4.6)	
4.6	*If yes:* Would you rate this difficulty that you had doing your daily work as extreme difficulty (0), moderate difficulty (5), small difficulty (9), or somewhere in between?	0= you were not able to work at all 10= you were able to do everything without limitations	
4.7	During the past 4 weeks, did you have any bodily pain?	0= no (enter '10' for Q4.8 and SKIP to Q4.9) 1= yes (go to Q4.8)	
4.8	*If yes:* Would you rate this pain as the worst possible pain (0), moderate pain (5), very low pain (9), or somewhere in between?	0= very severe pain 10= no pain at all	
4.9	During the past 4 weeks, how much energy did you have? Almost no energy (0), moderate energy (5), very good energy (10), or somewhere in between?	0= no energy 10= very good energy	
4.10	During the past 4 weeks, have you been feeling anxious, sad, depressed, or irritated at all?	0= no (enter '10' for Q4.11 and SKIP to Q4.12) 1= yes (go to Q4.11)	

Form 2, Page 4 of 4

Associated Field Site code: ______________________ HH code: ________

4.11	*If yes:* Did you have this feeling of anxiety, sadness or depression all the time (0), about half the time (5), just a few times (9), or somewhere in between?	0= all the time 10= not at all	
4.12	During the past 4 weeks, did your physical health or emotional problems limit your usual social activities with family or friends at all?	0= no (enter '10' for Q4.13 and SKIP to Q4.14) 1= yes (go to Q4.13)	
4.13	*If yes:* How much did your health problems limit your social activities? Did it completely limit you from doing any social activities (0), limit you somewhat (5), limit you just a little bit (9), or somewhere in between?	0= you have not been able to do any social activities 10= you have not been limited in your social activities at all	

Finish time: ________________

Appendix 4 (Continued)

Associated Field Site code: ________________________ HH code: ___________________________

Child Nutrition Survey, Form 3 **DEC 2014**

Administered to mother of selected child, or primary caregiver of child if mother is not in household

Section 1. Interview details

1.1 *Date:* ____ / _____ /______ *Start time:* ________________

1.2 *Interviewer:* _______________________________________

1.3 Respondent's first name: ___________________________________

1.4 Child's first name: _______________________	***1.5*** *Child's code (Q1.12, Form 1):*_______

1.6 Child's date of birth (MM/YYYY): ________ *Calculate child's age:* _________*months*

Section 2. Child's Dietary Diversity Score (CDDS).

2.1 How many meals did (CHILD) eat yesterday during the day and night? _______

I would like you to describe everything that (CHILD) ate yesterday during the day and night, both at home and outside the home. ***Note:*** *Write down all foods and drinks mentioned. When mixed dishes are mentioned, ask for a list of ingredients and write them out separately.*

a) When (CHILD) first woke up yesterday, did (he/she) eat anything at that time? *If yes:* Please tell me everything (CHILD) ate at that time. *Probe:* Anything else? *Continue probe until nothing else.*

b) What did (CHILD) do after that? Did (CHILD) eat anything at that time? *If yes:* Please tell me everything (CHILD) ate at that time. *Probe:* Anything else? *Continue probe until nothing else.*

Repeat question (b) above until respondent says that the child went to sleep for the night.

c) Did (CHILD) sleep through the night? *If no:* Did (CHILD) eat anything during the night?

Morning	Afternoon	Evening / Night

- *Probe for condiments, sugar, and oils/fats.*
- *When recall is complete, circle each food that is mentioned in 'Example Items' column below and place a '1' in each row if any items from that food group were mentioned.*
- *If the food mentioned is not listed below, circle it above and discuss with supervisor*
- *If foods are used in small amounts for seasoning, include them as "condiments"*

Appendix 4 (Continued)

For any food group not mentioned, probe: (Yesterday/ 2 days ago) during the day or night, did (CHILD) taste and (FOOD GROUP), such as (EXAMPLE ITEMS)?

	Food groups	**Example items**	**NO= 0 YES= 1**
2.2	Starchy staples (cereals)	Maize, rice, wheat, sorghum, millet, other grains or foods made from grains (nshima, bread, buns, fritters, noodles, porridge)	
2.3	Vitamin A rich vegetables	Pumpkin, butternut, carrot, squash, red or yellow yams, red or orange or yellow sweet potato, red sweet pepper	
2.4	Roots and tubers	Irish potatoes, white yams, white sweet potato, manioc, cassava, other roots or tubers	
2.5	Dark green leafy vegetables	Kale, rape, amaranth, cassava leaves, Chinese rape, cowpea leaves, spinach, pumpkin leaves (chiwawa), collard greens, sweet potato leaves, other leafy greens, including wild forms	
2.6	Vitamin A rich fruits	Ripe mango, cantaloupe, apricot, papaya (paw paw), peach	
2.7	Other fruits and vegetables	Other vegetables not included above (e.g. tomato, onion, eggplant, cabbage, mushrooms, green peppers, okra, cucumber); other fruits not mentioned above, including wild fruit, bananas, oranges, guava, grapes, masau, watermelon, baobab, nchenja, cashew nut fruit, African Horned melon (kiwano, orange spiky cucumber)	
2.8	Organ meat	Liver, kidney, heart or other organ meats (offal)	
2.9	Meat (excluding fish)	Beef, pork, lamb, goat, rabbit, bushmeat (nyama), field mice, chicken, duck, pigeon, other poultry; not including insects or grubs	
2.10	Eggs	Eggs from chicken, duck, guinea fowl, or any other egg	
2.11	Fish	Fresh or dried fish, kapenta, shellfish	
2.12	Legumes, nuts and seeds	Beans, soybeans, cowpeas, green gram (kankhoma), pigeon peas, peas, lentils, sunflower seeds, groundnuts, sesame, other nuts, seeds or foods made from these (e.g. peanut butter, Soya Pieces)	
2.13	Milk and milk products	Animal-sourced milk, cheese, yogurt, cream, or other milk products; NOT INCLUDING BREASTMILK	
2.14	Oils and fats	Any oil, fats, butter, or foods made with any of these	
2.15	Sugar	Any sugary foods, e.g. sugar, sugar cane, chocolate, sweets, candy, pastries, cakes or biscuits, honey, soft-drink, juice or juice drinks	
2.16	Condiments	Anything used in small amounts, including chilies, spices, herbs, fish powder, salt, baking soda (including spices in Soya Pieces)	
2.17	Insects	Grubs, snails, caterpillars, or insects	
		Total CDDS (add 2.2 through 2.17; range 0–16):	

In the past 7 days, how many times did (CHILD) eat (ROW ITEM)?		**No. of times**
2.18	Meat of any kind (nyama/ bushmeat, field mice, beef, pork, lamb, goat, chicken, duck, guinea fowl), but not including fish or kapenta	
2.19	Fish	
2.20	Kapenta	
2.21	Milk, cheese, yogurt, or other animal-sourced milk products (NOT INCLUDING BREASTMILK)	
2.22	Eggs from chicken	
2.23	Eggs from duck, guinea fowl, or any other non-chicken poultry	
	Total ASF Score (add 2.18 through 2.23):	

Form 3, Page 2 of 3

Appendix 4 (Continued)

Associated Field Site code: _________________________ HH code: ____________________________

Section 3. Breastfeeding history

3.1	Has (CHILD) ever been breastfed? *(0= no, SKIP to Q 3.4; 1= yes; 99= don't know)*	
3.2	Was (CHILD) breastfed yesterday during the day or night? (*0= no; 1= yes, SKIP to 3.4; 99= don't know)*	
3.3	At what age did you stop breastfeeding (CHILD)? (*Enter in months. Enter '0' if less than 1 month)*	
3.4	Sometimes babies are fed breast milk in different ways, by spoon, cup or bottle, or are breastfed by another woman. Did (CHILD) consume breast milk in any of these ways yesterday during the day or night? (*0= no, SKIP to 3.7; 1= yes; 99= don't know)*	
3.5	Was (CHILD) given breast milk in this way yesterday? *(0= no; 1= yes, SKIP to 3.7)*	
3.6	At what age did you stop giving (CHILD) breast milk in this way? *(Enter in months)*	
3.7	At what age did (CHILD) drink water for the first time? (*Enter in months. Enter '0' if less than 1 month.)*	
3.8	At what age did (CHILD) eat solid or semi-solid foods for the first time? (*Enter in months. Enter '0' if less than 1 month.)*	

For children 24 months of age or less:

Section 4. Liquids
Did (CHILD) have any (ROW ITEM) yesterday during the day or night?
If yes for 4.2, 4.3 or 4.5: How many times yesterday during the day or night did (CHILD) consume (ITEM)?

Item		**0= NO; 1= YES; 99= DON'T KNOW**	**No. of times**
4.1	Plain water?		
4.2	Infant formula?		
4.3	Milk from cow, goat, or other animal (non-breast milk, incl. powdered, tinned, or fresh)?		
4.4	Juice or juice drinks?		
4.5	Clear broths?		
4.6	Very thin porridge?		
4.7	Other liquids? (specify: ________________________)		

For all children:

Section 5. Child health

Did (CHILD) have (ROW ITEM) in the past 2 weeks?		**0= NO; 1= YES; 99= DON'T KNOW**
5.1	Diarrhea (≥ 3 stools in one day)?	
5.2.	Diarrhea with blood in the stool?	
5.3.	Fever?	
5.4.	Illness with cough and short, rapid breathing?	
5.5.	Diagnosis of malaria by a health professional?	
5.6.	Vomiting	

Finish time: ________________

Appendix 4 (Continued)

Associated Field Site code: ____________________ HH code: ______________________

Luangwa Valley Anthropometrics, Form 4

For all children in HH aged 6 to 36 months of age and their mothers (age 15-49 years), or other woman completing Form 2

Section 1. Session details Date: ____ / _____ / ______

Measurer 1: ______________________________ Measurer 2: _______________________________

Section 2. Child anthropometric data. *Check Question 1.12 on Form 1 for any children age 6 to 36 months in this HH. Enter names and codes from Form 1, Q1.12. Confirm age in months. Enter the mother's individual code or check "NA" if the mother is deceased or otherwise not a member of the household. Take a third measure if the difference between the first two measures is greater than or equal to the allowed difference. Check for bilateral edema.* ***Ref= refused; NA= not applicable (if third measure is not needed)***

	Child 1	**Child 2**	**Child 3**	**Child 4**
2.1 Child name / code				
2.2 Child's age	months	months	months	months
2.3 Mother's code	_______ ☐ NA	_______ ☐ NA	_______ ☐ NA	_______ ☐ NA
2.4 Weight (kg)				
First measure	______. ___ kg	______. ___ kg	______. ___ kg	______. ___ kg
Second measure	______. ___ kg	______. ___ kg	______. ___ kg	______. ___ kg
Third measure (*if differences ≥ **0.5 kg)***	______. ___ kg	______. ___ kg	______. ___ kg	______. ___ kg
2.5 Height (cm)				
First measure	_______. ___ cm	_______. ___ cm	_______. ___ cm	_______. ___ cm
Second measure	_______. ___ cm	_______. ___ cm	_______. ___ cm	_______. ___ cm
Third measure (*if difference ≥ **1 cm)***	_______. ___ cm	_______. ___ cm	_______. ___ cm	_______. ___ cm
2.6 Measured lying down or standing up?	☐ Lying down ☐ Standing up	☐ Lying down ☐ Standing up	☐ Lying down ☐ Standing up	☐ Lying down ☐ Standing up
2.7 MUAC (cm)				
First measure	______. ___ cm	______. ___ cm	______. ___ cm	______. ___ cm
Second measure	______. ___ cm	______. ___ cm	______. ___ cm	______. ___ cm
Third measure (*if difference ≥ **0.5 cm)***	______. ___ cm	______. ___ cm	______. ___ cm	______. ___ cm
2.8 Bilateral edema?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

Section 3. Maternal anthropometric data. *Measure all women age 15-49 years with a child measured above. If mother is not currently at home, make a callback appointment. If the mother of child is deceased, or if no eligible child is in the HH but the HH is part of the egg production group, measure one woman age 15-49 years who completed Form 2.* ***Ref= refused; NA= not applicable (if third measure is not needed)***

	Woman 1	**Woman 2**	**Woman 3**
3.1 Woman name / code			
3.2 Weight (kg)			
First measure	________. ___ kg	________. ___ kg	________. ___ kg
Second measure	________. ___ kg	________. ___ kg	________. ___ kg
Third measure (*if differences ≥ **0.5 kg)***	________. ___ kg	________. ___ kg	________. ___ kg
3.3 Height (cm)			
First measure	_______. ___ cm	_______. ___ cm	_______. ___ cm
Second measure	_______. ___ cm	_______. ___ cm	_______. ___ cm
Third measure (*if difference ≥ **1cm)***	_______. ___ cm	_______. ___ cm	_______. ___ cm
3.4 MUAC (cm)			
First measure	______. ___ cm	______. ___ cm	______. ___ cm
Second measure	______. ___ cm	______. ___ cm	______. ___ cm
Third measure (*if difference ≥ **0.5 cm)***	______. ___ cm	______. ___ cm	______. ___ cm

APPENDIX 5

Variances and model diagnostics from null and adjusted models for the four outcomes of interest.

	Dietary Diversity		ASF consumption		HAZ		Stunting	
	Null	**Adjusted**	**Null**	**Adjusted**	**Null**	**Adjusted**	**Null**	**Adjusted**
Random effects[a]								
Level 2 variance	0.056	0.029	0.325	0.176	5.28E-17	3.52E-17	0.049	0.089
Level 1 variance	2.062	1.823			1.688	1.452		
Fit statistics								
-2 log likelihood	-1453.0	-1340.0	-394.4	-343.8	-1342.9	-1282.6	-561.5	-485.7
Wald chi2		113.9		68.28		130.2		86.18
AIC	2912	2840	793	723	2692	2613	1127	1017
ICC (rho)	0.027	0.016	0.090	0.051		0.000	0.015	0.026
Overall R^2 [b]		0.1256		0.1380		0.1398		0.1490
R^2, Level 2		0.4821				0.3333		
R^2, Level 1		0.1159				0.1398		

Notes: [a] Level 2 variances refers to the between village variance; Level 1 variance refers to the within village (between household) variance. Stata does not estimate Level 1 variance for random-intercept logistic models. [b] For binary outcome, R^2 was calculated using the method described in Tjur, T. (2009) "Coefficients of determination in logistic regression models - A new proposal: The coefficient of discrimination." *The American Statistician* 63: 366-372. For continuous outcomes, R^2 and its composite parts calculated from Raudenbush & Bryk (2002) *Hierarchical Linear Models: Applications and Data Analysis Methods.* 2nd ed. Thousand Oaks, CA: Sage.

Abbreviations: AIC, Akaike's information criterion; ICC, intraclass correlation coefficient; ASF, animal source food; HAZ, height-for-age z-score

APPENDIX 6

Multilevel mixed-effects linear and logistic regression models assessing the relationship between four child nutrition outcomes and eleven commonly used measures of livestock ownership, compared with findings using livestock typologies as the measure of livestock ownership.

Model	Outcome			
	Child DDS Adjusted β (95% CI)	**Odds of ASF consumption** Adjusted OR (95% CI)	**HAZ** Adjusted β (95% CI)	**Stunting odds** Adjusted OR (95% CI)
Any livestock (yes/ no)	**-0.331***** (-0.542, -0.120)	1.113 (0.730, 1.697)	0.061 (-0.134, 0.259)	0.857 (0.604, 1.217)
Total number of livestock	-0.003 (-0.012, 0.005)	1.015 (0.994, 1.037)	-0.002 (-0.010, 0.007)	1.005 (0.990, 1.020)
TLU	0.003 (-0.062, 0.068)	1.028 (0.895, 1.181)	-0.006 (-0.066, 0.053)	1.030 (0.923, 1.150)
Any chickens	**-0.320***** (-0.524, -0.116)	1.084 (0.717, 1.638)	0.052 (-0.140, 0.243)	0.917 (0.653, 1.288)
Number of chickens (among chicken owners)	**0.022***** (0.006, 0.039)	1.023 (0.979, 1.069)	0.006 (-0.010, 0.023)	0.993 (0.963, 1.025)
Any goats	-0.130 (-0.455, 0.195)	1.336 (0.676, 2.642)	-0.242 (-0.533, 0.050)	1.201 (0.709, 2.035)
Number of goats (among goat owners)	0.004 (-0.037, 0.044)	0.992 (0.857, 1.148)	-0.038 (-0.084, 0.008)	1.044 (0.943, 1.155)
Any pigs	-0.244 (-0.567, 0.080)	0.970 (0.501, 1.879)	-0.039 (-0.335, 0.258)	1.085 (0.639, 1.841)
Number of pigs (among pig owners)	0.011 (-0.017, 0.039)	0.996 (0.906, 1.094)	-0.021 (-0.060, 0.017)	1.048 (0.960, 1.145)
Any cattle	0.206 (-0.213, 0.626)	1.815 (0.688, 4.787)	-0.065 (-0.444, 0.314)	0.941 (0.464, 1.912)
Number of cattle (among cattle owners)	0.126 (-0.009, 0.260)	0.895 (0.568, 1.410)	0.091* (-0.007, 0.188)	0.863 (0.641, 1.162)
Livestock typology (vs. Type 1)				
Type 2	**-0.477***** (-0.733, -0.221)	0.976 (0.582, 1.636)	0.206* (-0.025, 0.437)	0.683* (0.445, 1.048)

Appendix 6 (Continued)

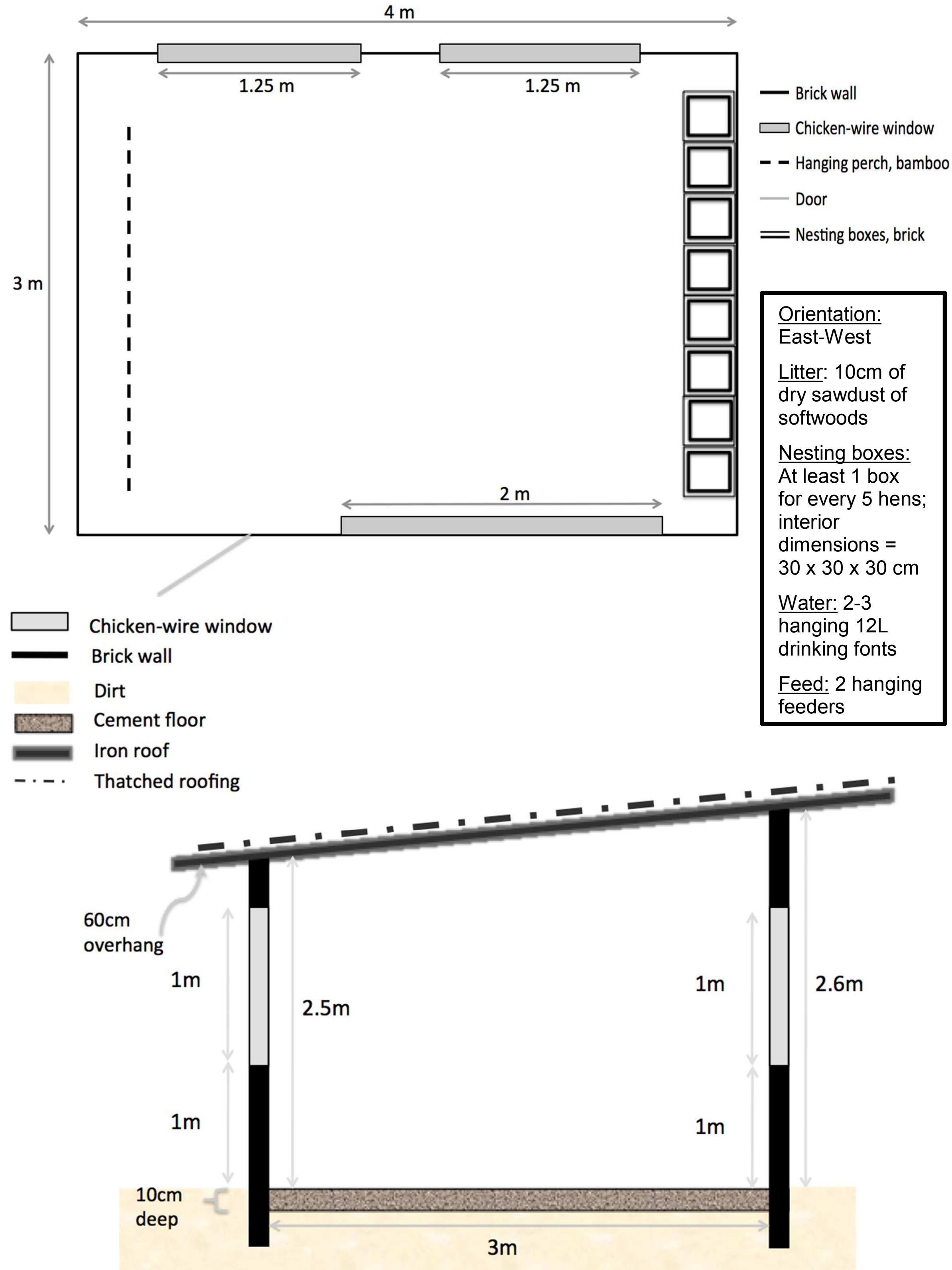
Model	Outcome			
	Child DDS Adjusted β (95% CI)	**Odds of ASF consumption** Adjusted OR (95% CI)	**HAZ** Adjusted β (95% CI)	**Stunting odds** Adjusted OR (95% CI)
Type 3	-0.216 (-0.612, 0.179)	0.932 (0.419, 2.075)	0.036 (-0.315, 0.379)	0.7530 (0.387, 1.463)
Type 4	-0.318 (-0.744, 0.106)	0.682 (0.313, 1.488)	-0.324* (-0.703, 0.055)	1.404 (0.708, 2.781)
Type 5	-0.180 (-0.447, 0.087)	1.782* (0.990, 3.207)	-0.034 (-0.276, 0.207)	1.031 (0.659, 1.612)

Notes: "Model" is the primary exposure used. All models included field site random effects nested within Chiefdom and covariates for households, maternal, and child characteristics. * p< 0.1; ** p< 0.05; *** p< 0.01.

Abbreviations: ASF, animal source foods; DDS, dietary diversity score; HAZ, height-for-age z-score; TLU, tropical livestock units

APPENDIX 7

Egg Production Center: Building Plan and Budget



Appendix 7 (Continued)

Item	Unit	Cost/ unit	# units	Subtotal per EPC (ZMW)	Subtotal per EPC (US$)
Labor, builder	EPC	500	1	500	80.65
Cement	packets	85	6	510	82.26
Bricks	bricks	0*	1300	0	0.00
Roofing nails	kg	20	2	40	6.45
Iron sheets, 12ft long	sheets	68	6	408	65.81
Wood, roof, 4x6"	planks	75	4	300	48.39
Tying wires, roof	m	15	1	15	2.42
Sand	wheel-barrows	0*	3	0	0.00
Crushed stones	wheel-barrows	0*	3	0	0.00
Deformed bars	m	85	10	850	137.10
Chicken wire	sq m	18	5	90	14.52
Door, 1x8"	planks	20	5	100	16.13
Door/window frames, 2x4"	planks	20	4	80	12.90
Hinges	hinges	15	2	30	4.84
Nails, frames, 3"	kg	20	2	40	6.45
Nails, chicken wire, 1"	kg	20	1	20	3.23
Labor, carpenter	facility	210	1	210	33.87
Barrow bolts	each	15	1	15	2.42
Padlock	each	30	1	30	4.84
Waters	each	45	2	90	14.52
Feeders	each	45	2	90	14.52
Lights	each	30	1	30	4.84
Batteries for lights	each	1.5	9	13.5	2.18
TOTAL, per facility				**K 3461.50**	**$ 558.31**

* Provided by producers
Exchange rate at time of materials acquisition (July 2014): US$ 1 = ZMW 6.2

APPENDIX 8

Monthly Egg Production and Sales Record

MONTHLY EGG PRODUCTION AND SALES RECORD

GROUP NAME: ________ CHIEFDOM: ________ VILLAGE: ________ MONTH/ YEAR: ____/____ **FLOCK SIZE:** ____

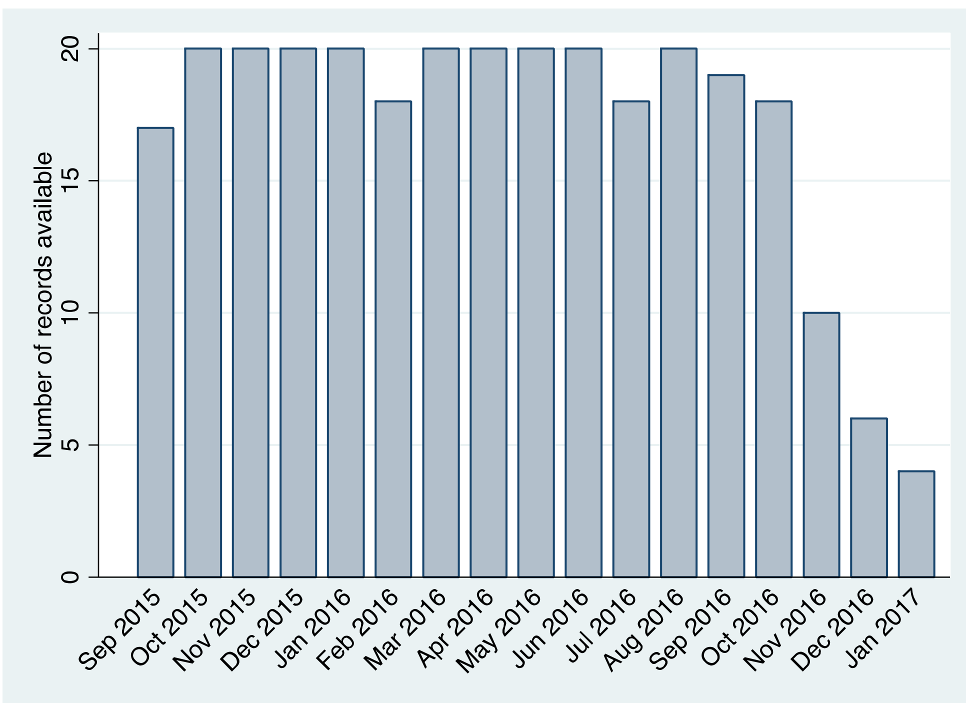
DATE	TOTAL # EGGS COLLECTED	# EGGS EATEN BY GROUP	TOTAL # EGGS SOLD	PRICE PER EGG	**TOTAL INCOME**	FEED EXPENSES	OTHER EXPENSES	**TOTAL EXPENSES**	**TOTAL PROFIT (Income - Expenses)**	ILLNESS	DEATHS	**COMMENTS**
TOTALS:												

APPENDIX 9

Missing production and sales records

Chiefdom	Field site	Number of missing records	Missing records
Jumbe	J2	1	Sep 2015*
	J3	2	Sept 2015*, Sep 2016*
	J4	1	Sept 2015*
	J6	1	Jul 2016 †
Mnkhanya	M1	1	Feb 2016 †
	M2	1	Oct 2016 †
	M4	1	Jul 2016 †
	M7	1	Feb 2016 †
Mwanya	Mw1	15	Sep 2015*, Dec 2015 to Jan 2017*
	Mw2	14	Sep 2015*, Oct 2015*, Dec 2015 to Feb 2016*, May 2016 to Jan 2017*
	Mw3	13	Jan 2016 to Jan 2017*
	Mw4	10	Mar 2016*, May 2016 to Jan 2017*

* Lost
† Omitted due to inconsistent data



Graph showing the number of production and sales records available from 20 EPCs by month. Records from the four facilities in Mwanya were excluded due to high frequency of lost records.

APPENDIX 10

Level-2 variables considered as covariates in a polynomial random-coefficient model of egg productivity and their correlation with overall group productivity.

	Variables[a]	Definition	Corr	Included as potential covariate	Retained in final model
Group characteristics	Distance from paved road[b]	Distance between EPC and nearest paved road (km), measured along roadways or main walking paths	-0.135	Yes	Yes
	≥ 1 man in group	Dummy variable indicating at least one man is a member of the EPC group	-0.291	Yes	Yes
	≥ 1 person with primary education	Dummy variable indicating that at least one member of the EPC group completed their primary education (Grade 7)	-0.105		
	5 group members	Dummy variable indicating the EPC group has five members; if 0, group had < 5 members	0.267	Yes	
	Mean HFIAS	A 9-item questionnaire that captures the frequency of experiences of food insecurity in the HH in the 4 weeks prior to the survey, summed to produce a score from 0 (food secure) to 27 (severely food insecure) and averaged for all EPC members in the group	0.219	Yes	Yes
	Mean HH size	Number of people in a HH, defines as living together and sharing meals at least 4 days per week, averaged for all EPC members in the group	-0.236	Yes	Yes
	% female-headed HHs	Percent of group members who live in a female-headed HH	0.072		
	Mean WDDS	Number of food groups (0 to 9) that the woman (either the egg producer or his wife) consumed in the 24 hours preceding the survey, averaged for all EPC members in the group	0.072		
	Mean asset score	A measure of HH welfare relative to the sample based on a HH's pattern of asset ownership and quality of housing materials, reduced into a single continuous variable with principal components analysis and averaged for all EPC members in the group	0.321	Yes	Yes

Appendix 10 (Continued)

	Mean years in COMACO	Self-reported number of years the egg producer has been a member of COMACO, averaged fro all EPC members in the group	0.204	Yes	Yes
Community characteristics	% of HHs drinking protected water	Percent of HHs in the community who collect their drinking water from a protected well, borehole, or public tap	0.071		
	% of HHs with access to electricity	Percent of HHs in the community with electricity in their homes from solar, battery, or connection to the national grid	0.100		
	% HHs members of COMACO	Percent of HHs in the community who were members of COMACO at the time of the survey	-0.310	Yes	

Abbreviations: COMACO, Community Markets for Conservation; HFIAS, Household Food Insecurity Access Scale; HH, household; WDDS, Women's Dietary Diversity Score

Notes: [a]Variables with $|r| \geq 0.20$ were considered in initial models as potential covariates. During modeling, covariates with the highest p-values were removed from the model sequentially until only variables with $p \leq 0.20$ were retained in the final model. [b]Distance from a paved road was considered despite low correlation based on theory.

APPENDIX 11

Luangwa Valley Annual Egg Producer Interview Guide (Form 6)

For members of the poultry group that own and operate the egg production facility

Thank you for taking the time to meet with me today. The goal of this interview is to help me understand how the egg production business is affecting your and your family's lives. We also wish to know about any troubles and how COMACO can help you to improve your business. This interview is confidential – I will not share any of the details of our discussion with anyone in your group or the community, so you may feel free to be open with me. If you would prefer not to answer any question, let me know and we will move on. I will be recording this interview so please speak up so that you can be heard.

Section 1. Interview details *(Enter in Memo)*

1.1 Date: ____ / _____ /______

1.2 Interviewer name: ____

1.3 Chiefdom, village, and EPC ID number: ______________________________________

1.4 Poultry Group name: ____________________________

1.5 Respondent's first and last name: ____

1.6 Position with poultry group (Ex: president, vice-president, secretary, treasurer, member)

Section 2. Interview

2.1. Why did you initially want to raise layers? What were your goals?

2.2. Tell me about your role in the egg production business. From the time you wake up to the time you go to sleep, what are all the things that you do in the business? *(Probe on various activities, such as cleaning, watering/feeding, egg collection, egg sales, feed purchase and collection, and record keeping).*

2.3. Tell me about the amount of time that you spend on the business.

- **2.3.1.** Does the work change by season? Or by week?
- **2.3.2.** How does the time you spend on this business affect your ability to take care of other responsibilities at home, in the fields, or in other work?
- **2.3.3.** How does the time you spend on this business affect the time you have to rest or sleep?
- **2.3.4.** How much time per week, on average, do you spend in the business?

2.4. Think back to when your group decided on the dividing the workload. How did your group divide work in this business?

2.5. Does the work feel evenly and fairly divided, in your opinion? Does everyone do their fair share?

Appendix 11 (Continued)

2.5.1. If you could, would you want to change how the work is divided now?

2.5.2. Are you happy working with your group or would you rather work alone?

2.6. How does the group make decisions regarding whether eggs should be eaten by your own families or sold?

2.7. Do you take any non-cash payment (trades) you take for eggs? How often? What kind of things will you trade for? What are the advantages of doing this? What are the disadvantages?

2.8. Tell me about the things you and your family or group has been able to buy using the income from egg sales.

2.8.1. How was it decided to buy these things?

2.8.2. Who in your family made the decisions on what to buy?

2.9. Tell me about how this program has benefited your family. *(Probe: What is the income benefit? What is the benefit of having eggs to eat? Is there a social benefit? Do people in your community look at you differently because of your role with this business?)*

2.10. Tell me about what is difficult about being involved in the program. Has the program made you life harder in any way?

2.11. Thinking about your goals for this business, do you feel you met them this year?

2.11.1. Do you plan to continue in this business next year?

2.11.2. Why do you want to continue *(or why do you not want to continue)*?

2.12. What are the things you think <u>you can do</u> to make your business better?

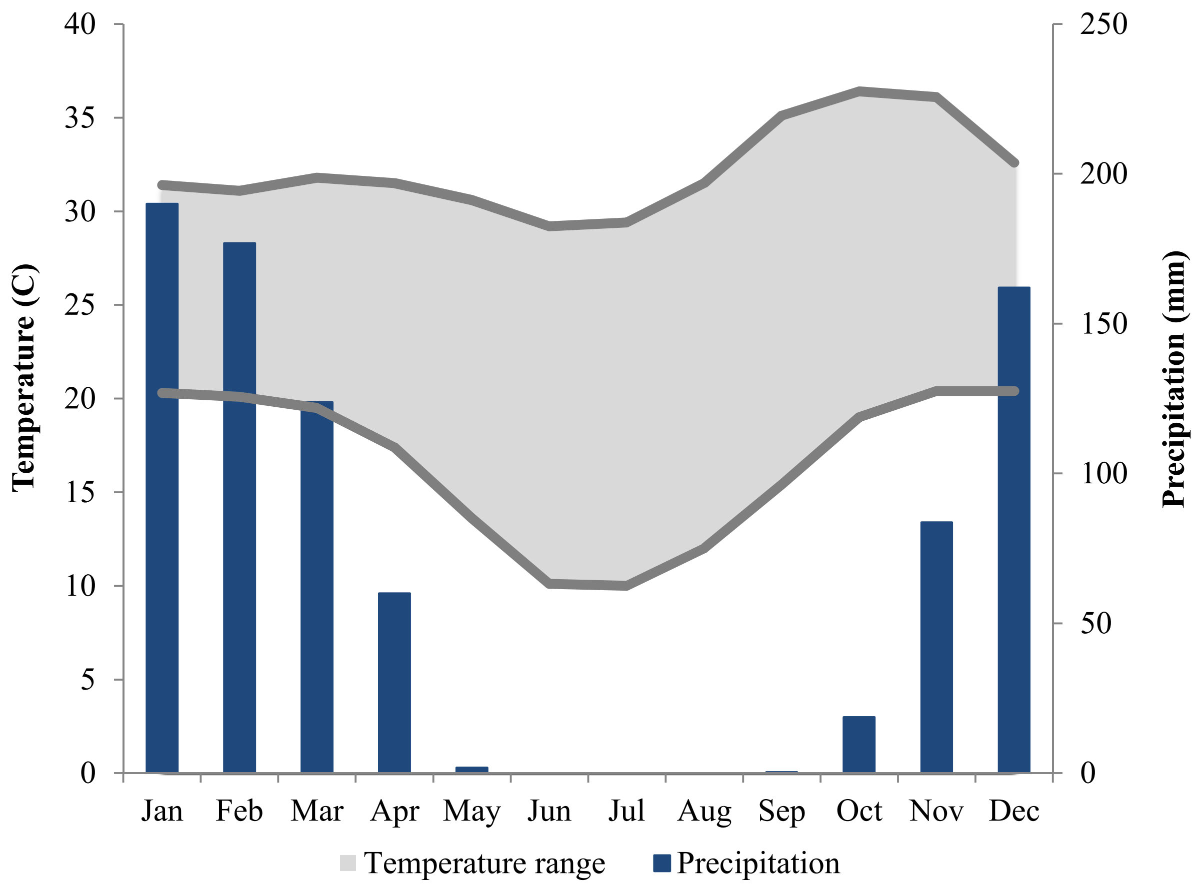
2.12.1. How do you think <u>COMACO</u> could make this program better?

2.13. Overall, do you feel satisfied with this business and this program?

2.14. Is there anything else you'd like to tell me?

APPENDIX 12

Average temperatures and precipitation in Mfuwe, 1961 - 1990



Source: World Meteorological Organization (WMO) and Zambia Meteorological Department, Accessed at https://www.wmo.int/cpdb/zambia#chart_26099

APPENDIX 13

Variables included in the computation of the asset index, derived from the first principal component arising from principal components analysis (PCA), their scoring factors, and the prevalence of ownership across the poorest, middle, and wealthiest households in the dataset.

		Item ownership by wealth tertile		
Variable	**Scoring factor**	**Poorest tertile**	**Middle tertile**	**Wealthiest tertile**
Owns solar panel	0.2946	0.0%	9.2%	60.0%
Owns TV	0.2882	0.0%	0.7%	31.2%
Electricity access	0.2851	1.0%	14.6%	67.7%
Iron or tiled roof	0.2807	2.3%	33.6%	78.2%
Owns DVD or CD player	0.2733	0.0%	3.8%	35.3%
Owns bed	0.2615	0.1%	11.0%	48.6%
Owns invertor or battery	0.2587	0.0%	2.1%	35.7%
Brick walls	0.2550	7.0%	39.5%	78.0%
Dwelling has at least 3 rooms	0.2480	6.1%	29.4%	67.4%
Concrete or tiled floors	0.2418	0.0%	4.4%	32.8%
Owns table	0.2359	5.3%	30.1%	64.9%
Owns sofa	0.2130	0.0%	0.9%	19.1%
Owns radio	0.1981	19.0%	48.0%	75.7%
Owns mattress	0.1967	8.4%	34.2%	62.6%
Owns mobile phone	0.1828	11.2%	33.7%	60.1%
Owns bicycle	0.1554	47.1%	74.6%	90.2%
Owns other asset worth at least K 160	0.1542	0.5%	3.9%	14.3%
Employed agricultural laborers last year	0.1216	9.6%	21.9%	34.3%

Notes: Each variable takes the value of 1 if true and 0 otherwise. Scoring factor is the weight assigned to each variable in the linear combination of the first principal component. Additional variables initially considered for inclusion in the index were: having a private toilet for the household; using a protected drinking water source; using fire as primary method of cooking; employment of a domestic employee; and household ownership of a refrigerator or freezer, vehicle, motorcycle, boat, plough, cart, gun, snare, water pump, clock, bank account, agricultural land, cattle, sheep or goats, pigs, chickens, or other poultry. Twelve variables were excluded from the analysis if there was limited variance within the sample (less than 5% or greater than 95% ownership). Ten additional variables were excluded in a step-wise fashion due to very low scoring factors (<0.1), indicating their low contribution to the discriminatory power of the analysis. In the final PCA, the first component explained 30.3% of the covariance with an eigenvalue of 5.45 and overall Cronbach's alpha of 0.8508.

APPENDIX 14

Descriptions of the Level-1 and Level-2 covariates included in models for each outcome of interest.

Variable	Variable description	Outcome: 1: Household egg acquisition	2: Child egg consumption	3: Women's egg consumption	4: Child dietary diversity	5: Women's dietary diversity	6: Children's HAZ
Household characteristics							
Head of household age	Continuous variable of head of household's age, in years, as indicated on a government document or as recalled by the respondent	X	X	X	X	X	X
Head of household gender	Dummy variable indicating that the head of household is female	X	X	X	X	X	X
Head of household educational attainment	Dummy variable indicating that the head of household completed a primary education (through Grade 7)	X	X	X	X	X	X
Household size	Continuous variable of the number of persons permanently residing in the home at the time of the interview	X	X	X	X	X	X
Member of an EPC group	Dummy variable indicating that someone in the household is a member of the EPC group	X	X	X	X	X	X
Household wealth	An asset index, retained as a continuous variable, determined by the household's pattern of ownership of productive and non-productive assets, household dwelling quality and size, electricity access, and water source	X	X	X	X	X	X
Moderate household hunger	Dummy variable indicating that household experiences of food insecurity over the past 4 weeks were moderate, using the Household Hunger Scale (HHS)	X	X	X	X	X	X
Severe household hunger	Dummy variable indicating that household experiences of food insecurity over the past 4 weeks were severe, using the HHS	X	X	X	X	X	X

Appendix 14 (Continued)

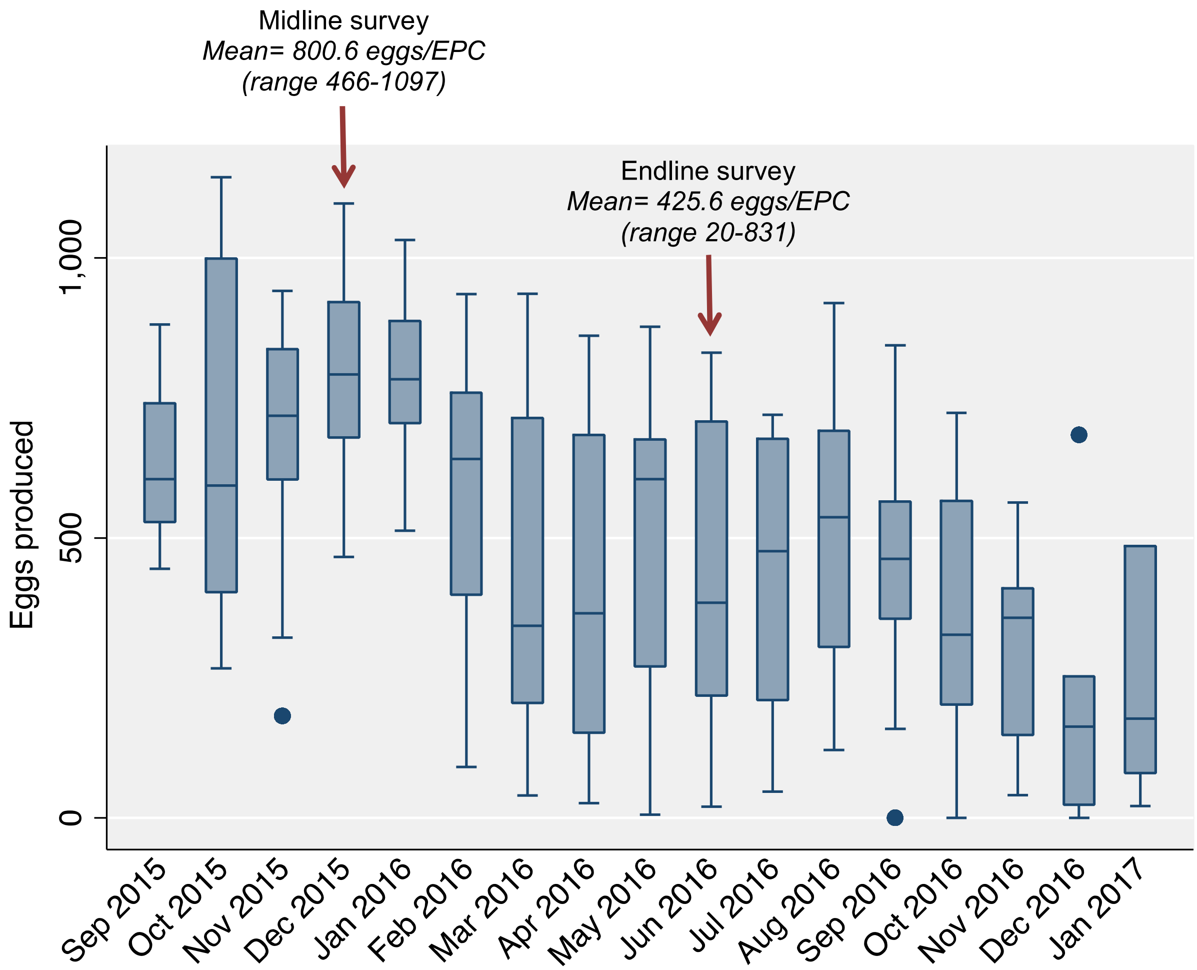
Variable	Variable description	Outcome					
		1: Household egg acquisition	*2: Child egg consumption*	*3: Women's egg consumption*	*4: Child dietary diversity*	*5: Women's dietary diversity*	*6: Children's HAZ*
COMACO member	Dummy variable indicating that someone in the household is a member of COMACO	X	X	X	X	X	X
Off-farm income sources	Dummy variable indicating that the household has had at least one source of income other than selling crop or livestock products over the past 3 months (including from natural resources, earned wages, business ownership, remittances, gifts, or other sources)	X	X	X	X	X	X
Owns chickens	Dummy variable indicating that the household owns at least one chicken	X	X	X	X	X	X
Owns other poultry	Dummy variable indicating that the household owns at least one pigeon, guinea fowl, or duck	X	X	X	X	X	X
Owns cattle	Dummy variable indicating that the household owns at least one cow or bull				X	X	X
Owns goats or sheep	Dummy variable indicating that the household owns at least one goat or sheep				X	X	X
Owns pigs	Dummy variable indicating that the household owns at least one pig				X	X	X
Protected drinking water source	Dummy variable indicating that the household's primary source of drinking water is from piped water, a public standpipe, borehole, or protected well						X
Private household latrine	Dummy variable indicating that the household has a latrine that is used by members of that household only (i.e. not shared with other households)						X

Appendix 14 (Continued)

Variable	Variable description	Outcome					
		1: Household egg acquisition	2: Child egg consumption	3: Women's egg consumption	4: Child dietary diversity	5: Women's dietary diversity	6: Children's HAZ
Women's characteristics							
Woman's educational attainment	Dummy variable indicating that the mother or primary female caretaker of the eligible child completed a primary education (through Grade 7)		X	X	X	X	X
Woman's age	Age of mother or primary female caretaker of the eligible child, in years, as recorded on her National Registration Card (NRC) or as specified by the woman if her NRC is not available		X	X	X	X	X
Woman's BMI	Woman's body mass index, calculated using her height and weight, as measured at the time of the interview						X
Woman's height	Woman's height (cm), measured at the time of the interview						X
Children's characteristics							
Child gender	Dummy variable indicating that the child is female		X		X		X
Child age	Continuous variable of child age in months at the time of the survey as indicated by the child's date of birth recorded on his/her "Children's Clinic Card"		X		X		X
Current breastfeeding status	Dummy variable indicating that the child breastfed or drank human breastmilk from a bottle, cup, or spoon at least once on the day prior to the survey		X		X		X
Child's recent history of morbidities	Dummy variable indicating that the child experienced at least one episode of diarrhea, vomiting, fever, or rapid or difficult breathing with coughing in the past 14 days, as observed and recalled by the mother, or malaria diagnosed by a health professional in the past 14 days		X		X		X

APPENDIX 15

Total number of eggs produced per month in 16 egg production centers* (EPCs)



* *Notes:* 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. Maroon arrows indicate the months that midline and endline surveys were conducted.

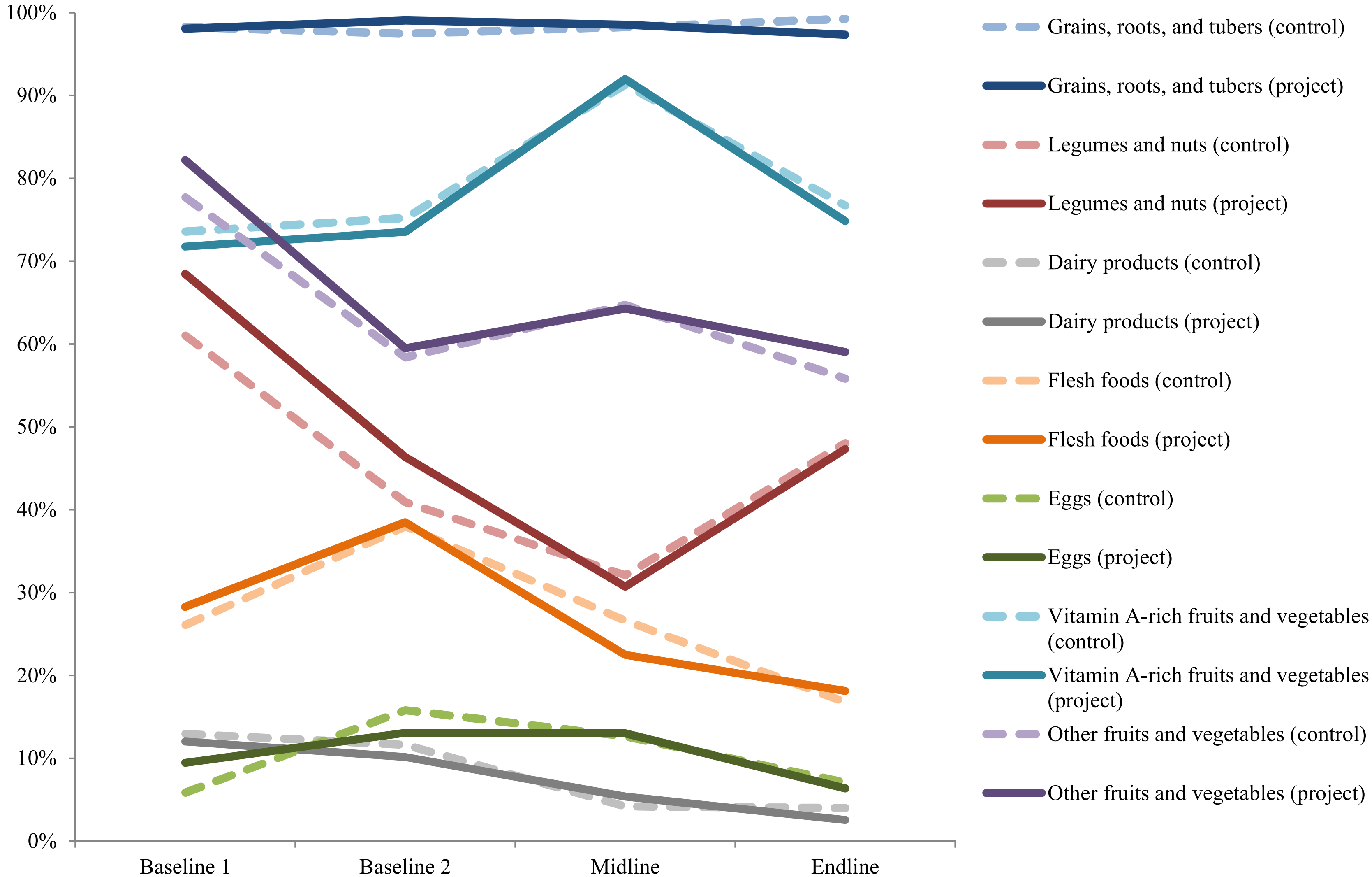
APPENDIX 16

Predicted probability of children's consumption of each food group in the 24 hours preceding the survey

	Baseline 1		Baseline 2		Midline		Endline	
	Control	*Project*	*Control*	*Project*	*Control*	*Project*	*Control*	*Project*
Grains, roots, and tubers	98.27%^{ab}	98.05%^{ab}	97.47%^{a}	99.03%^{ab}	98.26%^{ab}	98.53%^{ab}	99.26%^{b}	97.32%^{a}
Legumes and nuts	61.03%^{d}	68.45%^{d}	40.92%^{b}	46.36%^{bc}	32.12%^{a}	30.72%^{a}	48.06%^{c}	47.33%^{bc}
Dairy products	12.96%^{c}	12.04%^{c}	11.65%^{c}	10.14%^{c}	4.20%^{ab}	5.40%^{b}	4.01%^{ab}	2.54%^{a}
Flesh foods	26.11%^{bc}	28.27%^{c}	38.00%^{d}	38.48%^{d}	26.61%^{bc}	22.48%^{ab}	16.79%^{a}	18.14%^{a}
Eggs	5.88%^{a}	9.44%^{ab}	15.82%^{c}	13.07%^{c}	12.67%^{bc}	13.02%^{c}	7.09%^{a}	6.37%^{a}
Vitamin A-rich fruits and vegetables	73.59%^{a}	71.75%^{a}	75.23%^{a}	73.54%^{a}	91.32%^{b}	91.98%^{b}	76.73%^{a}	74.84%^{a}
Other fruits and vegetables	77.70%^{c}	82.19%^{c}	58.42%^{ab}	59.50%^{ab}	64.73%^{b}	64.28%^{b}	55.84%^{a}	59.05%^{ab}

Notes: Unadjusted pairwise comparisons of marginal linear predictions, assuming that the random effect of community is zero. Margins sharing a letter in the superscript are not significantly different at the 5% level.

Appendix 16 (Continued)



Predicted probability that children in project (solid lines) and control (dashed lines) areas consumed each of the seven food groups in the 24 hours preceding the survey, conditional on the random effect for community.

APPENDIX 17

Proportion of children aged 6-36 months who consumed any animal source foods (ASF) in the seven days prior to the survey, as recalled by their mother or primary caregiver