Healthy chickens, healthy children?
Exploring contributions of village poultry-keeping to the diets and growth of young children in rural Tanzania

by Julia de Bruyn

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Statement of originality

This thesis is submitted to the University of Sydney in fulfilment of the requirements for the degree of Doctor of Philosophy. The material presented has not been submitted for a degree at this or any other institution. I certify that the intellectual content of this thesis is the product of my own work, and that all sources and assistance received in preparing this thesis have been acknowledged.

Julia de Bruyn
December 2017

Abstract

One in three Tanzanian children under five years of age is affected by stunting: an outcome of chronic undernutrition and an indication of impaired physical and cognitive development. The potential for livestock-keeping to contribute positively to children's growth, including by providing nutrient-dense animal-source foods and household income to enable other nutritious food purchases, has been well-described but poorly demonstrated. Village chickens are an accessible and versatile form of livestock, kept in small free-ranging flocks by many households in resource-poor settings and often managed by women. This mixed methods research was undertaken in villages of Manyoni District in central Tanzania, alongside a project establishing a community-based vaccination service against Newcastle disease in village chickens.

Significantly larger chicken flock sizes were identified as an outcome of vaccinating in a given campaign and of continuing to vaccinate at four-monthly intervals, compared to vaccinating less often or not at all. Chicken meat and eggs were infrequently eaten during the study period, with eggs more commonly hatched to increase chicken numbers and chickens retained for sale in times of need. Consumption of poultry products by mothers and their young children was closely linked and no gender-based differences in children's consumption frequency were found. Analysis of national and regional food composition tables highlighted the need for recent and locally-derived data on the nutrient content of animal-source foods, to better reflect the products of indigenous livestock in low-input management systems. This thesis did not identify a significant impact of chicken-keeping on the height-for-age of children over a two-year period; however, importantly, it found no negative health or growth impacts which would undermine a continued focus on poultry interventions as a strategy to sustainably enhance nutrition at a household level.

Acknowledgements

While the final months spent writing this thesis have seemed a solitary venture, the underlying body of work has involved a team which has spanned several countries, languages and research disciplines. My entry into the field of international food and nutrition security in late 2013 marked an abrupt shift from a career as a clinical veterinarian. The learning curve which has followed would not have been possible without the guidance, support and opportunities provided by many people.

I owe a great deal to my primary supervisor, Professor Robyn Alders, who has instilled in me the value of consultative field-based research. I continue to be inspired by Robyn's commitment to tackling the issues which matter to smallholder farmers in resource-poor settings, and working towards sustainable outcomes. My co-supervisor Professor Ian Darnton-Hill's generosity in sharing his experience in international public health nutrition research and policy has been much appreciated, as has his diplomacy and eye for detail. Time spent with my social anthropologist advisor, Dr Brigitte Bagnol, in our study sites and in discussions, has been both enjoyable and invaluable in developing my skills and appreciation of qualitative and cross-cultural research. I have also benefited greatly from the support and endless patience of my statistics advisor, Associate Professor Peter Thomson, in helping me to navigate rich and complex datasets to reach valid conclusions.

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The key role of community leaders, local enumerators and chicken vaccinators in implementing this project cannot be overstated. Thanks especially to our "Community Assistants": Robert Delisa, Theresia Mathias, Jeni Zacharia, Simon Beatus, Johnson Mkuyu, Rosemary Ackley, Esther Kapande, Moses Joseph, Selafina Maloda, Amos Maloda, Angelina Masiaga, Laurent Charles, Suzana Joseph, Happiness Cassian, Marino Alphonce, Agnes Joseph, Mandela Gabriel, Modesta Martin and Yohana Joseph.

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It is hard to imagine the last three-and-a-half years without my friend and ally Johanna Wong. Our chats, discussions and debriefs (from our respective field sites, loitering by the office photocopier, and over dinner) have made the transition to this new subject area and the highs and lows of PhD student life a far greater experience. Thanks also to Dr Darryl Stellmach for the pep-talks, Friday writing sessions, and for broadening the diversity of our female-veterinarian-dominated research group.

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Table of contents

A note on section numbering within chapters:

This thesis contains four published chapters (Chapters 3-6) which have been included in journal format and, as such, deviate from the multi-level numbering which has been used in the unpublished chapters (Chapters 1, 2, 7 and 8). For tables and figures, a consistent approach has been used for numbering within each chapter.

Author contributions to published papers

Four chapters in this thesis have been published in peer-reviewed journals. The ideas, development and writing of all manuscripts were the principal responsibility of the thesis candidate, working within the School of Life and Environmental Sciences in the Faculty of Science at The University of Sydney, under the supervision of Associate Professor Robyn Alders and Professor Ian Darnton-Hill, with support from Associate Professor Peter Thomson and Dr Brigitte Bagnol. The inclusion of additional co-authors acknowledges collaboration on specific papers and input into team-based research.

de Bruyn, J., Wong, J., Bagnol, B., Pengelly, B. and Alders, R. (2015). Family poultry and food and nutrition security. *CAB Reviews* 10, No. 013.

> This publication constitutes Chapter 3 of this thesis. The scope of this literature review was developed through discussions between the thesis candidate and co-authors. The thesis candidate conducted literature searches (with additional references contributed by co-authors), wrote a first draft of the review, responded to suggestions and input from co-authors, and finalised the manuscript for publication.

de Bruyn, J., Thomson, P. C., Bagnol, B., Maulaga, W., Rukambile, E., & Alders, R. G. (2017). The chicken or the egg? Exploring bi-directional associations between Newcastle disease vaccination and village chicken flock size in rural Tanzania. *PLOS One*, 12(11), e0188230. doi:10.1371/journal.pone.0188230

> This publication constitutes Chapter 4 of this thesis. The thesis candidate was involved in the implementation of research activities contributing to this paper, including the training of local chicken vaccinators, and the training and supervision of enumerators for questionnaire-based data collection (together with other members of the field team, including co-authors W. Maulaga and E. Rukambile). The thesis candidate was responsible for database construction, data entry and cleaning; conducted analyses (with statistical support from P. Thomson, and guidance from R. Alders and B. Bagnol); wrote the first and subsequent drafts; incorporated input from co-authors; and undertook minor revisions in response to reviewer feedback.

de Bruyn, J., Ferguson, E., Allman-Farinelli, M., Darnton-Hill, I., Maulaga, W., Msuya, J., & Alders, R. (2016). Food composition tables in resource-poor settings: Exploring current limitations and opportunities, with a focus on animal-source foods in sub-Saharan Africa. *British Journal of Nutrition*, 116(10), 1709-1719. doi:10.1017/S0007114516003706

This publication constitutes Chapter 5 of this thesis. The general concept of the paper was developed by the thesis candidate in consultation with her primary supervisor (R. Alders), with one co-author (E. Ferguson) contributing to formative discussions to refine the approach taken. The thesis candidate compiled relevant data sources, conducted the analysis and wrote the first and subsequent drafts, with input from all co-authors. Major revision of the manuscript was undertaken by the thesis candidate in response to reviewer feedback, with support from all co-authors (in particular M. Allmann-Farinelli, E. Ferguson and R. Alders).

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Maulaga, W., Thomson, P. C., & Alders, R. (2017). Characterising infant and young child feeding practices and the consumption of poultry products in rural Tanzania: A mixed methods approach. *Maternal & Child Nutrition*, e12550. Advance online publication. doi:10.1111/mcn.12550

This publication constitutes Chapter 6 of this thesis. The thesis candidate developed the primary concept of the paper; led enumerator training and supervised questionnaire application (together with other members of the field team); developed the qualitative component of the study (with support from all co-authors); conducted in-depth interviews; and performed quantitative and qualitative data analysis (with support from P. Thomson and B. Bagnol, respectively). The thesis candidate drafted the manuscript (with guidance and input from all co-authors), and undertook major revisions in response to reviewer feedback prior to publication.

Authorship attribution statement

Student

I believe the statements above to be a true reflection of my contribution to the publications which form Chapters 3-6 within this thesis.

Julia de Bruyn

November 2017

Supervisor

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statement above is correct.

Associate Professor Robyn Alders

November 2017

Additional publications and presentations

Publications

Alders, R., Aongola, A., Bagnol, B., **de Bruyn, J.**, Kimboka, S., Kock, R., . . . Young, M. (2014). Using a One Health approach to promote food and nutrition security in Tanzania and Zambia. *GRF Davos Planet@Risk, 2*, 187-190.

Alders, R., **de Bruyn, J.**, Wingett, K., & Wong, J. (2017). One Health, veterinarians and the nexus between disease and food security. *Australian Veterinary Journal, 95*(2), 451-453. doi:10.1111/avj.12645

Bagnol, B., Clarke, E., Li, M., Maulaga, W., Lumbwe, H., McConchie, R., **de Bruyn, J.** & Alders, R. G. (2016). Transdisciplinary project communication and knowledge sharing experiences in Tanzania and Zambia through a One Health lens. *Frontiers in Public Health, 4*(10), 1-6. doi:10.3389/fpubh.2016.00010

Bagnol, B., Naysmith, S., **de Bruyn, J.**, Wong, J., & Alders, R. (2016). Effective animal health programming requires consideration of and communication with those at the human–animal interface. *CAB Reviews, 11*(030), 1-7.

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*. Advance online publication. doi:10.1016/j.gfs.2017.04.003

Conference Presentations

Alders, R., Aongola, A., Bagnol, B., **de Bruyn, J.**, Darnton-Hill, I., Jong, J., . . . Wong, J. (2015, September). *Village chickens and their contributions to balanced diverse diets throughout the seasons.* Paper presented at the World Veterinary Poultry Association Congress, Cape Town, South Africa.

Alders, R., Bagnol, B., **de Bruyn, J.**, Jong, J., Lumbwe, H., Maulaga, W. & Wong J. (2015, June). *Women's empowerment, poverty alleviation and food and nutrition security: the multiple contributions of village chickens.* Paper presented at the 5th Annual Leverhulme Centre for Integrative Research on Agriculture and Health, London, UK.

Bagnol, B., Li, M., Lumbwe, H., Maulaga, W., **de Bruyn, J.** & Alders, R. G. (2016, September). *Research for new policy options: Raising village chickens to tackle food and nutrition insecurity*. Paper presented at the XXV World's Poultry Congress, Beijing, China.

Bruce, M., Mramba, F., Alders, R., **de Bruyn, J.**, Kalloka, M., Maulaga, W. & Rushton, J. (2016, June). *Exploring the pathways between animal health interventions and child nutrition in Tanzania: is system dynamics a useful tool?* Paper presented at the Agriculture, Nutrition and Health Academy Week, Addis Ababa, Ethiopia.

Bruce, M., Mramba, F., Alders, R., **de Bruyn, J.**, Kalloka, M., Maulaga, W. & Rushton, J. (2016, December). *Modelling the links between parasitic disease in livestock and child nutritional status in rural smallholder households, Tanzania.* Paper presented at the International One Health Ecohealth Congress, Melbourne, Australia.

de Bruyn, J., Thomson, P., Darnton-Hill, I., Bagnol, B., Maulaga, W., Simpson, J., . . . Alders, R. 2016. *Village chicken ownership, irrespective of location of overnight housing, is positively associated with height-for-age Z-scores of infants and young children in central Tanzania.* Paper presented at the International One Health Ecohealth Congress, Melbourne, Australia.

de Bruyn, J., Alders, R., Bagnol, B., Guyonnet, V., McGregor, O., & Thieme, O. (2015, October). *Let them eat eggs: Promoting the vital contributions of eggs to food and nutrition security in resource-poor settings.* Paper presented at the GRF One Health Conference, Davos, Switzerland.

de Bruyn, J., Alders, R., Bagnol, B., Darnton-Hill, I., Kock, R., Li, M., . . . Wong, J. (2015, September). *Taking a nutrition-sensitive approach to improving village poultry value-chain efficiency in sub-Saharan Africa.* Paper presented at the World Veterinary Poultry Association Congress, Cape Town, South Africa.

de Bruyn, J., Alders, R., Bagnol, B., Darnton-Hill, I., Li, M., Maulaga, W. & Lumbwe, H. (2014, November). *Family poultry and food sovereignty: Exploring locally-appropriate, sustainable solutions to child undernutrition in sub-Saharan Africa.* Paper presented at the Agri-Food XXI Conference: Food, People and Planet, Sydney, Australia.

Maulaga, W., Rukambile, E., Alders, R., **de Bruyn, J.**, Muyengi, E., Lyimo, E., . . . McConchie, R.. (2016, December). *Supporting policy implementation through collaboration: Sustainable solutions to the food and nutrition security challenge in Tanzania.* Paper presented at the International One Health Ecohealth Congress, Melbourne, Australia.

Rukambile, E., Maulaga, W., **de Bruyn, J.**, Bagnol, B., Alders, R., & Mramba F. (2015, December). *An overview on the village chicken keeping practices at Sanza Ward in Singida Region and proposed areas of intervention.* Paper presented at the 33rd Tanzania Veterinary Association Conference, Arusha, Tanzania.

Conference Posters

Alders, R., **de Bruyn, J.**, Wingett, K. & Wong, J. (2016, December). *Ecohealth and the nexus between disease and food security.* Poster session presented at the International One Health Ecohealth Congress, Melbourne, Australia.

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Thomson, P., Maulaga, W. & Alders, R. (2017, July). *Exploring infant and young child feeding practices and the consumption of poultry products in rural Tanzanian villages: A mixed methods approach.* Poster session presented at the Conference on Agri-Health Research at Agriculture, Nutrition and Health Academy Week, Kathmandu, Nepal.

de Bruyn, J., Thomson, P., Bagnol, B., Darnton-Hill, I., Maulaga, W. & Alders, R. (2017, April). *Changing associations between livestock ownership and height-for-age in young children in the semi-arid central zone of Tanzania.* Poster session presented at the Planetary Health Annual Meeting, Boston, MA.

de Bruyn, J., Maulaga, W., Rukambile, E., Bagnol, B., Li, M., Darnton-Hill, I., . . . Alders R. (2016, June). *Chicken ownership has a positive association with length-for-age Z-scores of infants and young children in central Tanzania.* Poster session presented at the Conference on Agri-Health Research at Agriculture, Nutrition and Health Academy Week, Addis Ababa, Ethiopia.

de Bruyn, J., Bagnol, B., Darnton-Hill, I., Maulaga, W., Rukambile, E. & Alders, R. (2015, November). *Assessing the impact of a community-based poultry vaccination program on food and nutrition security in central Tanzania.* Poster session presented at the Marie Bashir Institute of Infectious Diseases and Biosecurity Annual Colloquium, Sydney, Australia.

Wong, J., Bagnol, B., **de Bruyn, J.**, Grieve, H., Jong, J., Li, M. & Alders, R. (2015, September). *Valuing the resilience of village chicken production systems.* Poster session presented at the World Veterinary Poultry Association Congress, Cape Town, South Africa.

Seminars

Alders, R., **de Bruyn, J.**, Jong, J. & Wong, J. (2016, August). *Options for achieving optimal diets in resource-limiting settings, with a focus on animal-source foods.* Seminar presented at the Department of Foreign Affairs and Trade, Canberra, Australia.

de Bruyn, J. (2016, November). *Case study: Village chickens and children's nutrition in central Tanzania.* Seminar presented at the Increasing the Development Impact of Agricultural Research Short Course, Nairobi, Kenya.

de Bruyn, J. & Wong, J. (2015, August). *Village chicken and egg value chains and their links to nutrition and gender.* Seminar presented at the Resetting the Australian table: Adding value and adding health symposium, Sydney, Australia.

de Bruyn, J., Alders, R., Bagnol, B., Costa, R., Msami, H. & Young M. (2014, December). *Opportunities for improving village poultry value chains: Experiences from Singida District in central Tanzania.* Seminar presented at the National Workshop on Strengthening Poultry Producers Through Organised Action in Zimbabwe, Harare, Zimbabwe.

Abbreviations and acronyms

ACC/SCN	Administrative Committee on Coordination / Sub-Committee on Nutrition
ACIAR	Australian Centre for International Agricultural Research
ACTRN	Registration number with Australian New Zealand Clinical Trials Registry
ASF	Animal Source Food
β	Regression coefficient (in statistical analysis)
BAKITA	*Baraza La Kiswahili la Taifa* (National Swahili Council, Tanzania)
BMI	Body mass index
Ca	Calcium
CAB	Centre for Agriculture and Biosciences
CCC	Country Coordinating Committee
CDC	Centers for Disease Control and Prevention (United States)
CHD	Coronary heart disease
CLGF	Commonwealth Local Government Forum
Coeff.	Regression coefficient
DD	Dietary diversity
DFE	Dietary folate equivalents
DHS	Demographic and Health Survey
FAO	Food and Agriculture Organization of the United Nations
FCT	Food composition table
Fe	Iron
g	Grams
GDP	Gross Domestic Product
H5N1	Subtype of highly-pathogenic avian influenza
HAZ	Height-for-age Z-score
Hb	Haemoglobin
HDAI	Household Domestic Asset Index
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
HPAI	Highly-pathogenic avian influenza
I-2	Thermotolerant vaccine for Newcastle disease
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute

ILRI	International Livestock Research Institute
INFOODS	International Network on Food Data Systems
IQR	Inter-quartile range
IYCF	Infant and young child feeding
IYCMDD	Infant and Young Child Minimum Dietary Diversity
kg	Kilograms
kJ	Kilojoules
LMIC	Low- and middle-income countries
MCHN	Maternal and Child Health and Nutrition
MDD-W	Minimum Dietary Diversity for Women of Reproductive Age
mg	Milligrams
Mo	Months (of age)
MoH	Ministry of Health (Zanzibar)
MoHCDGEC	Ministry of Health, Community Development, Gender, Elderly and Children (Tanzania Mainland)
NBS	National Bureau of Statistics (Tanzania)
ND	Newcastle disease
NIMR	National Institute of Medical Research (Tanzania)
NLAI	Non-livestock Asset Index
No.	Number
NNS	National Nutrition Strategy (Tanzania)
OCGS	Office of the Chief Government Statistician (Zanzibar)
P	Phosphorus
PAHO	Pan American Health Organization
PhD	Doctor of Philosophy
PUFA	Polyunsaturated fatty acids
RAE	Retinol activity equivalents
RNI	Recommended Nutrient Intake
SD	Standard deviation
SDG	Sustainable Development Goal
Se	Selenium

SE	Standard error
TFNC	Tanzania Food and Nutrition Centre
TLU	Tropical Livestock Unit
TVLA	Tanzania Veterinary Laboratory Agency
TZS	Tanzanian Shillings (1 USD ≈ 2225 TZS in November 2017)
μg	Micrograms
UK	United Kingdom
UN	United Nations
UNICEF	United Nations Children's Fund
US / USA	United States / United States of America
USD	United States dollars
USDA	United States Department of Agriculture
WFP	World Food Programme
WHO	World Health Organization
WHZ	Weight-for-height Z-score
Zn	Zinc

Glossary

Animal-source food	Food of animal origin, including meat (muscle and organs), fish and other seafood, milk and dairy products, eggs, snails and arthropods.
Anthropometry	Measurements of the human body, in terms of the dimensions of bone, muscle and adipose (fat) tissue, used to obtain information about nutritional status. These include weight, height, circumferences and skinfold thicknesses (Fryar, Gu, & Ogden, 2012).
Bioavailability	The proportion of a nutrient present in food that the body is able to absorb and utilise. Bioavailability estimates the amount of physiologically utilisable nutrient in the diet, relative to the total nutrient content of the diet (Carpenter & Mahoney, 1992).
Community Assistant	Community representative selected in consultation with community leaders and employed by the *Nkuku4U* project to assist with the implementation of research activities, ongoing data collection and community liaison activities. Two Community Assistants (one male, one female) were employed in each village in the study.
Community Vaccinator	Community member selected in consultation with community leaders and trained to conduct four-monthly vaccination campaigns against Newcastle disease in village chickens, including awareness-raising, registration of chicken numbers, vaccine procurement, administration of I-2 ND vaccine via eyedrop, and follow-up monitoring activities. Payment is received from chicken-keepers for each bird vaccinated.
Complementary feeding	The process intended to start when breast milk alone is no longer sufficient to meet the nutritional requirements of infants, whereby other foods and liquids are introduced, along with breast milk. The target age range for complementary feeding advocated by the WHO is 6-24 months of age, although breastfeeding may continue beyond two years (Pan American Health Organization, 2003).

Demographic and Health Survey	Nationally-representative household survey that provides data for a wide range of monitoring and impact evaluation indicators in the areas of population, health and nutrition. The standard DHS has a sample size of 5,000 – 30,000 and is conducted approximately every five years. The DHS program was established by the United States Agency for International Development (USAID) in 1984 (ICF International, 2012).
Diarrhoea	The passage of three or more loose or liquid stools per day, or more frequent passage than is normal for an individual. Frequent passing of formed stools is not diarrhoea, nor is the passing of loose, "pasty" stools by breastfed children (WHO, 2017).
Dietary diversity	A measure of the number of different food groups ("Dietary Diversity Score") or unique foods ("Food Variety Score") consumed over a given reference period. Dietary diversity can be measured at the level of the household, as an indicator of food security or socioeconomic status, or the individual, to reflect the nutrient adequacy of diets (Ruel, 2003).
Dietary quality	Used to describe the nutrient adequacy of a diet, or how well a diet meets requirements for energy and all essential nutrients (Ruel, 2003).
District	An administrative unit in Tanzania. Manyoni District, where research contributing to this thesis has been undertaken, is the largest and most populous of the six district councils within Singida Region (NBS & OCGS, 2016).
Enumerator	A person responsible for the counting and listing of people during a census, or for assisting respondents in answering questions and completing questionnaires (Department of International Economic and Social Affairs, 1991). In this study, local enumerators have been selected in consultation with community leaders, employed on a casual basis and trained to record participants' responses to semi-structured questionnaires using an interview approach.

Environmental enteric dysfunction	An incompletely-defined syndrome of inflammation, reduced absorptive capacity and reduced barrier function in the small intestine. The term "tropical enteropathy" was used in the 1960s, but the condition was renamed "environmental enteropathy" in the late 2000s in recognition that it was not only seen in tropical climates, and given the current term around 2014 (Crane, Jones, & Berkley, 2015).
Exclusive breastfeeding	Infants receiving no other food or drink, even water, except breast milk, but allowing for oral rehydration solutions and drops or syrups, such as micronutrient supplements and medications (WHO, 2002).
Family poultry	The full variety of small-scale poultry production systems found in rural, urban and peri-urban areas of low- and middle-income countries. This term avoids defining production systems, but encompasses poultry systems managed by individual families as a means of obtaining food security, income and gainful employment (Besbes, Thieme, Rota, Guèye, & Alders, 2012).
Food security	A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, access, utilisation and stability (FAO, 2009).
Generalised Linear Mixed Model	A statistical model, as an extension of a linear regression model, that incorporates fixed effects and random effects, the latter to allow for geographic clustering of data such as region, district, ward and village. Used for modelling binary and count outcome variables (Welham, Gezan, Clark, & Mead, 2014)
Gogo	One of approximately 120 ethnic groups in Tanzania. The language of the Gogo people (*Kigogo*) is the predominant language spoken within the study sites in central Tanzania. Gogo have been described as sedentary cultivators, who subsist on a precarious agricultural system, yet whose values are oriented towards pastoralism (Rigby, 1969).

Household	A group of people living together and sharing food from the same pot, for at least three days of each week for the previous six months. Household members share some common resources and make some common budget and expenditure decisions (Alkire et al., 2013).
Household Domestic Asset Index	An index developed by the International Livestock Resource Institute (ILRI) for use in sub-Saharan Africa, calculated based on all movable assets owned by a household, including livestock. Each asset is assigned a weight and then adjusted for age (Njuki et al., 2011). Several variants of this index have been used in this thesis, as outlined in Chapters 4 and 7.
I-2 Newcastle disease vaccine	A vaccine developed from an avirulent strain of the Newcastle disease virus, with the characteristic of thermotolerance making it particularly suitable for use in settings without a reliable cold chain and multi-age flocks. The I-2 vaccine can be administered via eye drop (as in this study), drinking water, certain feeds and injection (Copland & Alders, 2005).
Improved toilet facility	A facility that is not shared between households and that hygienically separates excreta from human contact. Open pits or latrines without a proper slab to cover the pit are considered non-improved (WHO & UNICEF, 2006).
Improved water source	A supply of drinking water that is protected from outside contamination, particularly faecal matter. Improved water sources include piped water in a dwelling, yard or plot, a public tap, a borehole, a protected dug well, a protected spring or rainwater (WHO & UNICEF, 2006).
Infant	A child under 12 months of age.
Kigogo	The language of the Gogo people.
Kisukuma	The language of the Sukuma people.
Kiswahili	The Swahili term for the Swahili language, sometimes also used in English.

Linear Mixed Model	A statistical model, as an extension of a linear regression model, that incorporates fixed effects and random effects, the latter to allow for geographic clustering of data such as region, district, ward and village. Used for modelling quantitative continuous outcome variables (Welham et al., 2014).
Livestock ladder	A term which presents livestock ownership as an opportunity for rural households to accomulate assets and rise out of poverty. It reflects a hierarchical concept of livestock ownership, with small animals such as poultry considered the lowest step on the livestock ladder, and larger animals such as cattle or buffalo as the highest step (Dolberg, 2001).
Low-income country	A country with a Gross National Income per capita of less than US $1005. The World Bank assigns economies into four income groups (high, upper-middle, lower-middle and low), with classifications updated on 1 July each year (World Bank, 2017).
Macronutrients	Essential dietary factors that are required in large amounts (i.e. measured in grams): carbohydrates, fats and protein (Bender, 2014).
Micronutrients	Essential dietary factors that are required in small amounts (i.e. measured in milligrams or micrograms): vitamins and minerals (Bender, 2014).
Middle-income country	A country with a Gross National Income per capita of US $1006 – 12,235, with sub-categories of lower-middle income (US $1006 – 3956) and upper-middle income (US $3956 – 12,235). The World Bank updates classifications on 1 July each year (World Bank, 2017).
Newcastle disease	A viral disease of poultry, caused by avian paramyxovirus serotype 1 (APMV-1) viruses, responsible for high levels of mortality amongst poultry flocks and associated with substantial costs of vaccination and biosecurity measures globally (Alexander, 2000).

Nkuku4U	The abbreviated title for the project "Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia" (ACIAR FSC/2012/023). *Nkuku* means "chicken" in Nyanja, one of the official languages in Zambia. A similar word (*kuku*) is used in Swahili, the national language in Tanzania.
Nutrition security	A situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life for all household members. Nutrition security differs from food security in that it also considers the aspects of adequate caring practices, health and hygiene in addition to dietary adequacy (FAO, IFAD, & WFP, 2015).
Nutrition-sensitive	Interventions or programs that address the underlying determinants of nutrition, including poverty, food insecurity, inadequate caregiving resources, and scarcity of access to health services and a safe and hygienic environment, and incorporate specific nutrition goals and actions. Examples of program areas include agriculture and food security, early child development, and water, sanitation and hygiene (Ruel & Alderman, 2013).
Nutrition-specific	Interventions or programs that address the immediate determinants of nutrition, including adequate food and nutrient intake, feeding and caregiving, and a low burden of infectious disease. Examples include micronutrient supplementation or fortification, and promotion of optimal breastfeeding and complementary feeding (Ruel & Alderman, 2013).
Poultry	Domesticated avian species that are raised for eggs, meat and feathers. This term is often used synonymously with chickens, but also includes turkeys, guinea fowl, ducks, geese and other species such as quails and pigeons, or birds considered to be game, like pheasants. Chickens are by far the most important poultry species globally (FAO, 2014).

Recommended Nutrient Intake	The daily intake of a given nutrient estimated to meet the nutrient requirements of 97.5% of healthy individuals in an age- and sex-specific population group. Based on the Estimated Average Requirement (which meets the needs of 50% of a population group) plus two standard deviations (WHO & FAO, 2004).
Region	An administrative unit in Tanzania. Singida Region, where research contributing to this thesis has been undertaken, is one of 25 regions which constitute the mainland of Tanzania (Commonwealth Local Government Forum, 2012).
Smallholder farming	Production systems with inputs primarily derived from within the household, and with outputs intended to contribute to household needs. This definition avoids prescriptive guidelines on livestock numbers or land size, and retains a focus on a farmer-centred unit (McDermott, Randolph, & Staal, 1999).
Stunting	Height-for-age which is more than two standard deviations (or for severe stunting, more than three standard deviations) below the gender-specific WHO growth standards. An indicator of chronic undernutrition (Black et al., 2008; Shrimpton et al., 2001).
Subvillage	An administrative unit in Tanzania, also referred to as a hamlet (or *kitongoji* in Swahili). The eight villages contributing to this research are each comprised of 3-6 subvillages. These are the smallest units of local government in rural areas, with an elected chairperson and advisory committee (Commonwealth Local Government Forum, 2012).
Sukuma	The largest of approximately 120 ethnic groups in Tanzania (estimated to constitute 16% of the national population). Sukuma are traditionally agropastoralists and are often considered wealthy based on livestock holdings and areas of land cultivated, and known for the value placed on family size and cattle ownership (Garenne & Zwang, 2006; Hadley, 2005).

Tropical Livestock Unit	A measure of smallholder livestock holdings, of mixed species, breeds and ages, calculated using an approximation of the metabolic weight of each. This unit was developed as a means of quantifying production and relating livestock numbers to human populations or land resources (Jahnke, 1982).
Undernourishment	A state, lasting for at least one year, of inability to acquire enough food, defined as a level of food intake insufficient to meet dietary energy requirements (FAO et al., 2015).
Village	An administrative unit in Tanzania. Research contributing to this thesis has been undertaken in eight villages, four from each of Sanza and Majiri Wards. There are 2,918 registered villages in mainland Tanzania (Commonwealth Local Government Forum, 2012).
Village poultry	Poultry kept in small numbers for home consumption, sale and various sociocultural uses in low- and middle-income countries, originally concentrated in village settings (FAO, 2014).
Ward	An administrative unit in Tanzania. Sanza and Majiri Wards, where research contributing to this thesis has been undertaken, are two of the 30 wards within Manyoni District (NBS & OCGS, 2013).
Wasting	Weight-for-height more than two standard deviations (or for severe wasting, more than three standard deviations) below the gender-specific WHO growth standards. An indicator of acute undernutrition (Black et al., 2008; Shrimpton et al., 2001).

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Chapter 1.
Background, introduction and research aims

Chapter 1 begins with an introduction to the nutritional challenges which underly this body of work. It defines and describes the impact of undernutrition, with a focus on chronic undernutrition and Tanzania. The evolving and interrelated concepts of food security and nutrition security are introduced, and their determinants outlined.

Opportunities for agriculture to have a positive impact on human nutrition are presented, along with the documented gaps in evidence to demonstrate agriculture-nutrition linkages to date. A particular focus is given to livestock, outlining the varied roles of animals within households in low- and middle-income countries and the value of animal-source foods in enhancing diet quality, as well as the potential for adverse impacts on human health.

Interdisciplinary and mixed methods research, using appropriate nutritional indicators, is highlighted as being central to strengthening food and nutrition security and improving the wellbeing of humans, animals and the environment. The chapter concludes by outlining the aims, scope and structure of this thesis.

Image 1. Three girls return home, carrying water from the river in Ntope Village, Sanza Ward in the Central Zone of Tanzania – one of eight communities in the research project which has contributed to this thesis. More than 95% of households participating in this study reported relying on unimproved water sources, including rivers and open wells, during the study period.

Photo credit: Julia de Bruyn, 2016.

Chapter 1. Background, introduction and research aims

1.1 Introduction

Poor nutrition remains a pervasive threat to human survival, wellbeing and productivity, with suboptimal diets among the leading causes of death and disability globally (Black et al., 2008; Masters et al., 2017). Efficient and sustainable strategies to meet the nutritional needs of current and future populations have become a high priority on global research and development agendas (UN, 2015). There is increasing recognition of the complex, interrelated causes and profound consequences of malnutrition: of acute and chronic nature, both undernutrition and overnutrition. Estimates for 2016 suggest the global prevalence of undernourished people to have risen to 11%, marking a possible reversal of the sustained downward trend reported over the past fifteen years (FAO, IFAD, UNICEF, WFP, & WHO, 2017). Sub-Saharan Africa remains the region with the highest levels of undernourishment at 22.7%, with one in three people (33.9%) in Eastern Africa estimated to be chronically undernourished.

Currently, the burden of undernutrition falls disproportionately on young children and on pregnant and breastfeeding women in low- and middle-income countries (LMIC). The "nutritionally vulnerable" status of these groups may reflect the combined influence of (a) heightened nutrient requirements per unit of body mass, relative to other age groups, and (b) lower social status, affecting intra-household food allocation, increased risk of infectious disease and less access to health services (Girard, Self, McAuliffe, & Olude, 2012). *The Lancet*'s 2013 series on maternal and child nutrition emphasises the nutritional status of women at the time of conception and throughout pregnancy as being central to foetal growth and development, and, together with nutrition during the first two years of life, a key determinant of the growth, health and future disease risk of children (Black et al., 2013; Horton & Lo, 2013).

1.2 Undernutrition

Undernutrition denotes the various states which may result from insufficient food intake to meet physiological requirements: stunting, wasting, underweight and micronutrient deficiencies. While sometimes used synonymously, the broader term malnutrition describes "all deviations from adequate and optimal nutritional status" (Shetty, 2006, p. 524) and also encompasses overweight and obesity. International development targets often refer to the state of "hunger" (UN, 2015; UN General Assembly, 2000), used in common parlance to describe a feeling of discomfort caused by not eating. Reports by the Food and Agriculture Organization of the United Nations (FAO) use the term hunger interchangeably with undernourishment to describe a state, lasting for at least one year, of inability to acquire enough food to meet dietary energy requirements (FAO, IFAD, & WFP, 2015). Quantifiable assessments of undernutrition are based on height, weight and circumference measurements, which are able to be compared with internationally accepted growth standards (WHO Multicentre Growth Reference Study Group, 2006) and used to characterise undernutrition as acute or chronic in nature, as well as identify geographic, seasonal or temporal variation in the nutritional status of individuals or populations.

Underweight is a broad term used to describe low body weight compared with that expected of a well-nourished individual of the same age and gender (Black et al., 2008). Two more specific anthropometric indicators are stunting (low length- or height-for-age), a chronic restriction of growth which is evident as short stature, and wasting (low weight-for-height), an indication of acute weight loss. It is important to consider the prevalence of wasting and stunting separately, since these states have different determinants and respond to different interventions (Waterlow, 1972). The two conditions are not necessarily associated on a geographical basis, and there may be a significant disparity between levels of stunting and wasting within the same community.

1.2.1 Stunting

Stunting indicates a failure to achieve one's genetic potential for growth (Dewey & Begum, 2010) and reflects the outcome of frequent or extended periods of ill health and poor nutrition, particularly during the first two years of life (Bhutta & Salam, 2012). Studies of affluent households across a wide variety of ethnic backgrounds and cultural settings have indicated growth potential in preschool children to be highly similar across countries (Bhandari, Bahl, Taneja, de Onis, & Bhan, 2002; WHO Multicentre Growth Reference Study Group & de Onis, 2006). Chronic restriction of growth may arise from multiple factors, including recurrent infections and poor nutrition in the antenatal, intrauterine and postnatal periods (de Onis, Blossner, & Borghi, 2012; Grantham-McGregor et al., 2007). Children measuring more than two standard deviations below internationally-accepted growth standards are considered stunted, and those measuring more than three standard deviations below are severely stunted (WHO Multicentre Growth Reference Study Group, 2006).

Although the short-term mortality risk is less than that associated with wasting, the implications of stunting extend well into adulthood (Figure 1). Analysis of cohort studies from five LMIC has identified child stunting to be correlated with diminished cognitive and physical development, reduced educational attainment and physical work capacity, lower earning potential and an increased risk of chronic disease, such as obesity, diabetes or cardiovascular disease, in adulthood (Adair et al., 2013; Black et al., 2013; Martorell et al., 2010; Victora et al., 2008). The multiple dimensions of the cost of stunting to society include increased health care expenses, reduced earnings, and losses to national economic productivity (Shekar, Dayton Eberwein, & Kakietek, 2016).

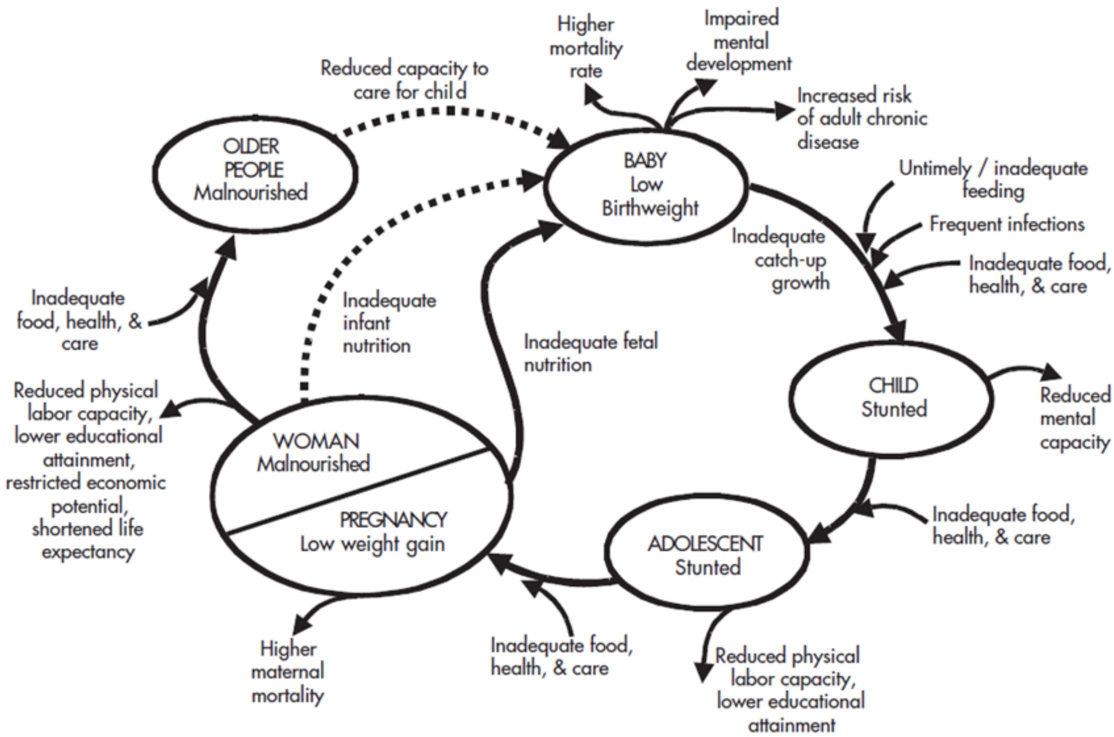

Figure 1. Proposed causes and consequences of undernutrition throughout the life cycle, highlighting the potential for genetic and environmental influences to have intergenerational effects (ACC/SCN, 2000).

Analysis of 39 nationally-representative datasets from LMIC in 2001 indicated the mean length-for-age at the time of birth to be very close to the formerly-used National Center for Health Statistics growth reference (Hamill, Drizd, Johnson, Reed, & Roche, 1977), with growth faltering beginning immediately after birth and continuing well into the third year (Shrimpton et al., 2001). Similar analyses comparing anthropometric surveys against the current World Health Organization (WHO) child growth standards (WHO Multicentre Growth Reference Study Group, 2006) show an even more dramatic faltering of length-for-age from birth until 24 months of age, emphasising the importance of the window of opportunity of the first two years of life to prevent long-term effects of undernutrition (Victora, de Onis, Hallal, Blössner, & Shrimpton, 2010).

A review of interventions targeting child undernutrition, including the promotion of improved breastfeeding and complementary feeding practices, micronutrient interventions, and general supportive strategies to improve household nutrition and reduce rates of infectious disease, suggest that these strategies are only able to reduce stunting at 36 months of age by around one-third (36%) (Bhutta et al., 2008). To eliminate stunting in the longer-term, there is a need to address the underlying determinants of undernutrition, such as poverty, limited formal education, disease burden and gender inequity, which may contribute to intergenerational effects (Ramakrishnan, Martorell, Schroeder, & Flores, 1999; Stein et al., 2004). Analysis of nationally-representative data from Bangladesh and India revealed both maternal and paternal education to be strong determinants of child stunting, and attributed a 4-5% decrease in the likelihood of stunting to each additional year of formal education for mothers (Semba et al., 2008).

Stunting levels in Tanzania

The United Republic of Tanzania is the fifth most populous country in sub-Saharan Africa, with a projected population of 51.6 million in 2017 (NBS Tanzania & OCGS, 2013). Strong and consistent economic growth has been recorded since around 2000, yet this has not translated into a significant reduction in poverty (Arndt, Demery, McKay, & Tarp, 2016; Atkinson & Lugo, 2010) and the country ranks at 96 of 118 countries on the Global Hunger Index, based on levels of undernourishment, child wasting, child stunting and child mortality (von Grebmer et al., 2016). Across sub-Saharan Africa, the prevalence of stunting has been reported to have remained stable at around 40% between 1990 and 2010, in contrast to a dramatic decrease from almost 49% to less than 28% in Asia over the same time period (de Onis et al., 2012). High levels of population growth in sub-Saharan Africa have translated into an increase in the number of stunted children, from 45 million in 1990 to 60 million in 2010.

Tanzanian data compiled from five consecutive applications of the Demographic and Health Survey (DHS) show a reduction in the national prevalence of stunting from 43.4% to 34.4%, and of severe stunting from 17.8% to 11.7%, between 1996 and 2015-16 (Figure 2). Higher levels of stunting are consistently reported amongst children living in rural areas compared to those in urban settings. Research in Central and Eastern Africa has attributed this pattern to differences in wealth between rural and urban households (Kennedy, Nantel, Brouwer, & Kok, 2006). Studies in Kenya and Zambia have also demonstrated poor child health outcomes, including levels of stunting, morbidity and mortality, in urban unplanned settlements or slums (Fotso, Ezeh, Madise, & Ciera, 2007; Fotso et al., 2012; Zulu et al., 2011). In Tanzania, a higher incidence of stunting has also been associated with poor maternal nutritional status, low levels of maternal education and lower household wealth (MoHCDGEC [Tanzania Mainland], MoH [Zanzibar], NBS Tanzania, OCGS, & ICF, 2016).

Substantial regional variation exists in the prevalence of stunting across the country. This has been attributed to the differing agro-ecological conditions, which influence the types of foods consumed and the timing of its availability, access and utilisation throughout the year (Lobell, Schlenker, & Costa-Roberts, 2011). Communities participating in the research project contributing to this thesis are located in Singida Region, in an area adjacent to the border with Dodoma Region. Stunting levels in Dodoma Region have consistently been recorded as being higher than in Singida (Figure 3), and were reported as the highest nationally in 2010, at 56.0% (NBS Tanzania & ICF Macro, 2011). Dodoma is characterised by a prevalence of highly food-insecure areas, with a reliance on rain-fed agriculture and a food system based predominantly on cereals (Mbwana, Kinabo, Lambert, & Biesalski, 2017), although with regular use of a wide range of non-cultivated fruits and vegetables (Mutabazi, 2013).

The communities participating in this study are located close to the border between Singida and Dodoma Regions. Based on common food systems and agro-ecological conditions in this area, the likelihood of study participants accessing markets and health facilities in both regions and the reported disparity in regional health statistics, nutritional figures for both Singida and Dodoma Regions are reviewed here.

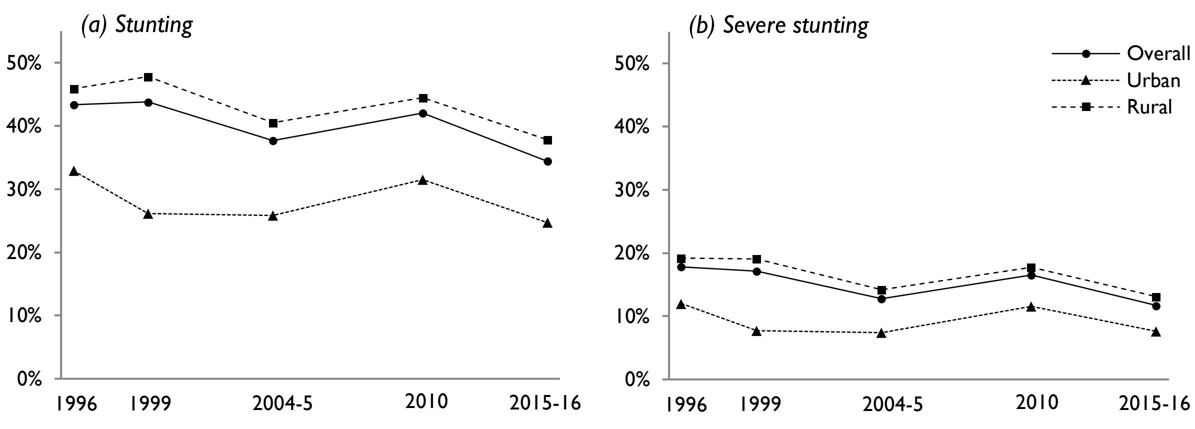

Figure 2. National prevalence of (a) stunting (HAZ <-2) and (b) severe stunting (HAZ <-3) in children under five years of age, overall and disaggregated by location of residence, compiled from Tanzanian Demographic and Health Survey data (1996 to 2015-16).

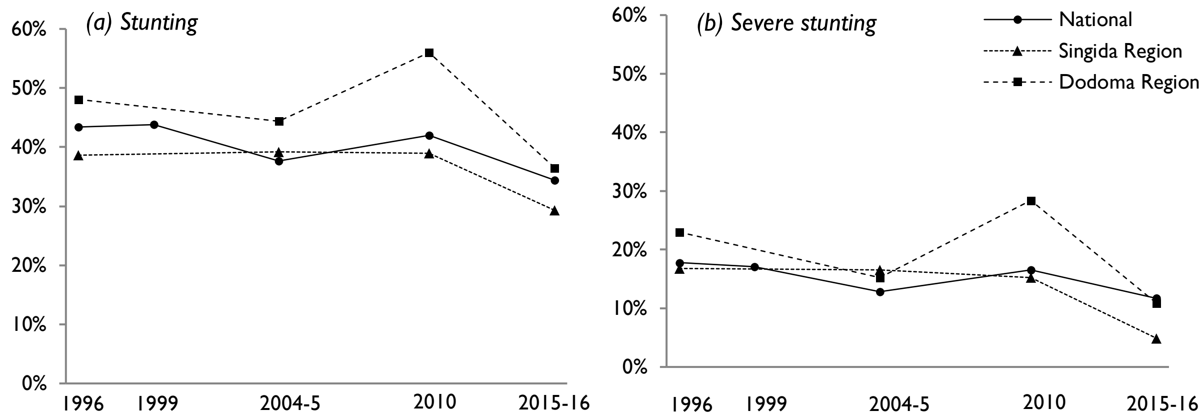

Figure 3. Prevalence of (a) stunting and (b) severe stunting in children under five years of age, at a national level and within Singida and Dodoma Regions, compiled from Tanzanian Demographic and Health Survey data (1996 to 2015-16).

1.2.2 Micronutrient deficiencies

Micronutrients are essential vitamins and minerals which are unable to be synthesised by the body and must be obtained from dietary sources. Approximately two billion people, across countries of all levels of development, consume diets with insufficient quantities of micronutrients (Bhutta & Salam, 2012; Péter et al., 2014). Deficiencies during childhood contribute to impairments of growth, immune function and physical development and are a major factor in nutrition-related deaths globally (Viteri & Gonzalez, 2002). While external clinical manifestations such as goitre and blindness may prompt recognition of a public health problem, subclinical deficiencies affect much larger segments of a population, often where energy requirements are met and people are not considered to be "hungry" in a classical sense (Kennedy, Nantel, & Shetty, 2003). Deficiencies of iodine, iron, vitamin A and zinc are considered the most prevalent and important of the numerous micronutrient deficiencies of public health significance (Tulchinsky, 2010). This chapter focuses on two of these, iron and vitamin A, due to the particular value of foods of animal origin in meeting human physiological requirements for each, and the availability of information on the prevalence of deficiencies through national surveys.

Vitamin A is a group of fat-soluble retinoid compounds needed for normal vision, growth and development, immune function, epithelial cell integrity and reproduction. There is strong evidence that improved vitamin A status is associated with large reductions in all-cause mortality, morbidity and vision problems in children under five years of age (Imdad et al., 2011; Mayo-Wilson, Imdad, Herzer, Yakoob, & Bhutta, 2011). Reasons for deficiency in young children have been suggested to include: (a) low levels of vitamin A in breast milk due to maternal deficiency, (b) early introduction of complementary foods low in vitamin A, (c) less bioavailable forms of vitamin A in diets associated with poverty, and (d) anorexia, malabsorption and increased catabolism of vitamin A resulting from a high burden of disease (Miller et al., 2002). Supplementation is recommended in all countries where the under-five mortality rate exceeds 70 deaths per 1000 live births, an internationally-accepted proxy for a high risk of vitamin A deficiency in children (UNICEF, 2007). It has been cautioned that widespread supplementation programs may impede efforts towards more sustainable food-based approaches and fortification programs (Darnton-Hill, 1999; Darnton-Hill, Neufeld, Vossenaar, Odendarp, & Martinez, 2017; Latham, 2010).

Dietary sources of vitamin A include pre-formed retinyl esters in ASF (including liver, milk and eggs) and pro-vitamin A precursors, such as β-carotene, in plant-source foods (including dark green leafy vegetables and deep yellow fruits and vegetables) (Ross, 2010). Absorption of pre-formed vitamin A is by far more efficient than that of carotenes (Allen & Haskell, 2002). A revision of former guidelines has seen a dramatic drop in the previously-estimated bioconversion ratio of 6 μg β-carotene to 1 μg retinol (FAO & WHO, 1988), to 26:1 for dark-green leafy vegetables and 12:1 for fruits and tubers (West, Eilander, & van Lieshout, 2002). There are limitations in relying on plant-based foods in efforts to prevent and address vitamin A deficiency in LMIC, and "promoting the consumption of animal-source foods if feasible" has been recommended, alongside supplementation and fortification of staple foods (Ramakrishnan & Darnton-Hill, 2002, p. 2951S). Dietary diversification and modification focus on improving the availability, access to and utilisation of foods with high levels of bioavailable micronutrients throughout the year (Gibson, 2011).

Iron deficiency is one of the most prevalent forms of undernutrition, affecting more than two billion people across low-, middle- and high-income countries (Camaschella, 2015; Stoltzfus, 2003). Iron deficiency has been implicated as the leading cause of anaemia globally (Kassebaum et al., 2014), often co-existing alongside other risk factors in resource-poor settings, including malaria, endoparasitism and deficiencies of other micronutrients, such as vitamin B12 and folate (WHO, 2008b). Iron, a trace mineral, is required in small amounts for the formation of haemoglobin, the oxygen-carrying component of red blood cells (Lutz, Mazur, & Litch, 2014). *Haem* iron, found only in animal products, is highly bioavailable: absorbed intact and less affected by inhibitory compounds within the diet which impede the uptake of non-*haem* iron, the sole form present in plant-source foods (Bothwell, Baynes, Macfarlane, & Macphail, 1989).

Absorption of both forms of iron varies with an individual's iron status and requirements, but non-*haem* iron is particularly sensitive to the presence of inhibitors such as phytic acid, tannins and certain forms of dietary fibre (Hallberg, 1981). A significant challenge exists in many resource-poor settings, where up to 50% of iron intake is derived from cereal-based diets (Bouis, 2000) which also contain high levels of phytic acid (Gibson, 1994).

Increased iron requirements associated with growth, menstruation, pregnancy and lactation contribute to a higher prevalence of iron deficiency amongst infants, young children and women of reproductive age (Asobayire, Adou, Davidsson, Cook, & Hurrell, 2001). Despite recognition of the widespread nature of iron deficiency, there is a lack of consensus about the nature and extent of its consequences on human health (Stoltzfus, 2003). Anaemia during pregnancy is associated with a heightened risk of premature delivery, low birthweight and higher levels of perinatal mortality and maternal deaths (Kalaivani, 2009; Lister, Rossiter, & Chong, 1985). Iron status has also been linked to long-term developmental and behavioural outcomes, with severe chronic iron deficiency during infancy associated with poorer mental and motor function ten years later, as well as higher levels of anxiety, depression and social problems (Lozoff, Jimenez, Hagen, Mollen, & Wolf, 2000; Shafir, Angulo-Barroso, Calatroni, Jimenez, & Lozoff, 2006).

As for vitamin A, food-based approaches are promoted as a sustainable strategy to prevent and address iron deficiency (WHO, 2008b). It has been suggested that, in many resource-poor settings, it is almost inevitable that children 6-12 months of age (mo) and pregnant women will be unable to meet their physiological requirements through an adequate amount of absorbable iron in the diet (Stoltzfus & Dreyfuss, 1998). Studies in Cambodia, Indonesia and Myanmar have highlighted the difficulty of achieving adequate intakes of iron based on existing complementary feeding practices (Hlaing et al., 2016; Santika, Fahmida, & Ferguson, 2009; Skau et al., 2014). The potential for plant-source foods to address iron deficiency has long been questioned (de Pee, West, Muhilal, Karyadi, & Hautvast, 1996; Yip, 1994), and the focus has instead been on programs involving fish and livestock which increase access to ASF (Roos, Wahab, Chamnan, & Thilsted, 2007; Ruel, 2001). Recent evidence recommends the large-scale fortification of staple foods, as has been done in more affluent countries for over 80 years (Darnton-Hill et al., 2017). The use of iron cooking pots or ingots has also been shown to be an effective and innovative form of home fortification of foods and an accessible means of improving iron intake (Charles et al., 2015; Geerligs, Brabin & Omari, 2003).

Micronutrient deficiencies in Tanzania

Information on vitamin A and iron supplementation, consumption of vitamin A- and iron-rich foods and the prevalence of anaemia (based on haemoglobin levels) was first included in the Tanzanian DHS in the 2004-05 survey (NBS Tanzania & ORC Macro, 2005). Amongst priorities outlined in the Tanzanian National Nutrition Strategy (NNS), targets to be achieved by 2015 included a reduction in the prevalence of vitamin A deficiency amongst children 6-59 mo to below 15%, and for anaemia, 55% for children 6-59 mo and 35% for pregnant women (Ministry of Health and Social Welfare [Tanzania], 2011).

No clear trends in levels of anaemia in young children and women of reproductive age are evident across the three most recent national surveys (Figure 4). World Health Organization cut-offs have been used to categorise anaemia as mild, moderate or severe – although use of the term "mild" has been suggested to be a misnomer, since in the case of iron deficiency anaemia the underlying condition is already advanced at this stage (WHO, 2011). A substantial decrease in the prevalence of anaemia in children (from 71.8% to 58.6%) can be seen between 2004-05 and 2010, but only a marginal further decrease (to 57.7%) in 2015-16. Prominent regional variation exists, with Singida Region recording the lowest levels of child anaemia nationally (36.6%) in the 2015-16 survey. Markedly lower levels of anaemia were seen amongst children whose mothers had achieved secondary education and those in the highest wealth quintile (MoHCDGEC [Tanzania Mainland] et al., 2016). In the case of women of reproductive age, reported levels of anaemia increased between the 2010 and 2015-16 DHS (from 40.1% to 44.8%, overall). Prevalence amongst pregnant women was particularly high (57.1%), and far above the national target for 2015 of 35%.

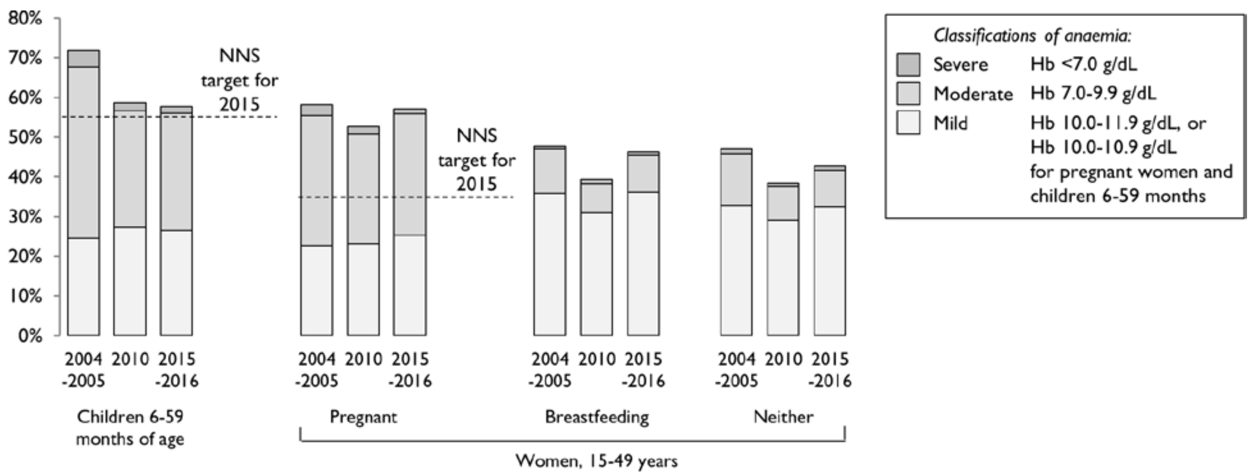

Figure 4. Prevalence of anaemia of varying levels of severity, amongst children 6-59 months of age and women of reproductive age, compiled from Tanzanian DHS data. Targets for 2015 outlined in the National Nutrition Strategy (NNS) for children and pregnant women are shown.

Opportunities to explore trends in the percentage of children consuming vitamin A- and iron-rich foods over time using DHS data have been complicated by the use of varying indicators over time. The 2004-05 survey recorded consumption of fruits and vegetables rich in vitamin A, while the two subsequent surveys also included ASFs. The 2004-05 and 2010 surveys reported on children under three years of age, while the 2015-16 survey was limited to children under two years. In a recent cross-sectional study in central Tanzania evaluating the adequacy of local foods in meeting nutrient requirements, large deficits were identified in the intake of iron by children 6-23 mo (Raymond, Agaba, Mollay, Rose, & Kassim, 2017). While children's vitamin A intake appeared to be adequate, the authors acknowledged this finding to be based on the published average intake and composition of breast milk, which may not reflect the situation within the study site, where poor maternal nutritional status may affect breast milk composition and thus the vitamin A status of children (WHO, 1998).

In rural communities in central Tanzania, it has been shown that optimal diets for children 6-23 mo can be developed using locally-available food items, but that this requires a two-fold increase in the food budget (Raymond, Kassim, Rose, & Agaba, 2017). While acknowledging the need to consider seasonal variation and to evaluate the bioavailability of nutrients in the proposed diets, the authors upheld the value of food-based approaches to overcome identified micronutrient deficiencies in Tanzania. Increasing the availability and consumption of a nutritionally adequate diet has been suggested to be the only sustainable and long-term solution to simulataneously addressing deficiencies of iron and multiple other micronutrients (Thompson, 2011).

1.3 Food and nutrition security

The Lancet's 2008 series on maternal and child nutrition was built on a framework that specified important underlying causes of undernutrition to include environmental, economic and sociopolitical contextual factors (Figure 5). The three proximate determinants of children's nutritional status were identified as food security, adequate care and health status (Black et al., 2008). The widely-accepted definition of the first of these, food security, emerged at the World Food Summit in 1996, to describe "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Basic concepts underlying food security can be traced to the early 1940s, when "freedom from hunger" was named an immediate priority during World War II.

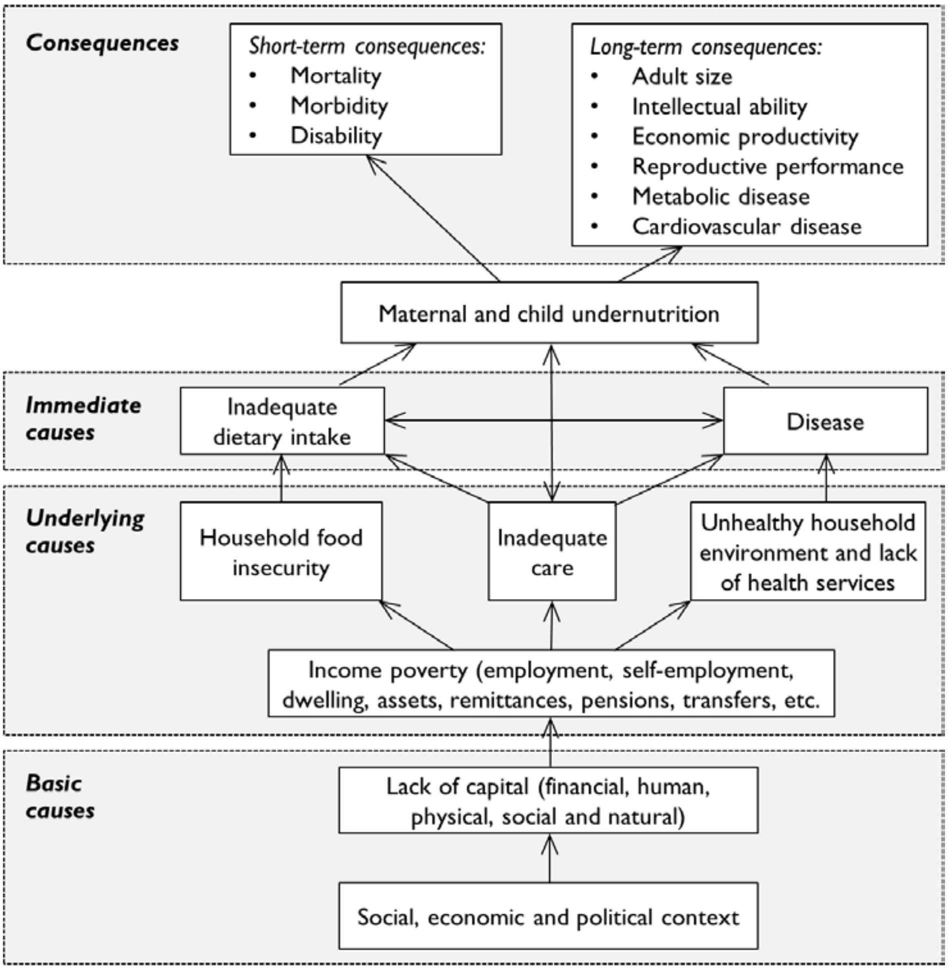

Figure 5. Framework of the linkages between poverty, food insecurity, and other basic, underlying and immediate causes of maternal and child undernutrition and its consequences (adapted from Black et al., 2008).

Pinstrup-Andersen (2009) built on this current definition of food security to include food safety, nutritional composition and dietary preferences. This acknowledges that a healthy and nutritious diet requires more than adequate calories, and that people with equal access to food but different food preferences, in terms of cultural and social acceptability, may have different levels of food security. The interrelated concept of nutrition security has grown in prominence since the 2009 World Summit on Food Security (FAO, 2009). Some decades earlier, Haddad et al. noted the less commonly-used term of nutrition security to require "the appropriate quantity and combination of inputs such as food, nutrition and health services, and caretakers' time … to ensure an active and healthy life at all times for all people" (Haddad et al, 1994, pp. 329-330) . It has been noted that a household might be food-secure, but intercurrent disease, limited nutritional knowledge or insufficient intake of micronutrients may prevent its members from being nutritionally-secure (Benson, 2004).

1.3.1 Determinants of food security

Factors contributing to the state of food security are commonly grouped into four core areas or "pillars": availability, access, utilisation and stability (FAO, 2009). These areas have been described as being inherently hierarchical, with food availability "necessary but not sufficient to ensure access, which is, in turn, necessary but not sufficient for effective utilisation" (Barrett, 2010, p. 825). The fourth pillar, stability, has been added more recently to acknowledge the importance of a reliable food supply, available at all times (FAO, 2009).

There has traditionally been a strong emphasis on food availability, particularly when considering global or national food security (Feleke, Kilmer, & Gladwin, 2005; Pinstrup-Andersen, 2009). In the African context, the most studied determinants of food availability at the household level include education, input availability, land size and quality, and technology adoption (Bashir & Schilizzi, 2013). A higher level of formal education has been associated, amongst other nutrition-related outcomes, with increased receptivity to advice from agricultural extension workers, which may improve food production. The price and availability of inputs such as seeds, fertilisers and irrigation water are shown to be important for farmers to achieve optimal crop yields (Msuya, Hisano, & Nariu, 2008). Varying results have been reported on the correlation between land size and food availability. In contrast to findings in Ethiopia (Feleke et al., 2005) and Nigeria (Amaza, Umeh, Helsen, & Adejobi, 2006), a Tanzanian study has proposed an inverse relationship between the scale and productivity of farms (Msuya et al., 2008). The authors contended that mixed cropping systems, as practised on small-scale farms, are more efficient and increase the production yield – and potentially the food availability – from a given area of land.

A paradigm shift in the understanding of food security has been attributed to Amartya Sen's essay (1981) which highlighted the significance of demand (food access) rather than supply (food availability). Access to food comprises both physical aspects, such as appropriate infrastructure, and economic aspects, which relate to food prices and the availability and division of income (FAO, IFAD, & WFP, 2014). Although improving agricultural productivity may boost food availability and provide long-term reductions in poverty and hunger, it may not solve the problem of achieving nutritious and diverse diets (Ruel & Alderman, 2013). Food security is now widely regarded as an issue of food access and requires that households – and their individual members – have the resources to achieve adequate, nutritient-rich diets. Barrett (2010) also draws attention to the role of sociocultural factors, influencing which foods fit with prevailing tastes and values, in determining an individual's access to food.

In considering access to food within households, it has been proposed that an increase in the number of household members puts more pressure on consumption than it contributes to production (Bashir & Schilizzi, 2013). Each additional member increases the likelihood of a household being food-insecure, although this effect is minimised in the case of adults able to secure employment to improve livelihoods and household income. Physical access to markets has also been shown to contribute to food security (Feleke et al., 2005). As the time taken to reach the market increases, the frequency of visits decreases and farmers become more likely to sell produce at times when prices are low, or buy when prices are high.

Food utilisation, which has historically received less attention than other aspects of food security, relates to individuals and households making effective and efficient use of available and accessible food resources (Barrett, 2010). This relies on adequate knowledge of ways to prepare and store food safely and in ways to deliver maximal nutritional value, as well as access to clean drinking water and adequate sanitary facilities to avoid the spread of infectious disease (Bashir & Schilizzi, 2013). The emphasis of nutrition security is on the utilisation aspect of food security. Higher levels of formal education, particularly amongst mothers, has been linked to improved child feeding and care-giving practices (Benson, 2004), with maternal education considered a better predictor of child health and nutrition than land ownership, household assets or paternal education (Mondal, Hossain, & Ali, 2009; Wamani, Tylleskär, Åstrøm, Tumwine, & Peterson, 2004). The positive influence of maternal education has been linked to socioeconomic status, health knowledge and attitudes to health care services in Bangladesh (Anwar, Nasreen, Batool, & Husain, 2013), and has been found to mitigate the potential negative effects of higher wealth status on the double burden of malnutrition, whereby stunted children and overweight mothers co-exist in the same household, in Mexico (Leroy, Habicht, González de Cossío, & Ruel, 2014).

The final dimension of food security, stability, requires that a household has access to adequate food at a given point in time and reasonable assurance that such access will continue in the future. The temporal dynamics of food insecurity were addressed in the World Bank report "Poverty and Hunger" (1986), which distinguished between chronic food insecurity, associated with poverty and low incomes, and transitory food insecurity, associated with seasonal shortages, natural disasters, economic collapse or conflict. Of particular interest in recent decades has been the impact of a changing climate on world food supply.

Rosenzweig and Parry (1994) reported a disparity between the agricultural vulnerability of countries of varying levels of income and development. Although their modelling predicted only a small decrease in crop production in response to a doubling of atmospheric carbon dioxide levels, this effect was suggested to be felt most strongly by LMIC. The most significant outcome is proposed to relate to the hydrological cycle, with changes to the seasonality and predictability of rainfall patterns (Bates, Kundzewicz, Wu, & Palutikof, 2008; Gleick, 2010). Shorter rainy seasons, more intensive rains and prolonged dry periods will make it difficult for farmers and state agencies to plan cropping activities effectively (Udaya Sekhar et al., 2012), making the 2.3 billion people living in rural areas or involved in small-scale agriculture even more vulnerable to food insecurity (Alderman, 2010).

1.3.2 Linking agriculture, food security and nutrition

Agriculture is recognised as having the potential to make substantive and sustainable positive contibutions to improving nutrition. Investment in agriculture has been promoted as "a critically important opportunity for reducing malnutrition" (Herforth, Jones, & Pinstrup-Andersen, 2012, p. 11), with agricultural policies and programs highlighted as being vital to lower the prevalence of stunting beyond the reduction of around 20% estimated to be possible through direct or nutrition-specific strategies (Bhutta et al., 2013). *The Lancet*'s 2013 maternal and child nutrition series included a call for a "new and more aggressive focus" on coupling effective nutrition-specific interventions, addressing immediate determinants of undernutrition, with nutrition-sensitive programs that target underlying causes of undernutrition (Figure 5; Ruel & Alderman, 2013, p. 536).

Pathways linking agriculture and nutrition have been well-described, involving economic, social and gender dimensions (Gillespie, Harris, & Kadiyala, 2012; Hawkes et al., 2012; Headey, Chiu, & Kadiyala, 2011; Masset, Haddad, Cornelius, & Isaza-Castro, 2011; Ruel & Alderman, 2013). Webb (2013) reports the efforts to frame causal pathways to have become increasing complex, as attempts have been made to identify intermediate outcomes on which research activities should focus. It is noted that such frameworks have focussed on opportunities for positive impacts on human nutritional status through agriculture, and do not illustrate the potential for adverse effects (including through zoonotic and foodborne disease, discussed in Section 1.4.3). Seven pathways have been proposed (Figure 6), although the number is acknowledged not to be fixed (Ruel & Alderman, 2013). In the most direct linkage, increased food production results in greater food availability for home consumption, strengthening food security at the household level. It is important to note that these benefits do not necessarily translate into improved nutrition for women of reproductive age and young children, particularly in settings where food resources may be preferentially allocated to male household members and elders (Girard et al., 2012).

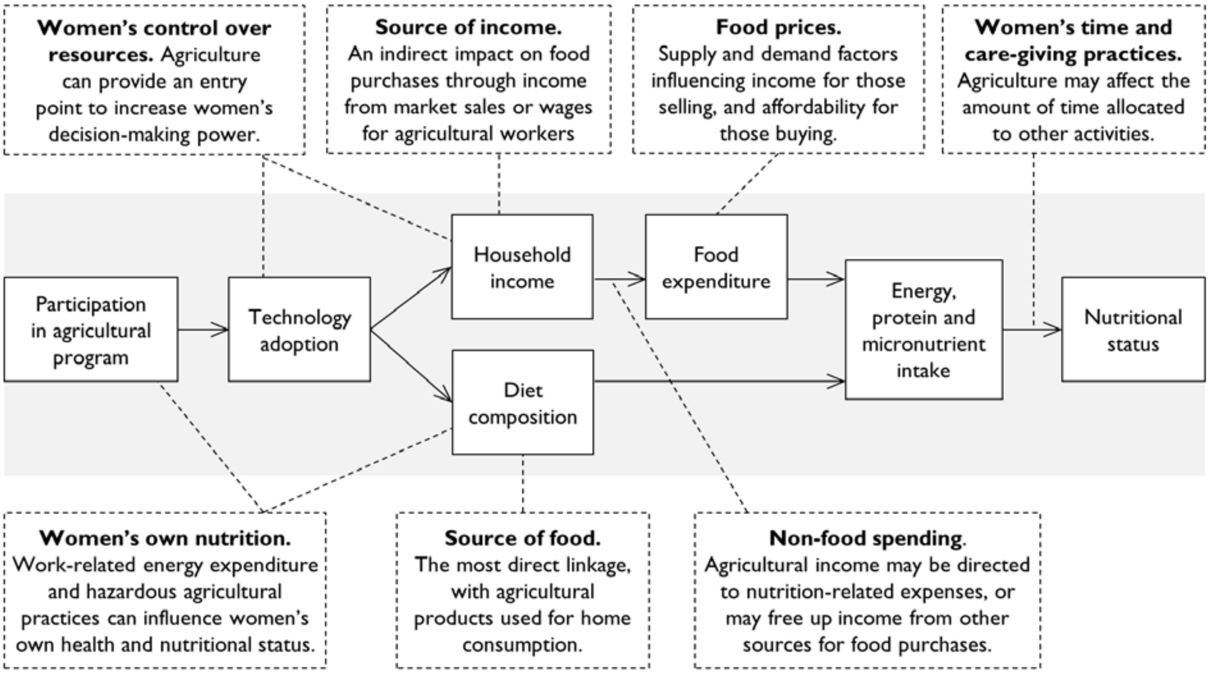

Figure 6. A summary of seven pathways through which agriculture is proposed to influence nutrition, using the framework developed by Masset et al. (2011) and the positioning of linkages presented by Webb (2013).

A complex relationship exists between agriculture, income growth and nutrition. A comparative study of the health and nutritional effects of cash crop production in six countries (including The Gambia, Kenya and Rwanda in sub-Saharan Africa) found a weak association with greater energy intake by preschool-aged children, but no significant effect on children's nutritional status or the incidence or duration of child illness (Kennedy, Bouis, & von Braun, 1992). A transition from subsistence agriculture to market-oriented crops has been associated with reduced involvement of women in production activities (von Braun, 1995), and findings from Malawi, Tanzania and Uganda indicate little evidence of the impact of agricultural commercialisation on improved nutrition outcomes (Carletto, Corral, & Guelfi, 2017). Ruel (2001) cautions that agricultural programs without a strong nutrition education component may fail to achieve improved dietary diversity, with households investing income in basic necessities other than food, or purchasing foods of suboptimal nutritive value.

Economic growth within the agriculture sector more broadly has been named as the least direct of the pathways linking agriculture and nutrition (World Bank, 2007). Opportunities exist to improve nutrition through contributions to national income, poverty reduction and lowering of food prices, yet the magnitude of this effect varies substantially between settings. Greater impact is expected in countries where agriculture contributes a main share to the national income and where farming is the primary livelihood strategy for a majority of poor households (Ecker, Breisinger, & Pauw, 2011). Using household survey data from twelve LMIC, Haddad et al. (2003) demonstrated a reduction in child undernutrition through sustained per capita income growth – however this effect was shown to be modest, and the importance of simultaneous investments in more direct interventions was emphasised. A recent review found structural adjustment programs in LMIC to have a detrimental effect on maternal and child health, due to adverse impacts on social determinants of health, such as income and food availability, and reduced access to quality and affordable healthcare (Thomson, Kentikelenis, & Stubbs, 2017). The authors highlight the far-reaching effects of economic policies and decisions made by international financial institutions on household food security.

Women are widely recognised as key mediators in agriculture-nutrition linkages, and are logical partners in agricultural programs seeking to improve nutrition. Women have been shown to be more likely than men to invest in their children's health, nutrition and education (Hoddinott & Haddad, 1994; Quisumbing, Brown, Feldstein, Haddad, & Pena, 1995), with income and resources under their control reported to "wield disproportionately strong effects on health and nutrition outcomes" (World Bank, 2007, p. xiii). Limited access to opportunities and resources is reported as a constraint to women's agricultural productivity. Figures are often cited about the severalfold increase in agricultural output and resultant decrease in undernutrition to be gained from granting women in LMIC access to the same productive resources as their male counterparts (FAO, 2011). Beuchelt (2013) highlights the need for gender-sensitive approaches and describes the potential for promising agricultural interventions to have negative repercussions for women. The author cites the example of improved maize varieties which have higher yields but longer cooking times, resulting in increased firewood requirements and greater labour inputs by women.

Making agriculture "nutrition-sensitive" requires that nutrition objectives are explicitly incorporated into agricultural policies, systems and research. Despite extensive efforts to elucidate the aforementioned pathways, the efficacy of agricultural interventions in improving nutrition is noted to have been poorly demonstrated to date (Meeker & Haddad, 2013). Numerous reviews conducted over the past two decades have highlighted the weak evidentiary link between agricultural interventions and progress in improving food and nutrition security.

Key findings from these reviews are summarised in Table 1. Recurring criticism centres on weak study design and a lack of methodological rigour, including inappropriate choice of control groups, reliance on participant "self-selection" rather than randomisation, and a lack of baseline data. Synopses of review findings have concluded that "the poor quality of the evidence prevents us from drawing any firm general conclusions on the impact of agricultural interventions on nutrition" (Meeker & Haddad, 2013, p. 9), and "the sooner methodologically rigorous studies can produce findings on how best to leverage agriculture's potential for nutrition, the better" (Webb & Kennedy, 2014, p. 130).

Table 1. Key findings from reviews evaluating the impact of agricultural programs on human nutrition

Review	Details	Results	Conclusions
Can food-based strategies help reduce vitamin A and iron deficiencies? (Ruel, 2001)	A review of food-based interventions designed to increase micronutrient intake, with a focus on home gardens, iron and vitamin A. 14 studies, 1995-1999. Outcomes evaluated: • Production and income • Knowledge, attitudes and practices • Dietary intake • Nutritional status	Few studies measured the impact on household production and income, but those that did indicated a positive effect. Activities promoting consumption of micronutrient-rich foods (e.g. education and marketing campaigns) were consistently successful. Only a few studies evaluated vitamin A or iron status indicators, and evidence of a positive impact was limited.	There is some evidence of a positive impact of home gardening interventions on production, knowledge and practices, but limited evidence of their effect on nutritional status. Improvements in study design should address a lack of replicate units, inappropriate selection of control or comparison groups, and the inability to adequately control for confounding factors.
A review of the effectiveness of agriculture interventions in improving nutrition outcomes (Berti, Krasevec, & FitzGerald, 2004)	A systematic review of agricultural interventions that measured impact on nutritional status. 30 studies, 1985-2001. Outcomes evaluated: • Dietary intake • Biomarkers • Anthropometry • Morbidity	Most studies showed some improvement in at least one agricultural indicator and positive dietary effects. Some studies showed positive effects on anthropometry, biochemical indicators and morbidity, however negative effects were also seen.	Agricultural interventions had mixed results in improving nutritional status. The impact of programs may have been overestimated by restricting analysis to studies with nutritional outcomes. Investing in human capital (especially nutrition education and gender issues) and other forms of capital (natural, physical, social and financial) may increase prospects for nutritional improvement.

Review	Details	Results	Conclusions
Can interventions to promote animal production ameliorate undernutrition? (Leroy & Frongillo, 2007)	A systematic review of the impact of animal production interventions on nutrition. 14 studies, 1987-2003. Outcomes evaluated: • Animal production • Household income and expenditure • Caregiver income, time and workload • Zoonosis • Dietary intake.	Most studies found a positive effect on animal production, and all which evaluated household income or expenditure reported a positive effect. Evidence of the impact on caregiver income, time and workload was inconclusive. No studies evaluated zoonotic disease. A positive impact on dietary intake was generally reported, but only four studies evaluated nutritional status. Results were not always positive, and attribution of the effects to animal production not always possible.	Available evidence is insufficient to answer whether promoting animal production is an effective means of alleviating undernutrition. Studies which directly measure the impact of animal interventions on nutritional status are rare. Future studies evaluating this link would benefit from stronger methodological designs.
From agriculture to nutrition: Pathways, synergies and outcomes (World Bank, 2007)	A review to assess the contribution of any agricultural intervention to nutrition. 52 studies, 2001-2007. Outcomes evaluated: • Food expenditure • Caloric intake • Anthropometry	Interventions involving staple foods were associated with higher income, greater food expenditures and usually higher energy intake. Dietary diversity was not assessed. Impacts on child nutritional status were inconclusive. Interventions involving ASF had mixed results on dietary intake and nutritional status. Home gardening interventions without a nutrition education component did not significant affect nutritional outcomes.	Agricultural programs have not always been successful in improving nutrition. There is a need to address other determinants of improved nutrition, beyond production. Agriculture and nutrition should be integrated during all phases of a project. Relationships with local partners, mainstreaming gender, and incorporating effective communication, education and monitoring and evaluation strategies are key priorities.
Agricultural interventions and nutrition: Lessons from the past and new evidence (Arimond et al., 2011)	A systematic review of agricultural interventions that provide evidence about individual-level nutrition outcomes. 39 studies, 1987-2003. Building on findings from previous reviews.	Commercialisation was associated with positive impacts on production of target crops, increased household income and food expenditures, but no significant impact on children's nutritional status. Homestead gardening interventions were likely to have positive impacts on nutrition when communication and nutrition education activities and gender considerations were included. Most livestock and aquaculture interventions showed a positive impact on ASF production, income and expenditure, but mixed results for nutrient intake and nutritional status.	A failure to design agricultural programs as nutrition interventions, and to include explicit behaviour change strategies, limits their impact on nutrition. Limitations in study design include a lack of baseline data, lack of adequate control groups, small sample size, and use of "self-selected" participants. There is suggestive evidence of the potential for well-designed agricultural interventions to improve nutrition, but well-designed evaluations are needed to confirm this potential.

Review	Details	Results	Conclusions
Effectiveness of agricultural interventions that aim to improve nutritional status of children: Systematic review (Masset, Haddad, Cornelius, & Isaza-Castro, 2012)	A systematic review to assess the effectiveness of agricultural interventions with the explicit goal of improving children's nutritional status. 23 studies, 1990-2010. Outcomes evaluated: • Program participation • Income • Dietary diversity • Micronutrient intake • Prevalence of undernutrition.	No studies involved a randomised design. Characteristics used to select controls were limited or poorly-reported. Participation rates and participant characteristics were not given. Programs generally had a positive effect on production and consumption of target agricultural items, but effects on total income or overall diet were rarely tested. There was some evidence of a positive effect on vitamin A levels in children, but no significant effect on iron levels and limited evidence of an effect on anthropometry.	There is no clear verdict on the effectiveness of agricultural interventions on children's nutritional status. Available data show a poor effect, but multiple methodological weaknesses are evident. There is a need for more rigorous and better designed studies, as well as guidelines for research in this area.
The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review (Girard et al., 2012)	A systematic review of agricultural interventions aiming to increase food production on nutrition and health outcomes for women of reproductive age and children under five years of age. 36 articles (27 projects), 1990- 2011. Outcomes evaluated: • Anthropometric and biological indicators of nutritional status • Dietary practices • Caregiver workload • Zoonosis	Evidence of an effect on anthropometry of women and children was limited, but better results were seen when the target food items were rich sources of not only micronutrients, but also of protein and energy. Increased consumption of vitamin A-rich fruits, vegetables and tubers, eggs and milk was demonstrated, but whether this was sufficient to meet nutrient requirements was unclear. Long-term impacts were rarely evaluated, and variable results and multiple methodological weaknesses prevented sustainability being assessed.	Despite improved study design and analysis, inclusion of nutrition education, gender integration and validated nutrition indicators, the evidence base for agriculture-nutrition linkages remains weak. Future studies should continue to strive for methodological rigour, and assess both nutritional status and consumption patterns. Selection of control groups and adjustments for confounding should be considered. There is also an urgent need for research in urban areas in LMIC.

1.4 Livestock, animal-source foods and human nutrition

Livestock are kept by both urban and rural households in LMIC. The most recent estimates of global livestock numbers report 1.47 billion cattle, 2.21 billion sheep and goats, 0.99 billion pigs and 21.41 billion chickens (FAO, 2014; Table 2). These figures reflect an approximation of the standing populations, and do not reflect the more rapid turnover of stock in intensive pig and poultry production systems. Limitations in the quality and accessibility of data on livestock numbers, distribution and use have been recognised as a major constraint to planning, policy development and analysis (Robinson, Franceschini & Wint, 2007).

Table 2. Estimates of livestock numbers: globally, in Africa and in Tanzania (FAO, 2014)

	Cattle	Goats	Sheep	Pigs	Chickens
Estimated standing population					
Global	1 474 526 581	1 011 251 833	1 195 624 523	985 673 301	21 409 683 000
Africa	312 327 289	374 380 445	340 749 117	34 332 061	1 809 059 000
Tanzania	25 800 000	16 700 000	8 701 000	505 000	36 000 000
Percentage of global estimates (%)					
Africa	21.2	37.0	28.5	3.5	8.4
Tanzania	1.7	1.7	0.7	0.1	0.2
Percentage of African estimates (%)					
Tanzania	8.3	4.5	2.6	1.5	2.0

The livestock sector includes nearly one billion smallholder farmers in LMIC, contributing 40% of agricultural GDP and up to one-third of household incomes (Rota, 2015). In Tanzania, three-fifths of rural households report livestock husbandry as an income source (Covarrubias, Nsiima, & Zezza, 2012). Smallholder farming systems vary according to ecological, demographic and socioeconomic influences, but may be broadly defined as production systems with inputs primarily derived from within the household, and outputs intended to contribute to household needs (McDermott, Randolph, & Staal, 1999). Such a definition avoids prescriptive guidelines on livestock numbers or land size, and retains a focus on a farmer-centred unit for understanding decision-making processes and priorities.

In a review exploring the relationship between livestock, poverty and food security, Turk (2013) highlights the situation in many LMIC where high numbers of food-producing animals are not reflected in the supply of animal protein per capita or in levels of food and nutrition security. This disparity is evident in Africa, which has been named as the region with the highest prevalence of undernutrition despite a 1:1 ratio of livestock to humans (FAO et al., 2015).

Livestock have the potential to influence household food and nutrition security via direct and indirect pathways. Consumption of animal-source foods (ASF) constitutes a direct and obvious pathway, while the use of income from the sale of livestock or their products on household food purchases is an indirect one. Proposed linkages between ownership of livestock and the human health and nutrition are presented in Figure 7. This diagram was developed by researchers at the International Livestock Research Institute (ILRI), Cornell University and the Global Livestock Collaborative Research Support Program with the aim of better visualising these linkages at the household or community level in resource-poor settings. In its original format, this conceptual framework was used to map pathways between dairy cow ownership and children's nutrition in Kenya (Nicholson, Mwangi, Staal, & Thornton, 2003).

Livestock-nutrition linkages can be seen to be complex and multidirectional, with the potential for both positive and negative impacts. Benefits of consuming ASF may be offset by the risks of food-borne infectious disease (Headey et al., 2017; Zambrano, Levy, Menezes, & Freeman, 2014). In mixed livestock-crop systems in Africa, larger livestock may provide traction (Okello et al., 2015) and manure for nutrient cycling (Zingore, Delve, Nyamangara, & Giller, 2008), but also reduce the availability of labour and land for crop production (Herrero et al., 2010). These pathways are noted to be highly context-specific, and to vary according to the livestock species in question. The net impact of livestock ownership on human health and nutrition in a given setting is thus difficult to determine without an in-depth understanding of the context, including animal management practices, environmental factors and sociocultural influences (Randolph et al., 2007).

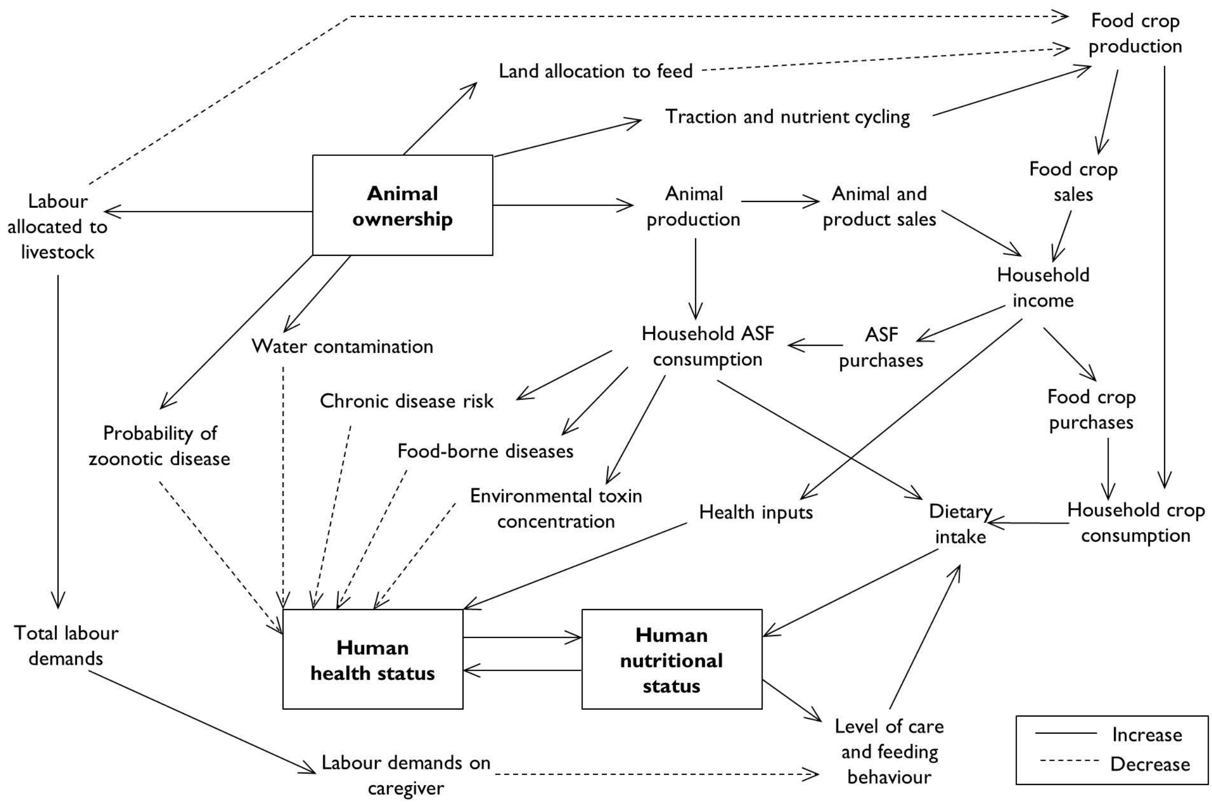

Figure 7. Hypothesised causal linkages between livestock ownership and human health and nutrition outcomes in resource-poor settings (adapted from Randolph et al., 2007).

1.4.1 Direct nutritional contributions

Animal-source foods are rich sources of balanced protein and a range of bioavailable micronutrients, of key importance to children's physical and cognitive development (Demment, Young, & Sensenig, 2003; Grillenberger et al., 2003; Murphy & Allen, 2003; Neumann, Harris, & Rogers, 2002). Micronutrient levels differ widely between different forms of ASF (such as red meat, poultry, liver, milk and eggs), but include iron, calcium, zinc, vitamin A, vitamin B12 and folate. The inclusion of small amounts of ASF increases the nutrient adequacy of traditional diets based on staple crops, such as maize, sorghum, millet and cassava. There is particular advantage in the consumption of ASF by young children, whose limited gastric capacity relative to high nutrient requirements for growth necessitates a nutrient-dense diet (Dewey & Brown, 2003; Gutierrez-Mazariegos, Theodosiou, Campo-Paysaa, & Schubert, 2011; Michaelsen et al., 2009). Animal-source foods offer the added benefit of supplying multiple micronutrients – a distinct advantage over single-nutrient supplements for individuals whose diets are marginally low in more than one nutrient (Murphy & Allen, 2003; Shenkin, 2006).

The "quality" of a protein is determined by both amino acid composition and digestibility, and reflects the efficiency with which a protein may be utilised by the human body, similar to the bioavailability of micronutrients (WHO, FAO, & United Nations University, 2007). Of twenty amino acids, those that cannot be synthesised from precursors by the body at a rate that meets metabolic requirements are considered essential or indipensable. The types of protein found in foods of animal origin, including eggs, milk and meat, have no limiting essential amino acids (Tome, 2012). Protein in chicken eggs has been cited as the best suited to human physiological requirements, and used as a benchmark against which the quality of other protein sources has been compared (Coles, Wratten, & Porter, 2016).

Evidence of the benefits of ASF on growth includes observational and randomised controlled trials. In a comparison of milk, meat and plant-based supplements on school-aged children in Kenya, Neumann et al. (2007) reported meat to improve cognitive function and physical activity, milk to be associated with amelioration of height-for-age in stunted children, and both to increase arm muscle mass and improve vitamin B12 status. Daily consumption of dairy products has been associated with significantly higher scores on multiple domains of cognitive function, including abstract reasoning, visual-spatial memory, working memory and mental organisation (Crichton, Elias, Dore, & Robbins, 2012). A randomised controlled trial in Ecuador has demonstrated improved length-for-age in children 6-9 mo provided with one egg per day over a 6 month period (Iannotti et al., 2017).

The consumption of bushmeat (i.e. wildlife hunted as a food source) is a common and well-researched phenomenon in Africa, representing both a key source of protein and micronutrients for hundreds of millions of rural people living in poverty and a major threat to biodiversity (Brashares, Golden, Weinbaum, Barrett, & Okello, 2011). While conservation projects often target economic factors (Fischer, Naiman, Lowassa, Randall, & Rentsch, 2014), drivers of bushmeat hunting are numerous and may vary between settings. A study in villages bordering the Serengeti National Park in Tanzania reported a reduction in the demand for bushmeat with greater availability of lower priced protein substitutes, such as fish or chicken (Moro et al., 2015). This association was not found in the Tarangire-Manyara ecosystem, also in Northern Tanzania, although Maasai pastoralists were reported to consume bushmeat significantly less frequently than other groups in the area (Kiffner, Peters, Stroming, & Kioko, 2015).

Small indigenous fish have been proposed as an affordable alternative to milk to improve the nutrient adequacy of complementary foods for young children in Cambodia (Skau et al., 2015), and a promising food-based strategy to meet micronutrient requirements of children and women of reproductive age in Bangladesh (Bogard et al., 2015). Particular nutritional benefits are gained from eating whole fish, including the head, bones and organs (Roos et al., 2007). Mixed methods research from central Tanzania suggests the hunting of rodents to be a common and frequent activity amongst young and adolescent boys (Ackland, 2014). Insects have also served as a wild source of protein and micronutrients for thousands of years, particularly in remote rural areas and in tropical countries with high biodiversity (Durst & Shono, 2008), and have been heralded as an untapped food resource (van Huis et al., 2013). Recent research has focussed on insects as a rich source of protein and micronutrients, with ecological and economic advantages over conventional ASF (Belluco et al., 2013; Payne, Scarborough, Rayner, & Nonaka, 2016).

1.4.2 Indirect nutritional contributions

Indirect pathways through which livestock may contribute to improved human nutrition align with the broader agriculture-nutrition linkages discussed earlier (Figure 6). The livestock sector offers important avenues to reduce poverty and stimulate rural development in LMICs, through income generation and employment opportunities (Katjiuongua & Nelgen, 2014). Income-mediated nutritional benefits, such as the financial capacity for dietary diversification and more frequent consumption of nutritious foods, may exist both for livestock owners and for multiple other actors within livestock value chains. In an appraisal of the market for indigenous chickens in Tanzania, such actors were identified to include intermediaries (who purchase chickens from producers or at local markets and sell onwards at a profit), restaurant operators, and market traders in the local community, in larger towns nearby, and in Dar es Salaam (Queenan et al., 2016).

Livestock are often the most important assets in poor rural households. As an alternative to traditional financial institutions such as banks, livestock often serve as a "living savings account", of varying liquidity according to species, which may be sold to provide cash income as required (Hoddinott, 2006; Moll, 2005). Substantial time and resources are required to raise large livestock species, such as cattle, to the point of maturity when sale is most profitable, while small livestock species, such as poultry, mature rapidly and may be sold as needed to meet household expenses (Mapiye et al., 2008; Wong et al., 2017). Increasing livestock ownership has been identified as an opportunity to enable households to invest in land and small businesses, diversifying their income, reducing vulnerability and strengthening food and nutrition security (Ellis & Freeman, 2004).

While the potential economic contributions of livestock may be great, Randolph et al. (2007) highlight the diverse roles served by animals in resource-poor households, maintaining that it is misleading to consider livestock to be an independent activity targeted towards production. Sales of livestock are often sporadic and prompted by immediate household needs such as school fees or medical expenses (Kitalyi et al., 2005). Experience has shown that livestock interventions which involve intensification of production systems and market-oriented approaches do not necessarily translate into the intended positive nutritional outcomes, (Hoffmann, Riethmuller, & Steane, 2003). Income-mediated pathways are likely to involve considerable dilution of the effects on nutrition security, with opportunities for income to be directed to other priorities within households or spent on less-nutritious food purchases.

To support women in their important role in linking agriculture with nutrition, there is a need for gender-sensitive approaches in livestock research and development programs. The ownership and management of different livestock species varies according to gender (UN Economic and Social Council, 2002), with women more likely to be responsible for the management of chickens and smaller livestock (Bagnol, 2009). Opportunities exist for change in the gendered nature of livestock management roles, according to social, economic, and environmental influences (World Bank, FAO, & IFAD, 2009). Amongst pastoralist groups of Morogoro and Tanga Regions in Tanzania, it is reported that women adopt the "male" task of herding cattle in times of labour shortages, but only in rare circumstances that men perform "female" tasks, such as poultry management – except where there may be potential to gain control over assets (Maeda-Machang'u et al., 2000)

In Kenya, livestock owned by women or "co-owned" by male and female household members was associated with greater height-for-age and more frequent ASF consumption amongst children, while male-owned livestock was not (Jin & Iannotti, 2014). The greater likelihood of women investing in foods for their children and families, compared to men, has been widely reported (Handa, 1996; Kennedy & Peters, 1992; Valdivia, 2001) and highlights the need to consider women as a key mediators of the indirect nutritional impact of livestock ownership.

1.4.3 Adverse nutrition and health impacts

As interest in the scope for livestock to contribute positively to child nutrition has grown, attention has also been directed to the potential for contact with domestic animals to adversely affect children's growth and health. Concerns about exposure to livestock faeces in rural communities relate both to pathogenic bacteria, responsible for infectious diarrhoea (Zambrano et al., 2014) and to non-pathogenic bacteria, implicated as a cause of subclinical environmental enteric dysfunction (previously described as tropical enteropathy), in which chronic damage to the gastrointestinal tract reduces nutrient absorption and causes low-level immune stimulation, restricting children's growth and development (Mbuya & Humphrey, 2016).

To date, efforts to determine the net impact of livestock ownership on child growth and health have largely reported on analysis of existing datasets rather than purpose-designed studies. Analysis of survey data from Ethiopia by the US Government-funded *Feed the Future* study demonstrated a significant positive association between chicken ownership and HAZ, although this was suggested to be counteracted by the practice of housing chickens inside human dwellings overnight (Headey & Hirvonen, 2015). Using data from another program aiming to combat child undernutrition, significant negative associations were identified between the presence of animal faeces in the homestead environment and children's HAZ in Bangladesh and Ethiopia, but not in Vietnam (Headey et al., 2017).

Animal-source foods, while offering an valuable opportunity to enhance protein and micronutrient intake, also represent an important source of foodborne disease – particularly in LMIC (Käferstein, 2003). This encompasses disease due to foodborne parasites, bacteria, viruses, chemicals and fungal toxins (Grace, 2015). Children under five years of age are at particularly high risk, constituting almost one-third of all deaths due to foodborne illness (WHO, 2015). Hazards have been associated both with fresh, perishable food items sold through informal markets, and with formal markets which involve longer and more complex value chains and may have lower compliance with food safety standards (Grace, Roesel, & Lore, 2014). Contamination of foods with fungal toxins such as aflatoxins, the toxic secondary metabolites produced by certain *Aspergillus* fungi, is a major problem in the African continent (Darwish, Ikenaka, Nakayama, & Ishizuka, 2014) and has been associated with eggs, meat and milk (Gizachew, Szonyi, Tegegne, Hanson, & Grace, 2016; Herzallah, 2009; Iqbal & Asi, 2013; Neff & Edds, 1981). Aflatoxins pose a threat of liver cancer (Liu, Chang, Marsh, & Wu, 2012), growth impairment (Khlangwiset, Shephard, & Wu, 2011) and immunosuppression (Bondy & Pestka, 2000).

Some authors have suggested a disconnect to exist between the zoonoses prioritised by national and international public health and veterinary agencies, and those of significance to the poor (Perry, Randolph, Omore, Perera, & Vatta, 2005). Randolph (2007) suggests researchers and practitioners unknowingly demonstrate a “Northern bias” (referring to the predominance of more affluent nations in the Northern hemisphere) that is acquired during professional training, and warns against extrapolation from better-characterised but dissimilar disease situations. This may be the case in village poultry systems, where little has been documented about the prevalence of bacterial pathogens of human health significance in indigenous breed birds kept under free-ranging conditions.

1.5 Research paradigms, methodology and indicators

The use of questionnaires has long been central to public health research, however a surge in the diversity of research methods has been seen in recent years. This has been interpreted as a reflection of the rise in interdisciplinary research teams, growing acceptance of the role of qualitative and social science research, and a move towards multi-level approaches to complex health problems (Creswell, Klassen, Plano Clark, & Smith, 2011). Interdisciplinary research has grown in prominence and perceived utility, through the increased recognition of the interdependent relationships between people, animals and the environment. Examples include the impact of H5N1 Highly Pathogenic Avian Influenza on human lives and livelihoods, and the threat to biodiversity posed by bushmeat hunting by food-insecure populations (Alders, de Bruyn, Wingett, & Wong, 2017).

Two broad movements tackling issues relating to the health of humans, animals and their social and ecological environments are *One Health* and *EcoHealth*, described as “subdivided and with complex interactive origins” (Mi, Mi, & Jeggo, 2016, p. 12). The former group arose as an extension of the “one medicine” concept, built on recognition of the shared principles, knowledge and approaches of human and veterinary medicine (Schwabe, 1964). One Health highlights the added value for human and animal health, financial savings and environmental outcomes which may be achieved through cooperation between human and veterinary medicine, compared to the two working separately in disciplinary “silos” (Zinsstag, Waltner-Toews, & Tanner, 2015). EcoHealth is distinguished from One Health by its emphasis on the condition and sustainability of ecosystems, both natural and human-made, and seeks to optimise ecosystem health in order to benefit human and animal health (Dakubo, 2010). A third movement, *Planetary Health*, emerged in 2015 with the aim of safeguarding “the health of human civilisation and the state of the natural systems on which it depends” (Horton & Lo, 2015, p. 1921). Planetary Health recognises the threats posed by environmental degradation and maintains the core role of natural systems in underpinning human health (Whitmee et al., 2015).

Holistic and integrated approaches are central to research and development programs aiming to sustainably strengthen food and nutrition security and address chronic undernutrition in resource-poor settings, issues described as “wicked problems” to reflect their complexity. Brown (2010, p. 4) indicates a wicked problem to be one which “defies complete definition, for which there can be no final solution, since any resolution generates further issues, and where solutions are not true or false or good or bad, but the best that can be done at the time”. Harnessing the potential of livestock to improve human nutrition in rural communities, alongside various social, economic, gender and cultural considerations, calls for a cohesive and coherent approach to data collection, management and communication (Bagnol et al., 2016).

1.5.1 Mixed methods research

As well as qualitative and quantitative approaches to research, mixed methods is now increasingly recognised as another major research paradigm (Johnson, Onwuegbuzie, & Turner, 2007). Campbell and Fiske (1959) are credited with formalising the practice of multiple research methods as part of a validation process, to ensure that observed variation is related to the phenomenon under investigation and not the research method. The convergence of findings from more than one method “enhances our beliefs that the results are valid and not a methodological artifact" (Bouchard, 1976, p. 268). Pluye and Hong (2014, p. 30) describe mixed methods research as combining "the power of stories and the power of numbers", identifying the value of stories in influencing health policy (Newman, 2003) and statistics in providing a strong rationale for making changes.

Triangulation involves studying the same phenomenon through multiple methodologies. Denzin (1978) distinguishes "within methods" triangulation, which uses multiple qualitative or multiple quantitative methodologies, from "between methods" triangulation, which combines both qualitative and quantitative methodologies. The latter approach (i.e. a *mixed methods* approach) has been advocated as a means of minimising the bias inherent in any one data source, method or investigator. Two types of triangulation are proposed: simultaneous, where data are collected through multiple sources or methods at the same time and results are compared on completion, and sequential, where results of one approach are used to inform and plan the next (Morse, 1991). In the design phase, quantitative data can serve to identify representative and outlying cases, while qualitative data can be used to guide research tool development. In data analysis, quantitative data may be used to assess how readily qualitative findings may be generalised, while qualitative data may enable deeper interpretation, clarification and validation of quantitative results, including attribution of causality (Pluye & Hong, 2014).

1.5.2 Nutritional indicators

Although recent literature reviews, as presented in Table 1 and summarised by Webb and Kennedy (2014), have consistently identified a lack of empirical evidence to support the impact of agriculture on nutritional status, limited attention has been given to the choice and appropriateness of the indicators employed within such projects. This issue was addressed by Herforth and Ballard (2016) in a review of 60 projects identified through a global mapping study of current agriculture-nutrition research (Hawkes et al., 2012; Turner et al., 2013). A greater breadth of indicators was found to be used by these studies than has been reported previously, and the indicators related well to at least parts of the conceptual framework linking agriculture and nutrition. Many studies measured both household and individual dietary diversity of women and young children, in contrast to a complete absence of dietary diversity indicators in agriculture-nutrition studies in a previous review (Herforth, 2010).

The widespread use of measurements of nutritional status, most commonly child stunting and biochemical markers, has been deemed unlikely to yield useful results within the sample sizes and timeframes of current international agriculture-nutrition projects (Herforth & Ballard, 2016). Two issues are proposed to exist: firstly, whether agriculture-nutrition projects can actually achieve a reduction in child stunting; and secondly, whether sample sizes are adequate to detect this outcome. Using the prevalence of child stunting as an example, a reduction of 15-20% was proposed to be the smallest magnitude of effect needed for a project's impact to be observed, based on the sample sizes of studies reviewed. Although an effect of this magnitude was documented in an evaluation of 29 United States Agency for International Development (USAID) Title II-funded maternal and child health and nutrition programs that ended in 2000 and 2001, this effect was likely to be multifactorial and was not able to be attributed to nutrition-specific interventions (Swindale, Deitchler, Cogill, & Marchione, 2004). It is suggested that a similar reduction in stunting prevalence would not be possible over the same time frame for agricultural interventions, which focus on underlying rather than immediate determinants of undernutrition (Ruel & Alderman, 2013; Figure 5).

Improved food access and consumption are proposed to be closer to the plausible impact pathways for agricultural programs than changes in stunting, which has numerous non-food causes. Many current agriculture-nutrition studies are likely to have adequate statistical power to observe impact on at least some dietary outcomes of interest, such as dietary diversity or the consumption of nutrient-rich target foods (Herforth & Ballard, 2016), as has been reported in home garden projects previously (Ruel, 2001). Measures of dietary diversity are the most common approach taken to evaluate dietary quality, or the adequacy with which essential nutrient requirements are met. Two broad approaches exist to describe foods consumed over a given reference period, usually of one to three days, although longer periods are also reported (Drewnowski, Henderson, Driscoll, & Rolls, 1997). Dietary diversity scores reflect the number of food groups consumed, while less commonly used food variety scores are based on the number of unique food items (Ruel, 2003). Increasing the range of foods consumed, both between and within food groups, has long been recommended in international dietary guidelines (WHO & FAO, 1998). Dietary diversity assessments are advocated as a straightforward means of data collection, readily conducted by trained field personnel and with minimal burden on respondents (Swindale & Bilinsky, 2006).

The numerous dietary diversity indicators vary in their aims, food classifications and target groups. Individual-level indicators include the Infant and Young Child Minimum Dietary Diversity indicator (WHO, 2008a), the Individual Dietary Diversity Score for children and adults (Kennedy, Ballard, & Dop, 2010; Swindale & Bilinsky, 2006), the Women's Dietary Diversity

Score (Kennedy et al., 2010) and the Minimum Dietary Diversity for Women of Reproductive Age (FAO & FHI 360, 2016). These indicators are used to measure the nutritional quality of an individual's diet, while the Household Dietary Diversity Score evaluates access to food and is positively correlated with household food security and socioeconomic status (Swindale & Bilinsky, 2006). The need for uniformity in assessing dietary diversity has been highlighted as important to maximise the comparability and generalisability of findings (Ruel, 2003), and the use of standard, validated indicators is to be encouraged within agriculture-nutrition studies (Herforth & Ballard, 2016).

1.6 Purpose of this thesis

This thesis investigates linkages between small-scale chicken-keeping and children's nutrition in rural communities of Tanzania. As discussed in this chapter, limited progress has been made towards hunger reduction targets in sub-Saharan Africa. In Tanzania, levels of chronic undernutrition vary widely between regions and between urban and rural communities. Of children under five years of age, one third have impaired height-for-age (i.e. stunting) and over half are affected by anaemia, the primary cause of which is iron deficiency. Adverse impacts of these conditions on health and productivity have been discussed. This chapter has identified livestock to be widely owned in LMIC and to serve a range of roles within smallholder households – although in most cases, livestock-keeping is not expressly oriented towards market production or household nutrition. Substantial potential exists for the nutritional contributions of livestock to be enhanced, and for animal ownership (and agriculture more broadly) to offer a sustainable pathway to improved food and nutrition security, yet previous studies have so far failed to generate evidence to this effect.

This thesis presents findings from data collected between May 2014 and October 2016 in eight villages of Manyoni District, Singida Region in the Central Zone of Tanzania. The overall aims of this doctoral research are: (1) to evaluate the contributions of village chicken-keeping to the diets and height-for-age of infants and young children over a two-year period; and (2) to explore opportunities to address barriers and fill knowledge gaps to enhance these contributions.

1.6.1 Thesis outline

Figure 8 provides a concept map of this thesis. **Chapter 1** reviews background literature to orient the reader, introduces the research aims and provides an overview of the thesis structure. **Chapter 2** situates this doctoral research within a broader cluster-randomised controlled trial, describes the study setting and participant selection process, and provides an introduction to quantitative and qualitative research methods employed. This section has been included to supplement information in later published or manuscript-style chapters.

Following on from the discussion of agriculture and livestock-keeping in Chapter 1, **Chapter 3** focuses on "family poultry" or small-scale chicken-keeping, as practised within the Tanzanian study sites, and outlines its documented and potential associations with household food and nutrition security. Newcastle disease (ND), a viral disease of poultry, is identified as a major constraint to village chicken production. **Chapter 4** uses data from the first two years following the introduction of community-based ND vaccination programs to evaluate the uptake of the vaccination service and its effect on chicken flock size within Sanza and Majiri Wards.

For increased village chicken production to contribute to household food and nutrition security and to children's diets, information on the nutrient content of poultry products is needed. **Chapter 5** analyses food composition databases from Tanzania, alongside six other African references and three databases from high-income countries, to assess the source, spectrum and quality of available nutrient data and consider the suitability of its use in resource-poor settings. To identify and pursue opportunities to enhance dietary quality (including through the consumption of chicken meat and eggs), an understanding of current behaviours is needed. **Chapter 6** uses a mixed methods approach, combining findings from sample-wide questionnaires with participant-completed dietary records and targeted in-depth interviews, to characterise existing infant and young child feeding practices in the study sites.

Having demonstrated the effect of ND vaccination on local chicken flocks (Chapter 4), evaluated available data on the nutrient content of chicken meat and eggs (Chapter 5), and described current diets and feeding patterns for children in the Tanzanian study sites (Chapter 6), **Chapter 7** tests associations between chicken-keeping and dietary, growth and health outcomes for children. This final results-based chapter uses longitudinal data to identify determinants of (1) diets of children and their mothers, (2) child HAZ, and (3) the incidence of diarrhoea in children. **Chapter 8** completes the thesis by drawing conclusions, summarising the major findings, and highlighting the policy and future research implications.

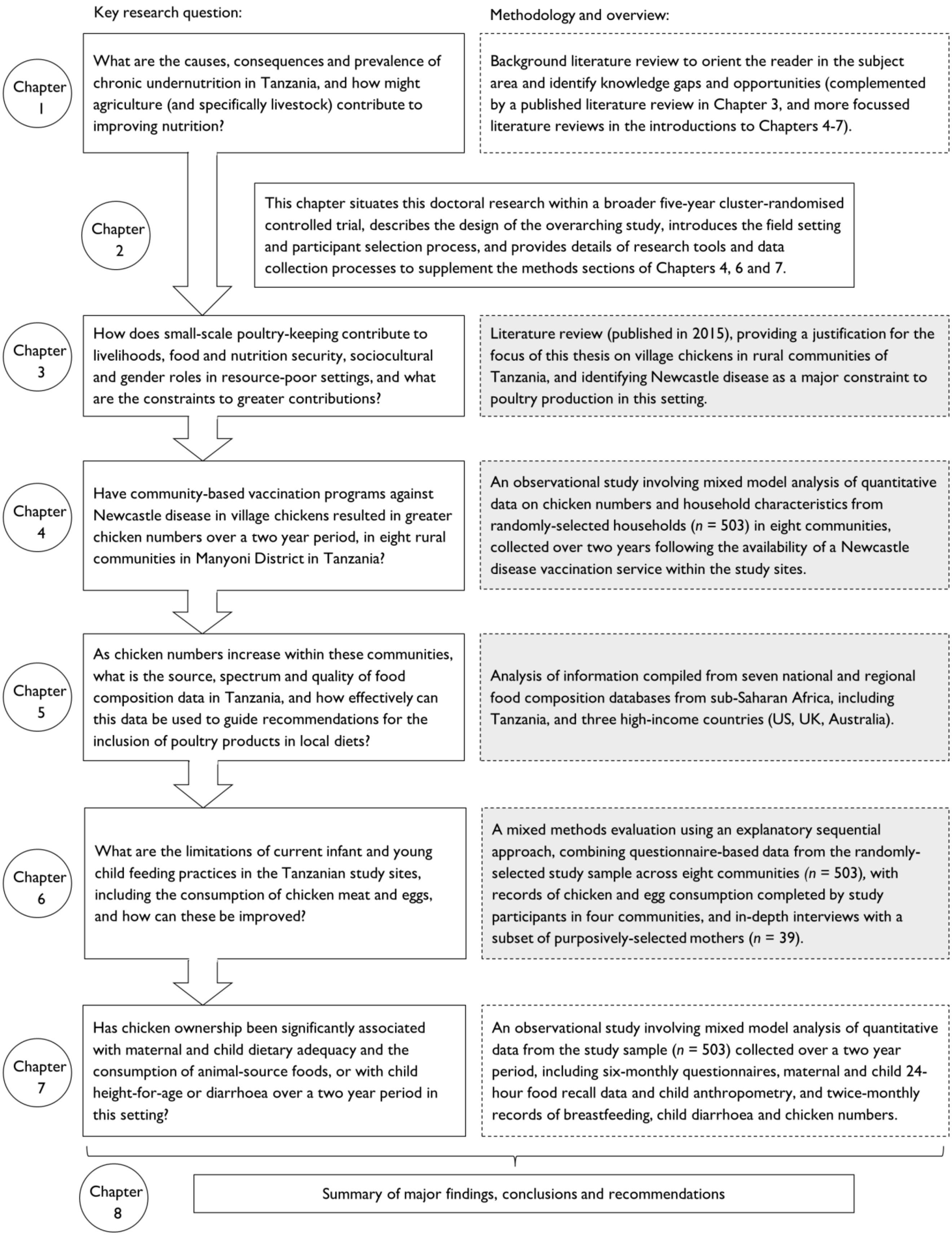

Figure 8. A conceptual diagram of the structure of this thesis, outlining the research questions addressed and approach taken in each chapter. Grey shading indicates chapters which have been published in peer-reviewed journals at the time of thesis submission.

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Chapter 2. Study design, setting and methods

Chapter 2 situates this doctoral research within a five-year cluster-randomised controlled trial, *Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia* (ACIAR FSC/2012/023). Study design, site selection, eligibility criteria, and the enrolment of participants are discussed. This thesis presents findings from eight of the twenty clusters in the broader study, from Sanza and Majiri Wards in Manyoni District in Tanzania.

As a thesis which includes publications, some information in this chapter is replicated in Chapters 4, 6 and 7, where details of specific research methods are also given. The present chapter provides additional information on qualititative and quantitative data collection (including the recruitment and training of local enumerators), a more detailed description of the study sites, an overview of research tools and details of ethics approval.

This chapter also elaborates on the use of language groups as a proxy for sociocultural influences on agricultural, dietary and child feeding practices within the study population. While not a core focus of this research, language groups have been found to be significantly associated with several outcomes of interest in this study, including chicken flock size and height-for-age in children.

Image 2. A house in the remote Chikuyu Bubu subvillage in Sanza Ward, Tanzania. Of 503 households participating in this study, a large majority live in houses with a thatched roof (81.7%) and mud walls (86.9%). At the time of baseline data collection, 13.1% of households reported owning a solar-panel for use as a power source, as seen on the roof of this home.

Photo credit: Julia de Bruyn, 2017.

Chapter 2. Study design, setting and methods

2.1 Introduction

This doctoral research has been undertaken in association with the interdisciplinary research project *Strengthening Food and Nutrition Security Through Family Poultry and Crop Integration in Tanzania and Zambia* (*Nkuku4U*, ACIAR FSC/2012/023[1], ACTRN 12617000291381[2]). *Nkuku4U* is a five-year cluster-randomised controlled trial evaluating whether community-based vaccination programs against Newcastle disease in village chickens and strategic improvements to crop systems, compared to existing poultry and crop systems, improve child height-for-age Z-scores (HAZ) in rural communities of Tanzania and Zambia.

The thesis candidate has been employed as a part-time research assistant on this broader project since October 2013, prior to commencing her PhD candidature in March 2014. The cluster-randomised controlled trial is led by Professor Robyn Alders at the University of Sydney, and was designed and developed together with Professor Judy Simpson, Professor Mu Li, Professor Robyn McConchie, Dr Brigitte Bagnol and Dr Siobhan Mor, as well as Tanzanian and Zambian partners (including those at the Tanzania Veterinary Laboratory Agency and Tanzania Food and Nutrition Centre). Although the thesis candidate was not involved in the overarching study design, her role within this project included contributing to the development and refining of research tools, implementing research activities in field sites, and coordinating data management.

Chapter 2, the present chapter, has been included to:

- describe the study design, sample size calculations and interventions of the *Nkuku4U* study;
- situate the aims, activities and contributions of this doctoral research within the context of the ongoing cluster-randomised controlled trial;
- orient the reader to the study sites in Tanzania;
- provide additional information on data collection processes and research tools contributing to this thesis, without the limitation of word counts imposed by academic journals.

[1] Australian Centre for International Agricultural Research (ACIAR) project identification.
[2] Australian New Zealand Clinical Trials Registry (ANZCTR) identification.

As a thesis which includes chapters published as peer-reviewed research articles, details of the study setting and methods relevant to each paper are included in Chapters 4, 6 and 7, and approaches to the collation and analysis of published data given in Chapter 5. Chapter 7, which has been written in the general style of a manuscript but not submitted for publication, provides a more comprehensive methods section, including a particular emphasis on data sources and the approach taken to defining predictor and outcome variables for analyses.

2.2 *Nkuku4U* study design and interventions

The *Nkuku4U* study commenced in February 2014 and is being implemented in twenty communities (clusters), with a staggered commencement of research activities across sites. Figure 1 shows the spread of clusters across countries, regions or provinces, districts and wards. Overall sample size calculation was based on an estimated baseline stunting prevalence of 35%, with the aim of reducing this to 25% by the end of the project (i.e. a 10 percentage point reduction), giving 80% power to detect this difference as being significant at the two-sided 5% level, assuming an intra-cluster correlation coefficient of 0.014.

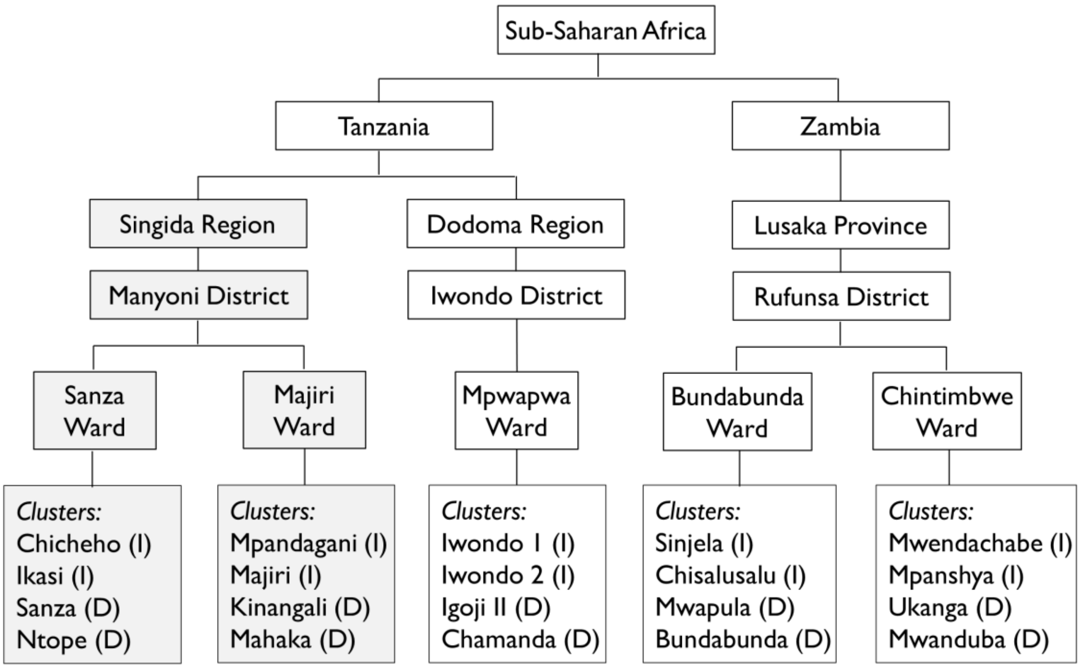

Figure 1. Communities participating in the *Nkuku4U* cluster-randomised controlled trial. Ten clusters were randomly allocated to the intervention group (immediate intervention, *I*) and ten to the control group (delayed intervention, *D*). Grey shading marks the eight clusters which have been included in this doctoral research.

Interventions for the *Nkuku4U* study have included two components:

(1) Vaccination against Newcastle disease (ND) in village chickens, through four-monthly campaigns led by trained community members ("Community Vaccinators") using the thermotolerant I-2 ND vaccine (produced by Tanzania Vaccine Institute in Tanzania and Central Veterinary Research Institute in Zambia), administered to chickens as an eye drop on a fee-for-service basis;

(2) Strategic interventions to improve crop production and reduce crop losses, which were informed by analysis of existing farming systems and participatory discussions with community members within each cluster. Interventions such as improved seed varieties and crop diversity, storage methods and cultivation and weeding practices were demonstrated in centralised farming plots, presented during training workshops and made available to community members.

The cost of Newcastle disease vaccination was initially set at 50 Tanzanian Shillings (TZS) per bird in all study communities, based on recommendations made by the national veterinary agency. For comparison, an appraisal of the indigenous chicken market in Tanzania conducted during the study period identified a single village chicken egg to sell for 400 TZS in Manyoni town (the capital of the district in which the study communities are located), and a commercial layer egg for 300 TZS (Queenan et al., 2016). In 2016, the vaccination price was increased to 100 TZS per bird in Majiri Ward based on general consensus amongst Community Vaccinators, local leaders and chicken-keepers. The vaccination price has remained at 50 TZS in Sanza Ward throughout the study period.

In each ward, four clusters (villages, or suitably-sized groupings of villages) served by a single health facility were identified. Allocation of clusters to intervention or control groups, stratified by health facility, was performed via a random draw conducted at community meetings. Communities were randomised to receive or not receive village chicken ND vaccination campaigns in the first year and a crop intervention in the second year (Figure 1). For ethical and logistical reasons interventions were offered to control (i.e. delayed intervention) communities after a delay of 12 months. Figure 2 uses the simple framework developed by Masset et al. (2011) as a model to map out the intended impact pathway within the poultry component of the *Nkuku4U* study. The trial was designed with the primary outcome of children's HAZ, and secondary outcomes of minimum dietary diversity and vitamin A, iron and haemoglobin levels in children.

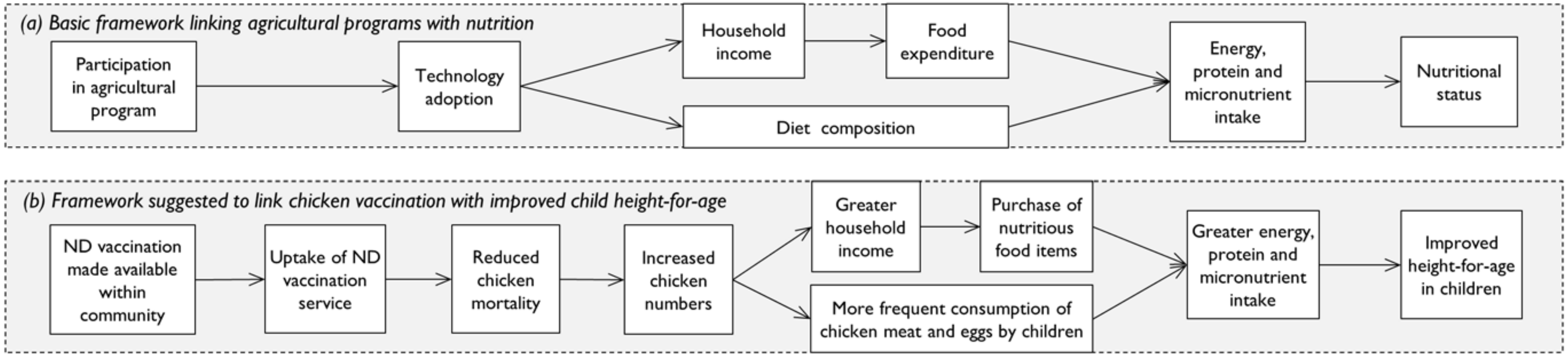

Figure 2. (a) A basic framework linking agricultural programs with nutritional outcomes, developed by Masset et al. (2011), and (b) use of this framework to illustrate the intended impact pathway from Newcastle disease (ND) vaccination programs to improved height-for-age in children in the *Nkuku4U* study.

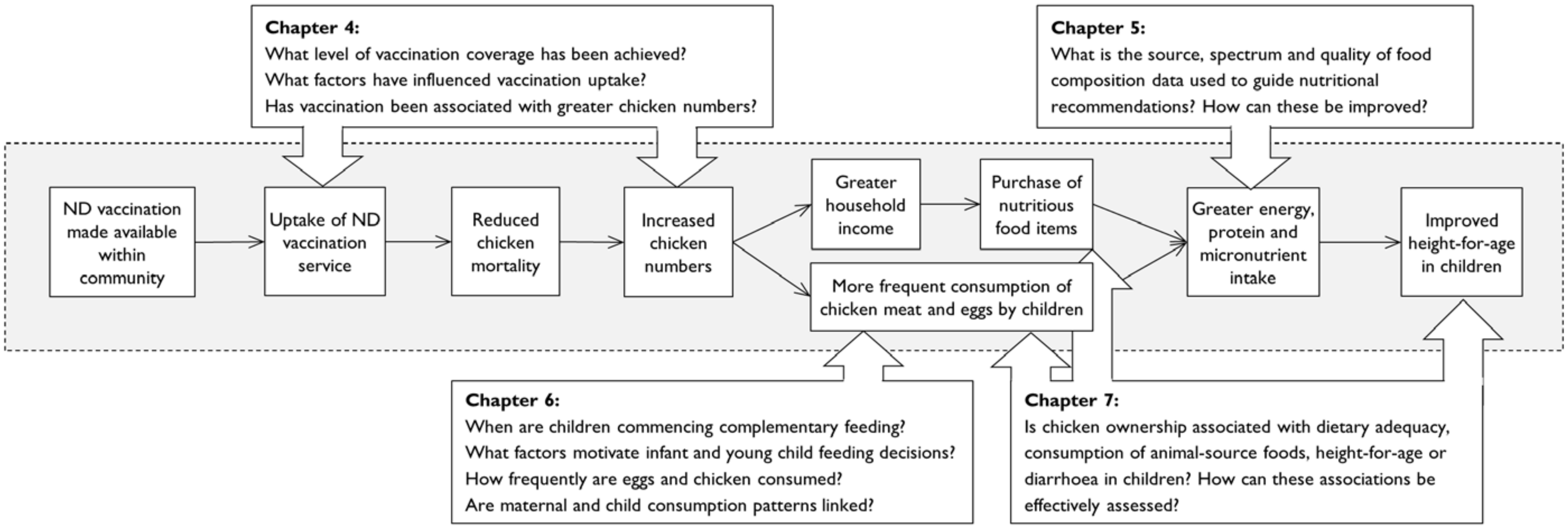

Figure 3. Intended pathway linking chicken vaccination programs with improved child growth outcomes, showing elements addressed in Chapters 4-7 of this thesis.

2.3 Relationship of this thesis to the *Nkuku4U* study

In support of the aims of the broader *Nkuku4U* study, this doctoral research has provided an opportunity to explore in greater depth the smaller "steps" or intermediate outcomes within the intended impact pathway. To demonstrate the influence of ND vaccination in village chickens on HAZ in children is an ambitious aim, and this thesis tests the premises on which this longer-term desirable outcome might be achieved. Multiple methodologies have been employed and separate analyses undertaken, including literature reviews (Chapter 1 and 3), quantitative analysis of published data (Chapter 5), a mixed methods evaluation integrating qualitative and quantitative data (Chapter 6), and observational studies using longitudinal quantitative data (Chapters 4 and 7). Figure 3 situates the questions addressed in each of the results-based thesis chapters within the broader impact framework.

This doctoral research has been conducted in eight of the twenty clusters participating in the *Nkuku4U* study, from Sanza and Majiri Wards in Manyoni District, Singida Region in Tanzania. Selection of these communities was based on the timing of project activities, which commenced in May 2014 in Sanza Ward and November 2014 in Majiri Ward. Quantitative data collection contributing to this research continued until May 2016 at both sites, with further qualitative research conducted in October 2016. While the overarching study design has involved a cluster-randomised controlled trial to evaluate the impact of agricultural interventions on child growth, this thesis reports on a number of observational studies conducted in the first two years of the broader project. As outlined in the concept map presented in Figure 8 in Chapter 1, these include:

- **Chapter 4** – An observational longitudinal study using quantitative data on chicken numbers and household characteristics from randomly-selected households (n = 503) in eight clusters from the *Nkuku4U* study, to test associations between ND vaccination and chicken flock size;
- **Chapter 6** – A mixed methods observational study using an explanatory sequential design (Ivankova, Creswell, & Stick, 2006), combining sample-wide questionnaire data from eight clusters with records of chicken and egg consumption completed by study participants in four clusters, and in-depth interviews with a subset of purposively-selected mothers (n = 39), to characterise infant and young child feeding practices within the study setting;
- **Chapter 7** – An observational study using longitudinal quantitative data on ownership of chickens and other livestock, household characteristics, dietary assessments, height-for-age and the occurrence of diarrhoea in children, to assess the influence of chicken ownership of child growth and health outcomes.

2.4 Research partners

The *Nkuku4U* study is led by the University of Sydney and conducted in partnership with government bodies and tertiary institutions in Tanzania and Zambia, together with international collaborators. The formation of a Country Coordinating Committee (CCC) in each country during the design phase has been central to the effective development and oversight of research activities (Bagnol et al., 2016; Maulaga et al., 2016). Core roles of the CCC have included identifying suitable project field sites, coordinating project implementation and knowledge management, and communicating key findings to communities and policy-makers. Figure 4 provides an overview of the institutions which form part of the national project team in Tanzania, mapped across multiple sectors.

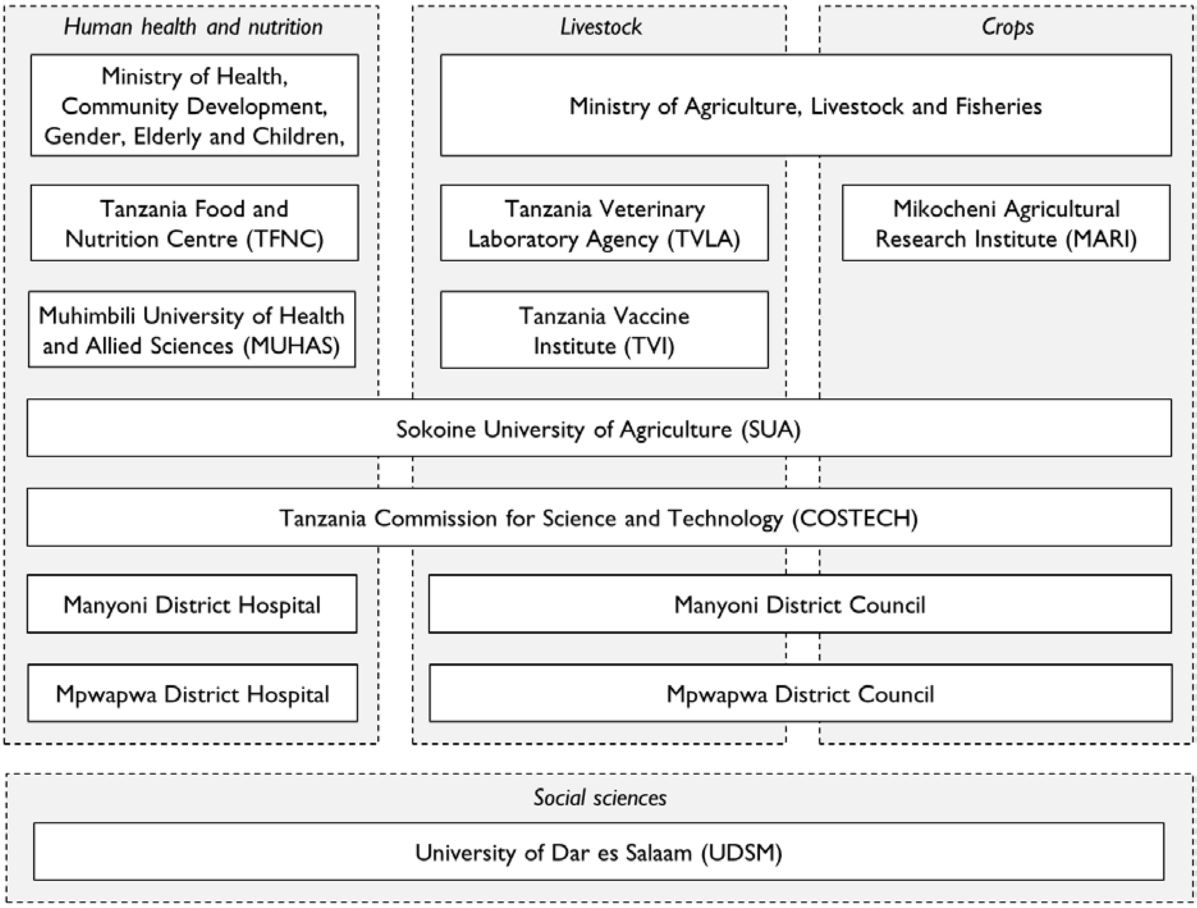

Figure 4. Government ministries, research agencies, universities and other partner institutions contributing to the *Nkuku4U* study in Tanzania, across sectors of human health and nutrition, livestock, crops and social sciences. The lead organisation, at which the Country Coordinator and Chair of the CCC are based, is the Tanzania Veterinary Laboratory Agency.

2.5 Study sites

Project sites in Tanzania were selected based on recommendations of the CCC, using the criteria of high levels of chronic undernutrition in children and an absence of ND vaccination programs and significant pre-existing or planned nutritional interventions. It was the original intention that sites from contrasting agro-ecological zones would be selected, however it was determined to be infeasible to carry out regular data collection and community liaison activities across multiple geographically-remote sites, given resource constraints in terms of the project budget and personnel.

Of the eight administrative zones of mainland Tanzania, the communities contributing to this thesis are located in the Rift Valley within the semi-arid Central Zone (Figure 5). The Great Rift Valley is one of Tanzania's most distinctive geological features (Bureau of Statistics [Tanzania] & Macro International Inc., 1997). The elongated depression extends down the centre of the country, flanked on its western side by a high east-facing escarpment (Dawson, 1992). The Central Zone has been characterised as having well-drained alluvial hardpan and saline soils of low fertility, and receiving unimodal rainfall of 500-800 mm per year (United Republic of Tanzania Vice President's Office, 2012). Within Manyoni District, in which all the research sites lie, rain is expected between November and April, with long-term data indicating mean annual rainfall of 624 mm (SD = 179 mm) and a mean number of rain days of 49 (SD = 15) (Lema & Majule, 2009).

The location of Sanza and Majiri Wards in Manyoni District, Singida Region, close to the boundary with Dodoma Region, is shown in Figure 6. Both wards are bordered on the west by the Rift Valley escarpment (Figure 7), and extend eastward from the tree-covered plateau into the valley. A single main road runs through Sanza Ward from south-east to north-west, connecting the four villages of Ntope, Sanza, Chicheho and Ikasi. Continuing north, the four villages of Majiri Ward (Mahaka, Majiri, Kinangali and Mpandagani) are similarly connected by a road, although access to Mahaka by vehicle is not possible during the wet season.

Lake Sulunga, which forms part of the Bahi Swamp, spans the border between Singida and Dodoma Regions, with a small portion in the northern part of Sanza Ward and a larger portion within Majiri Ward. The lake is largely dry for many months of the year, although fishing is possible during the wet season. Salt extraction from areas adjacent to Lake Sulunga is a significant source of income for many households in Majiri Ward and some in the northern part of Sanza Ward. Crop production is the primary economic activity for a large majority of households in this area, despite constraints of poor soil fertility, unreliable rainfall and a widespread reliance on cultivation using hand hoes. Major crops include maize, sorghum, sesame, sunflower and groundnuts, with a single annual harvest usually occurring in April-May.

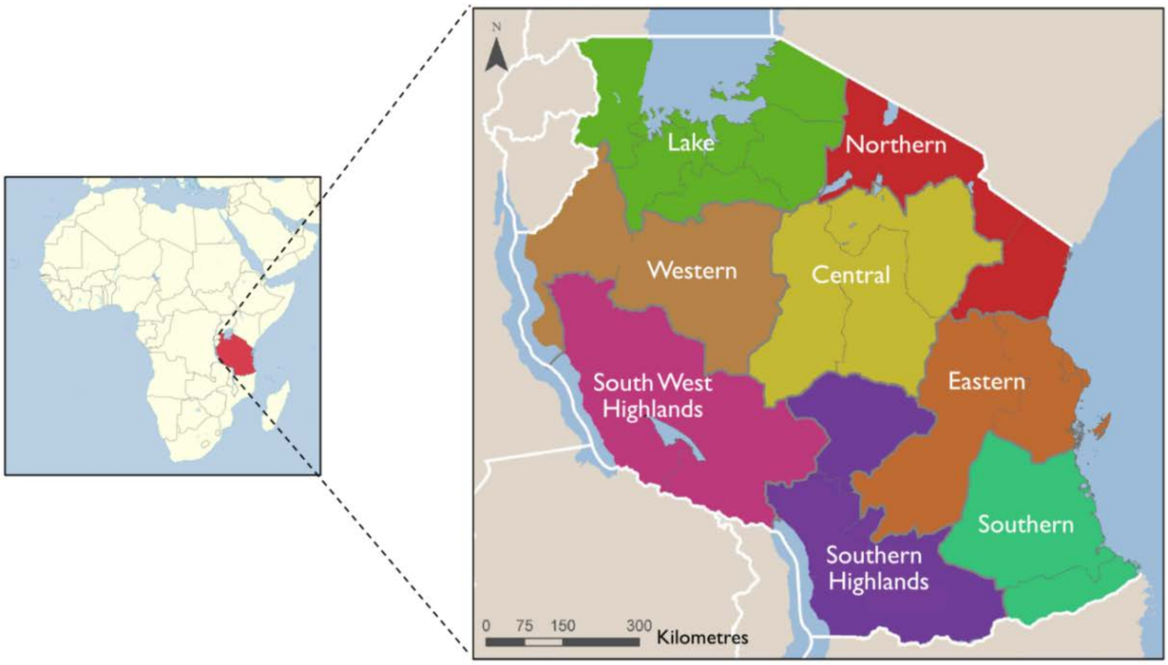

Figure 5. Map of the United Republic of Tanzania, located in East Africa, showing the eight administrative zones of the mainland. Communities participating in this research project are situated in the Central Zone. (adapted from MoHCDGEC [Tanzania Mainland], MoH [Zanzibar], NBS, OCGS, & ICF, 2016).

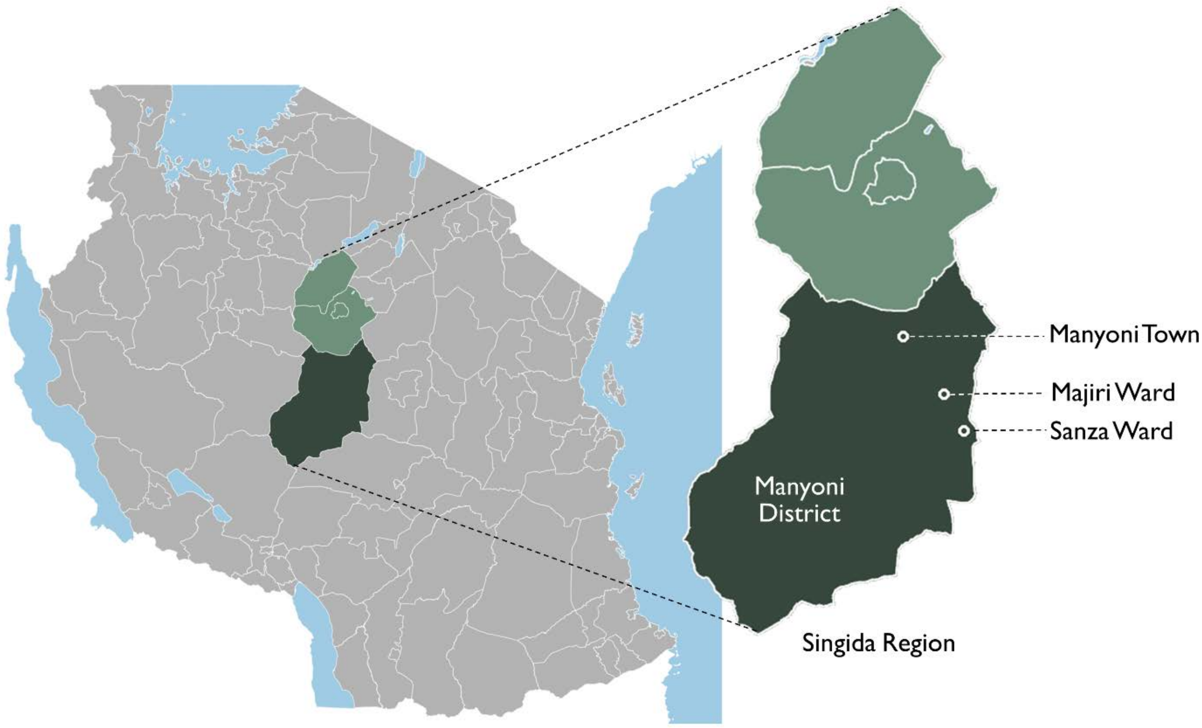

Figure 6. Map indicating the location of Sanza and Majiri Wards, in Manyoni District within Singida Region (developed using an open-access map from https://commons.wikimedia.org/wiki/File:Tanzania_Manyoni_location_map.svg).

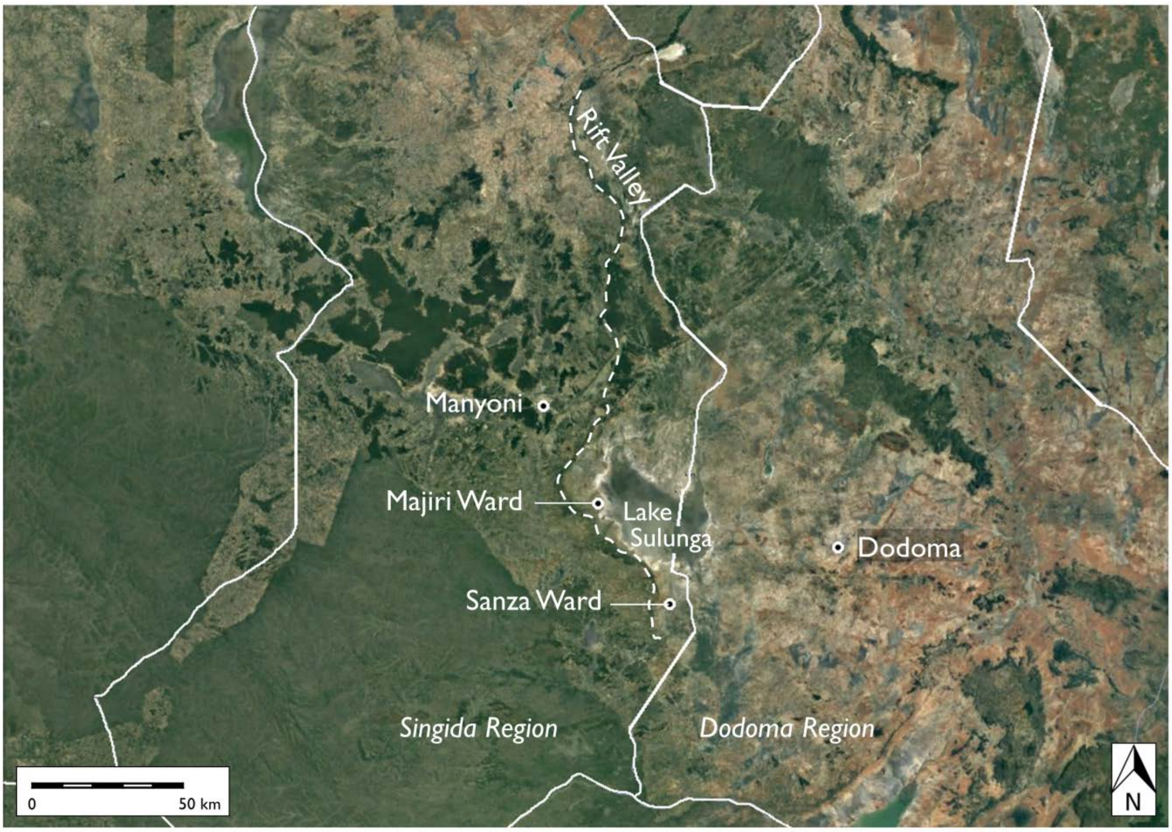

Figure 7. Satellite image showing the location of Sanza and Majiri Wards within the Rift Valley in Singida Region, in an area adjacent to Dodoma Region (developed using an image obtained from Google Earth V7.3.0.3832 (11 November 2015). Eye altitude 340.5 km. http://www.earth.google.com [31 October 2017]).

Subsistence farming in the neighbouring Dodoma Region has been described as being based around the growing of millet and sorghum, supplemented by livestock-keeping and other productive activities such as charcoal production or beer-brewing (Mabilia, 1996; Thiele, 1986). Rural populations in the Central Zone are recognised as facing the chronic risk of famine, as a result of low and irregularly distributed rainfall (Thiele, 1986; United Republic of Tanzania Vice President's Office, 2012).

2.6 Ethnicity and language groups

The emphasis placed on the demarcation of populations according to ethnic groups has been linked to the colonial period, when assumptions were made about cultural homogeneity within "tribes" (Berman, 1998). This has been criticised as a social construct, based on a subjective belief about shared traits (Banton, 2007) and the creation of arbitrary and artificial boundaries (Cohen, 1978). Julius Nyerere, the first prime minister of Tanganyika following its independence from the United Kingdom in 1961 and first president of the new state of Tanzania in 1964, is known for his efforts to build a secular national identity. This included the adoption of Swahili (*Kiswahili*), a language which evolved in connection with trade along the East African Coast, as the official national language of Tanzania (Campbell, 1999), and the compulsory villagisation program, which saw a transition from dispersed clusters of dwellings in rural areas to nucleated settlements (Shao, 1986).

While the use of ethnicity as an administrative category has been abolished, approximately 120 "ethnic groups" exist within Tanzania and distinctions according to cultural and linguistic identity persist (Allegretti, 2017). Research has commonly focused on socioeconomic dimensions of health, yet ethnic disparities have been identified as being of great importance in some sub-Saharan African settings (Brockerhoff & Hewett, 2000). There is concern that minority populations, particularly those which are geographically or linguistically remote, may fail to benefit from improvements in health experienced by the general population (Lawson et al., 2014). Factors influencing health, nutrition and agriculture are diverse and communication and influence across language groups have occurred for a long time. However, as livelihood strategies, agricultural practices and dietary patterns may still be linked to cultural identity, there is potential for the burden of undernutrition and food insecurity to vary between different ethnic groups.

In order to explore diversity within this study population while avoiding ethnic labels, languages have been used as a proxy indicator for certain social and cultural influences (Cohen, 1978). While still involving the categorisation of people according to traits, this approach reflects a person's own identification with a particular group, based on a shared language, rather than inflexible groupings imposed by an outsider. The first language or "mother tongue" has been recorded for both the mother and father of children enrolled in the study. *Kigogo,* spoken by the Gogo people (the *Wagogo*), is the predominant language in both Sanza and Majiri Wards. The Gogo have been described as sedentary cultivators, who subsist on a precarious agricultural system yet whose values are oriented towards pastoralism (Rigby, 1969). *Kisukuma,* the language of the Sukuma people (the *Wasukuma*), is less commonly spoken within the study setting. The Sukuma are the largest language group in Tanzania by a clear margin, estimated to constitute 16% of the national population, while no other group represents more than 5% (Garenne & Zwang, 2006). Sukuma are traditionally agropastoralists, often considered wealthy based on livestock holdings and areas of land cultivated, and known for the value placed on family size and cattle ownership (Hadley, 2005).

The influence of ethnicity or language groups on children's nutrition and health has been infrequently studied in the Tanzanian context. It has not been a core focus of this doctoral research; however, the consideration of language groups within analyses has been important to account for potential sociocultural influences on chicken-keeping and the uptake of ND vaccination (Chapter 4), infant and young child feeding practices (Chapter 6), and the diets and height-for-age of childen (Chapter 7).

2.7 Selection of study participants

A ward census was conducted by the project team in April 2014 in Sanza Ward and October 2014 in Majiri Ward. Enumerators travelled to all households able to be reached by foot, motorcycle or vehicle, to register the age and sex of household members, current ownership of village chickens, and interest in chicken-keeping. Lists were generated of all households eligible for inclusion in the study. Eligibility criteria required that households:

(1) included one or more children under 24 months of age at the time of the census;
(2) either currently kept chickens or expressed an interest in keeping chickens;
(3) intended to reside within the project area for the duration of the study.

Few households were excluded based on the latter two criteria. A two-stage sampling process used to select a total of 240 households in Sanza Ward and 280 households in Majiri Ward, by first enrolling all those with a child under 12 months of age, and then using random selection to enrol additional households with a child aged 12-24 months. For households containing more than one child under 24 months of age, the younger child was enrolled in the study, or in the case of twins, one child was randomly selected. The sample size in Majiri Ward was increased in response to higher than anticipated levels of drop-out amongst participating households within the first six months in Sanza Ward. An attrition rate of 16.9% was seen at the time of final questionnaire-based data collection in May 2016, due to relocation outside the study area, child deaths and households' decision to discontinue participation in the study.

While project interventions were made available across the wider community (e.g. vaccination against ND in village chickens on a fee-for-service basis, through four-monthly campaigns led by trained Community Vaccinators (Alders et al., 2002)), this thesis reports on longitudinal findings from the subset of randomly-selected households, hereafter referred to as "enrolled households", and specifically on outcomes relating to the "enrolled child" within each household.

2.8 Methodology and research tools

Details of research methods relevant to each chapter are given in Chapters 3-7. Chapter 3 outlines the databases and other search methods used to identify relevant literature for review. Chapter 5 describes inclusion criteria for national and regional food composition databases in sub-Saharan Africa, and the approach taken to collate and analyse data. Chapters 4, 6 and 7 provide information on the project sites in Tanzania, the two-stage selection of study participants, the research tools used, and the processes of data collection and analysis. Some repetition exists, as a result of the publication-based nature of this thesis. Additional information provided in this chapter includes an overview of the processes and people involved in data collection, and each of the research tools employed.

Amongst the challenges of a study involving repeated household visits over multiple rounds of data collection is the challenge of respondent fatigue. Researchers working in resource-poor settings commonly face ethical dilemmas about the nature and distribution of benefits to study participants and the wider community (Molyneux, Mulupi, Mbaabu, & Marsh, 2012), summarised by Ballantyne as: *"offer participants too little and they are exploited, offer them too much and their participation may be unduly induced"* (2008, p. 179). In the *Nkuku4U* study, small gifts such as soap, fabric or hats for children were provided to acknowledge the involvement of enrolled households, and refreshments were provided during focus group discussions. This appeared to contribute to maintaining good relationships with study participants, particularly during a period when poor and abnormally timed rainfall had adversely impacted on harvests. However, it has been suggested that such an approach may introduce bias, create expectations in follow-up rounds of data collection, alienate non-participating households, and set a precedent which other research projects may be unable to follow (Malleson et al., 2008).

2.8.1 Quantitative data

Questionnaire-based data were collected using face-to-face interviews with respondents, conducted by male and female enumerators recruited and trained from within each ward. These people were selected in consultation with local leaders, with the requirements of having adequate levels of literacy and numeracy, being well-respected within the community, and being available to work for periods of one to three weeks of data collection for a casual wage. Efforts were made to ensure approximately even numbers of male and female enumerators, and to accommodate the involvement of breastfeeding mothers. Many enumerators continued to work with the project across multiple data collection periods in each ward.

The decision to employ community members as enumerators contrasts with the approach of many large-scale research programs, which rely on external teams with prior data collection experience. Data for the most recent Demographic and Health Survey in Tanzania, for example, were collected by 16 male and 64 female interviewers, all trained nurses (MoHCDGEC [Tanzania Mainland] et al., 2016). Benefits of this approach include enumerators' likely familiarity with the research process, questionnaire design and interview technique and, for a multi-site survey, avoiding the need to train a new team in each location. By contrast, employing local people may reduce the perceived hierarchy between interviewer and interviewee (Molyneux, Wassenaar, Peshu, & Marsh, 2005) and has the distinct advantage of an awareness of the context in which the research is being conducted. In this project, enumerators contributed an understanding of local foods (including wild foods), livelihood strategies, health facilities, and the seasonality of rainfall, livestock diseases and agricultural activities.

Training sessions were conducted prior to each questionnaire application, in most cases led by the thesis candidate with translation assistance from Tanzanian colleagues. Questionnaires and training were in Swahili, but enumerators were encouraged to use local languages (*Kigogo* and *Kisukuma*) where appropriate to aid in communication with interviewees. Training sessions included opportunities to discuss the local translations for certain key words, including the food items listed in a dietary recall section. Time was also spent discussing unlisted food items which might be consumed within the study setting, including non-domestic animals and uncultivated plants, and in which category these items should be recorded. At the end of each training session, role play was used to provide opportunities for enumerators to rehearse interview skills and clarify areas of uncertainty. Training programs for community health workers in South Africa (Evangeli et al., 2009) and Vietnam (Fisher et al., 2014) have identified role play as an effective activity for building communication skills and increasing adherence to protocols.

Enumerators travelled by foot, or sometimes by motorcycle or vehicle, to locate the relevant respondents and complete the questionnaires, most commonly at their home or agricultural plot. Field supervisors, including the thesis candidate and members of the Tanzanian research team, reviewed completed questionnaires throughout each day to identify recording errors, sections which had been mistakenly skipped, issues of potential misunderstanding (by the enumerator or the respondent), and information suspected to be inaccurate. Enrolled households were revisited to clarify any outstanding points.

Anthropometry of enrolled children and their mothers was conducted at a central location within each village (a health facility, village office or primary school), with a level concrete surface on which digital bathroom scales could be used. Weight, length or height and mid-upper arm circumference measurements were conducted and recorded by trained representatives from the health sector (from the Ministry of Health, Community Development, Gender, Elderly and Children, the Tanzania Food and Nutrition Centre, or Manyoni District Hospital), together with the thesis candidate. Further details on the process of anthropometric data collection are given in Chapter 7.

Between major fieldwork sessions, conducted at six-monthly intervals between May 2014 and May 2016, regular data were collected by two representatives from each village (one male, one female) who were employed on a part-time basis by the *Nkuku4U* project as "Community Assistants". As for enumerators, the selection of Community Assistants was guided by leaders' recommendations, with similar requirements of literacy, numeracy and being well-respected within their village. This role included visiting households on a twice-monthly basis to record the number of chickens owned, the breastfeeding status of enrolled children, and maternal reports of child illness, as well as providing a point of contact between study participants and the research team.

2.8.2 Qualitative data

This thesis has predominantly utilised quantitative methodologies, however a targeted qualitative component was employed within a mixed methods study in Chapter 6. More broadly, time spent by the thesis candidate living and working in the study villages, over a cumulative period of approximately five months between May 2014 and May 2017, provided valuable opportunities to observe and engage with communities through daily interactions. This was instrumental in developing an understanding of the context in which this research has been conducted. Although not reported in this thesis, a series of focus group discussions held in March 2015, conducted separately for men and women, and for different language groups, also contributed to a formative understanding of food-related knowledge, attitudes and practices in the study setting.

A series of in-depth interviews with a subset of mothers of enrolled children (n = 39) was conducted in October 2016. Stratified purposive sampling was used to identify four to six women in each of the eight villages. Eligibility criteria were that women were available on the intended day of interview and willing to engage in discussions for approximately one hour. With the aim of achieving diverse representation of households, selection of mothers for interviews was also guided by children's HAZ, timing of introduction of complementary foods, chicken ownership and language group, as determined by prior analysis of questionnaire and anthropometric data.

The majority of interviews were conducted at women's homes, with a smaller number held in a central location in the village at the time that women and their children attended the local health facility. Distances to be travelled to reach women at their home were not a consideration in selection of interviewees. Discussions were conducted predominantly in Swahili, with occasional use of *Kigogo*, and were led by the thesis candidate using a semi-structured guide with open-ended questions and facilitated by a translator familiar with the study setting. For each interview, a Community Assistant was also present to lead introductions and provide additional translation assistance where required. Further details about selection of interviewees and the interview process are given in Chapter 6.

2.8.3 Research tools

An outline of research tools, including the scope of information covered, target respondents and periodicity, is given in Table 1. Two major semi-structured questionnaires were applied to all enrolled households: the Maternal and Child Health and Nutrition Questionnaire (Appendix A), for mothers of enrolled children at six-monthly intervals, and the Livelihood Questionnaire (Appendix B), for a male or female member of each enrolled household at twelve-monthly intervals. Information on chickens and children within enrolled households was collected by the Community Assistants during twice-monthly visits to enrolled households (Appendix C).

Chicken vaccination records were the only component of data extending beyond the enrolled households, to the wider community. For each vaccination campaign, Community Vaccinators were responsible for documenting the number of chickens intended for vaccination, ordering an appropriate quantity of the I-2 ND vaccine, recording the number of chickens vaccinated and payment received from each chicken-keeper (Appendix D).

The “Visual Diary” was a novel approach used to document the consumption of chicken meat and eggs by enrolled children and any pregnant or breastfeeding woman within their household over a period of four consecutive weeks, at four-monthly intervals (Appendix E). This household-level research tool was developed by Dr. Brigitte Bagnol, adapted from an approach used in reproductive health research in Tanzania and Uganda (Francis et al., 2013; Francis et al., 2012). Further details about the design and application of this research tool are given in Chapter 6.

Appendix F provides a set of questions used as a guide for semi-structured in-depth interviews with a subset of mothers of enrolled children, which also contributed to the mixed methods evaluation of infant and young child feeding practices in Chapter 6.

2.9 Ethical considerations

Study design, protocols and research tools were approved by the Tanzanian National Institute for Medical Research ethics committee in February 2014 (NIMR/HQ/R.8a/Vol.IX/1690), and the University of Sydney's Human Research Ethics Committee in March 2014 (2014/209) and Animal Ethics Committee in October 2013 (2013/6065). Letters of approval have been included as Appendices G, H and I.

Participants' informed consent was given via a signature or thumb print at the time of data collection, for each questionnaire, interview and set of anthropometric measurements (Appendices J, K and L). A participant information statement, written in Swahili, was provided to all participating households at the commencement of the study (Appendix M). To accommodate linguistic diversity and varying levels of literacy, all documents were read aloud to study participants by trained enumerators, using local languages where appropriate.

Confidentiality was ensured by allocating unique identifying codes to each ward, village and subvillage location, and to each household participating in the study. A separate piece of paper with the name of the enrolled child and their mother was attached to each questionnaire, to guide enumerators in identifying study participants, but this was detached at the time of the interview. Original hard copies of questionnaires (labelled only with participant codes) were kept in a locked storage location at the *Nkuku4U* project office at the Tanzania Veterinary Laboratory Agency in Dar es Salaam, with the key held by the Country Coordinator. Copies of electronic databases were stored at the Tanzanian project office and using the University of Sydney's secure Research Data Storage facility.

Table 1. Overview of research tools and data sources contributing to this thesis

Research tool	Format	Scope of information	Respondent	Periodicity	Use in this thesis
Maternal and Child Health and Nutrition (MCHN) Questionnaire	Semi-structured questionnaire (administered by local enumerators via interview)	• Household water source • Nature of toilet facilities • Access to health services • Use of mosquito nets • Maternal age, education and income • Decision-making within household • Antenatal care (e.g. micronutrient supplements, anti-malarial prophylaxis) • First language of enrolled child's parents • Location of birth of enrolled child • Child's date of birth, birth weight and sex • Breastfeeding and complementary feeding • Micronutrient supplements for child • Recent child illness • 24-hour food recall for mother and child	Mother (or primary caretaker) of enrolled children	Six-monthly (May 2014 – May 2016 in Sanza Ward; Nov 2014 – May 2016 in Majiri Ward)	Chapter 4 Chapter 6 Chapter 7
Livelihood Questionnaire	Semi-structured questionnaire (administered by local enumerators via interview)	• Role of respondent within household • Sex of household head • Household size • Wall, floor and roof materials of house • Household material assets • Sources of income • Livestock ownership, by species • Crops and land area cultivated • Amount of crops harvested • Reasons for not keeping chickens • Ownership of chickens within household • Feeding and housing of chickens • Use of chickens and eggs • Experiences with ND and vaccination • Access to extension services	Member of enrolled child's household, above 16 years of age. An intended balanced number of male and female respondents. (Actual sample of 60.5% female respondents, of 1354 questionnaires contributing to this thesis).	Annual (May 2014-2016 in Sanza Ward; Nov 2014-2015 in Majiri Ward)	Chapter 4 Chapter 6 Chapter 7
Twice-monthly records of children and chickens	Information recorded by Community Assistants during twice-monthly household visits	• Number of chickens owned (above and below two months of age) • Participation in ND vaccination campaigns • Breastfeeding status of child • Recent child illness, including diarrhoea	Mother (or primary caretaker) of enrolled children	Twice-monthly (middle and end of each month)	Chapter 4 Chapter 6 Chapter 7

Research tool	Format	Scope of information	Respondent	Periodicity	Use in this thesis
Records of ND vaccination in village chickens	Records kept by Community Vaccinators, table format	Prior to vaccination: • Number of chickens owned • Number of chickens intended to be vaccinated Vaccination day: • Number of chickens vaccinated • Payment received	Person responsible for chickens in households intending to vaccinate (community-wide, not just enrolled households)	Four-monthly (prior to and at the time of each vaccination campaign)	Chapter 4
Visual diary	Pictorial chart used to record dietary information using a tally system	• Consumption of chicken meat and eggs by enrolled child and pregnant or breastfeeding women within enrolled households • Four-week data collection period	Any household member. Intended to be suitable to people of all levels of literacy.	Four-monthly (April, August and December)	Chapter 6
Anthropometry	Records completed by thesis candidate or representatives from health sector	• Height, weight and mid-upper arm circumference of enrolled child	Enrolled child	Six-monthly (May 2014 – May 2016 in Sanza Ward; Nov 2014 – May 2016 in Majiri Ward)	Chapter 7
In-depth interviews	Semi-structured interviews of approximately 60 minutes' duration, led by the thesis candidate (with a translator)	• Breastfeeding and complementary feeding (practices, experiences and influences) • Children's diets and household diets • Children's growth • Influence of child gender • Influence of language group • Experiences of chicken-keeping	Mother of enrolled child	Single period of data collection (Oct 2016 in both wards)	Chapter 6

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Chapter 3. Reviewing the roles of family poultry in food and nutrition security

Chapter 3 introduces small-scale poultry-keeping, as practised within the project sites in Tanzania. Through a review of published literature, it discusses the potential contributions of village chickens to livelihoods, household food security, dietary adequacy, sociocultural practices and gender roles. This builds on prior evaluation of agriculture-nutrition linkages and the varied roles of livestock in resource-poor settings.

Despite constraints to productivity associated with disease and a reliance on environmental food resources, chicken-keeping is identified as an accessible, multi-purpose and culturally-accepted agricultural activity which is commonly managed by women. This forms part of a justification for interdisciplinary research efforts and for investments in poultry health programs as a means of addressing chronic food and nutrition insecurity.

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Image 3. A free-ranging cock in the village of Ikasi, Sanza Ward. As in many rural settings in Africa, poultry in the Tanzanian study sites are almost entirely extensively managed. The ability to roam freely in the village environment allows birds to utilise available feed resources, reducing requirements for labour and other inputs, but presents challenges in the control of infectious diseases, predators and theft.

Photo credit: Julia de Bruyn, 2016.

Family poultry and food and nutrition security

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Abstract

Family poultry production, which encompasses both extensive and small-scale intensive management systems, is practiced by many households in low-income food-deficit countries. Despite low production levels and potentially high losses due to disease, predation and theft, scavenging systems offer the advantage of requiring minimal land, labour and capital inputs. Human undernutrition remains a major public health challenge globally, contributing to over 3 million preventable maternal and child deaths each year. Animal source foods, including poultry (meat and organs) and eggs, can provide high-quality protein and micronutrients in bioavailable forms which, even in small quantities, substantially increase the nutrient adequacy of traditional diets based on staple crops. Women are recognized as key players in family poultry production systems and successful engagement with this sector should incorporate gender-sensitive approaches. It has been shown that agricultural interventions which target women are more likely to lead to positive nutritional outcomes. A multi-disciplinary research approach, multi-sectoral involvement within government institutions and the implementation of policies which target smallholder farmers is needed in order to maximize the potential impact of improvements to family poultry systems on food and nutritional security.

Keywords: Food security, Nutrition security, Undernutrition, Micronutrient deficiencies, Family poultry, Animal source foods, Developing countries.

Review Methodology: Literature relating to food and nutrition security and the health, management and roles of family poultry in developing countries has been collected over the many years two of the authors have worked in this field. This collection of data has been supplemented by searching the following databases: CAB Abstracts, Medline, Food and Agriculture Organisation of the United Nations, World Health Organization, United Nations Children's Fund, World Bank, International Food Policy Research Institute and Australian Centre for International Agricultural Research. In addition, articles obtained through these sources were used to identify additional relevant material.

Family Poultry

Scavenging flocks of indigenous breed poultry are found in communities throughout low-income food-deficit countries, where they provide a valuable contribution to human nutrition, livelihood and sociocultural activities. Rural poultry are defined as 'any genetic stock, improved or unimproved, that is raised extensively or semi-extensively in relatively small numbers' [1]. Chickens typically fall under the care of women and children and may provide animal protein in the form of meat and eggs, be sold or exchanged to meet basic needs, and used in traditional ceremonies and festivals [2].

While the term 'village poultry' reflects rural origins, increasing urbanization has led to similar systems being established in urban and peri-urban areas. 'Backyard poultry' is used for situations where birds are predominantly or always housed, while 'scavenging poultry' describes a reliance on environmental feed resources. The term 'family poultry' was adopted to encompass a spectrum of small-scale production systems, referring to poultry-keeping practiced by individual families as a means of providing food security, income and gainful employment [3]. This less rigid definition may be seen to cover four types of production systems: small extensive scavenging, extensive scavenging, semi-intensive and small-scale intensive [4].

Households throughout the developing world keep family poultry in numbers which range from single birds to flocks of 100, with a typical range of 5–15 adult birds [5, 6]. The number of chickens owned varies according to household size, wealth status, linguistic group and time of year. Under extensive or semi-intensive conditions, free-ranging poultry are largely reliant on scavenging environmental resources for their dietary intake. Although production levels are low, inputs are also low to non-existent, meaning family poultry are able to be maintained with minimal land, labour and capital inputs and 'therefore be kept by even the poorest social strata of the rural population' [7].

The major constraint to family poultry systems is disease. Beyond their own scavenging environment, it is common for chickens to be moved regularly through markets and for live birds to be given to visiting relatives and guests [8]. The nature of such systems facilitates the spread of infectious disease between birds and limits options for biosecurity measures to be enforced. Newcastle disease (ND) is considered the most significant poultry disease worldwide and a major constraint to village poultry production in many developing countries [4, 5, 9–13].

Food Security

Food security remains one of the most significant issues facing the world today, with the most recent estimates revealing 842 million people (or one in eight people) to be affected by chronic undernutrition [14]. It was at the World Food Summit in 1996 that the widely accepted definition for food security emerged, to describe 'a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life' [15]. Factors contributing to the state of food security are commonly grouped into four core areas: availability, access, utilization and stability [16].

Of people living in poverty in developing countries, over 70% are in rural areas and are dependent on agriculture for their livelihoods [17]. Although investments in agricultural development are recognized as having the potential to generate sustainable improvements in food security, there is increasing recognition of the weak evidentiary link between interventions to date and progress in increasing food security [18–21]. Recent reviews have identified fundamental deficiencies in research design and a failure to evaluate the impact of research work on health and nutrition outcomes [19]. The authors of one review attest that 'the sooner methodologically rigorous studies can produce findings on how best to leverage agriculture's potential for nutrition, the better' [20].

Livelihoods, Food Security and Sustainability

The role and importance of small-scale farming systems has received greater attention in recent years, with growing recognition of their potential contribution to livelihoods and food security in developing countries. A livelihood system refers to the complex set of daily activities undertaken to meet various needs within a household, including food and social needs [1]. Household food security implies resilience against risks, with access to adequate food at a given point in time, and reasonable assurance that such access will continue in the future. Family poultry comprise up to 80% of poultry stocks in low-income food-deficit countries [22] and, through sale or consumption, they are often incorporated into livelihood strategies adopted by families to maintain or regain food security. In some cases, this means people may resort to risky behaviour such as the slaughter and consumption of birds showing signs of disease, or those that have died [1, 23].

Attempts to quantify the contribution of village poultry to overall meat and egg consumption in Africa and Asia suggest that, despite comprising around 80% of the national flock, indigenous chickens only contribute around 50% of meat consumption [22]. Intensive production units with hybrid commercial genotypes are currently acknowledged to be a more cost-efficient means of supplying people living in cities and towns [22]. However, the conditions for successful intensive poultry production are rarely present in the majority of rural areas in developing countries and many people living in urban areas prefer to purchase meat and eggs from indigenous birds, which consequently command a premium price [24].

Although the production of indigenous chickens is lower than that of intensively raised commercial breeds, the low-input nature of village poultry systems [24] means that almost any meat or egg production generally constitutes a net profit for poultry-keepers. The contribution of poultry-keeping to household cash income is deemed to be difficult to assess, but estimates suggest an average flock of three hens and two cocks in Central Tanzania will provide additional income equivalent to USD 38.00 on an annual basis, equating to 9.5% of average annual income [25]. Attempts to determine the financial impact of various management changes have estimated a typical Lao village chicken flock to generate a net annual income of around USD 67.00 [26].

The relative difference between income received for poultry products and the cost of purchasing feed is often insufficient incentive for the intensification of production systems [27]. By consuming food products such as legumes and grains that could be eaten by people directly, intensively reared livestock also reduce the total amount of food available for human consumption [28]. Approximately half of the grain produced globally is fed to animals and it is estimated that an additional billion tonnes of grain will be required to meet future food, feed and fuel requirements [29]. There is great merit in the partial or complete reliance of village poultry on scavenged feed resources. Not only does this reduce or eliminate feed costs, estimated to constitute 65–70% of overall production costs in intensive systems [30], it also results in the conversion of less-palatable and less nutrient-dense foods into high-biological-value protein for human consumption [5, 28]. Even if the consumption of chickens occurs infrequently, the provision of eggs throughout the year can help to mitigate the effects of seasonal food unavailability [31].

Nutrition Security

The emphasis of nutrition security lies within the utilization aspect of food security, requiring that a household not only has secure access to food, but also to a sanitary environment, adequate health services and the required knowledge to make effective use of food resources [32]. It is recognized that although improving agricultural productivity may boost food availability and provide long-term reductions in poverty and hunger, it may not solve the problem of access to nutritious and diverse diets [33].

Undernutrition remains one of the major public health challenges of the current century, contributing to an estimated 3.1 million preventable maternal and child deaths annually [34]. Of the eight Millennium Development Goals, improvements to nutrition are implicit in the eradication of poverty and hunger, reduction of child mortality and progress in maternal health. Nutritional progress remains fundamental to The United Nations' post-2015 agenda, as expressed in the Sustainable Development Goals (SDG). The second SDG expresses the aim to 'end hunger, achieve food security and improved nutrition, and promote sustainable agriculture', with a particular focus on young children, adolescent girls, pregnant and lactating women [35]. Nearly one-third of children in developing countries are underweight or stunted, a chronic restriction of growth which results in short stature [36]. Impaired growth during gestation and the first 2 years of life has irreversible and far-reaching effects, on offspring birthweight, future school performance and income-earning capacity [37].

The nutritional merit of animal-source foods (ASF) is well documented [27, 38–40]. ASF have been shown to provide a number of micronutrients that are difficult to obtain in adequate quantities from plant source foods alone [39]. There is particular advantage in the consumption of ASF by young children, whose limited gastric capacity relative to their high nutritional requirements necessitates a diet with high nutrient density [39, 41], and in situations where opportunities for dietary diversification through the inclusion of fruits and vegetables is limited. When added to traditional diets based on staple crops such as maize, beans and cassava, even relatively small amounts of ASF can substantially increase nutrient adequacy 'thus providing *nutritional security* as well as food security' [42]. Whole-foods contain a greater variety of bioavailable micronutrients, and are more efficient at treating multiple micronutrient deficiencies than targeted single micronutrient supplementation [38, 40]. For example, liver contains significant levels of both iron and pre-formed vitamin A, offering a distinct advantage over single-nutrient supplements for individuals whose diets are marginally low in more than one nutrient [39].

Beyond the consumption of sufficient calories, a balanced and adequate intake of micronutrients is essential for growth, development and health [43]. Over two billion people are estimated to be at risk of vitamin A, iron and iodine deficiencies [44]. Many of the staple foods consumed in developing countries are recognized to contain 'anti-nutritional' factors which limit the availability of micronutrients. Diets based on cereals contain high levels of phytic acid, which dramatically reduces the uptake of iron and zinc by forming poorly absorbed complexes in the acidic environment of the stomach and small intestine [45]. The processing of cereals, for example milling and refining, removes phytates but also lowers the iron and zinc content of cereals, so the net amount of micronutrients absorbed does not change [40].

The presence of oxalate in plants, particularly green leafy vegetables, is known to impair the absorption of dietary calcium and other minerals [46]. Cooking vegetables has been shown to reduce their oxalate content, most markedly in the case of boiling whereby levels are lowered by 30–87% [47]; however, the adverse effects of high-oxalate plants remain relevant in the case of women in developing countries, for whom calcium requirements are high and dietary content may be low [48]. Chronic exposure to aflatoxins, considered by the US Food and Drug Administration to be an unavoidable contaminant of many staple foods in developing countries, affects protein synthesis and micronutrient status, and is linked to reduced rates of growth in both animals and people [49].

An iron absorption study in Switzerland revealed that increasing the levels of leafy vegetables in a traditional maize-based diet, as consumed in Burkina Faso, had no impact on the amount of iron absorbed by young women [50]. Not only do ASF contain iron in the bioavailable *haem* form, animal protein is known to enhance the uptake of less-readily absorbed *non-haem* iron found in cereals and green leafy vegetables [38, 51]. Incorporating small amounts of ASF to a vegetarian diet thus has the potential to substantially increase nutrient adequacy, without the expense associated with micronutrient supplementation or the dramatic changes in regulatory policies and consumer opinions required by biotechnology strategies [52].

Poultry meat has long been recognized as a healthy source of protein, promoted as a lean option over red meat [53]. In a comparison of a number of cuts of meat from different species, skinless chicken breast has been identified as having the lowest intramuscular fat and cholesterol content [54]. There is evidence to indicate a marked increase in the fat content of standard broiler chickens in recent decades, with the modern broiler providing more energy from fat than protein [55]. This has been attributed to the intensification of poultry production systems, with a lack of exercise, ad libitum access to high-energy food and selection for rapid weight gain. Information about the difference between meat from indigenous and commercial breed chickens is limited, but it is suggested that there is no significant difference in nutrient composition attributable to breed between birds raised under the same management conditions [56]. In the context of both Africa and Asia, many authors have documented consumers' strong preference for meat from indigenous breed chickens, resulting in premium prices for products from family poultry systems [7, 24, 57]. It is proposed that the older, firmer and more flavoursome meat of indigenous birds is more suitable for traditional forms of cooking than that of broilers [5].

Eggs constitute an important source of choline, vitamins A and B_{12}, essential fatty acids and a high-quality source of protein, with 97% of egg protein being digestible and 94% of biologic score (a measure of the efficiency of converting dietary protein to body tissue) [58, 59]. A 50 g edible portion of egg provides nearly half the recommended daily allowances of protein for children of 1–3 years of age, including all essential amino acids [60]. Current evidence refutes former concerns about the link between the high cholesterol content of egg yolk and an increased risk of coronary heart disease and stroke [61, 62] and indicates that eating up to seven eggs per week is compatible with a healthy diet [63]. Using data from the Nutrient Rich Foods Index, a formal scoring system which ranks foods according to their nutrient content, and a food prices database, Drewnowski [64] identifies eggs as being among the lowest-cost sources of protein, vitamin A, vitamin B_{12}, riboflavin, iron and zinc.

In many cases, the threat of losses in family poultry systems means that few eggs are used for sale or consumption. Instead, farmers capitalize on the broody behaviour exhibited by indigenous breed poultry and leave the majority of eggs to incubate under the hen [65]. Hatchability rates are high, but there is an expected attrition of 50–80% in the first 6 weeks [7], owing to a combination of disease, predation, malnutrition and climatic conditions. Through changes to management systems, such as restricting the number of eggs on which a hen is allowed to sit or designating some hens as 'brooders' and others as 'egg-producers', there is scope for family poultry to further contribute to nutritional security [66]. While both strategies avoid an increase in chicken numbers disproportionate to scavengeable feed availability and allow surplus eggs to be used for sale or consumption, the latter approach will bring hens back into lay sooner and result in greater annual egg production [65].

In a review exploring the relationship between livestock, poverty and food security, Turk [42] draws attention to the disparity between the apparent availability of food-producing animals, with approximately one animal for every human in Africa and one animal per two humans in Asia, and the continuing high rates of undernutrition. There is a significant gap between development efforts to expand knowledge and identify common nutritional deficiencies at the household level, and recognition of the potential for ASF to prevent such problems. In some societies, there is social value associated with the number of livestock owned and there may be a reluctance to slaughter animals (particularly cattle and small ruminants) for consumption. Participatory methodology used to explore dietary patterns in Ghana has suggested parents may be unwilling to offer ASF to children for fear that it would encourage unrealistic taste preferences and expectations that would not always be possible to meet [67].

The production of nutrient-rich fruits, vegetables and grains and the keeping of small animals (including chickens) have been shown to have a positive impact on families' diet quality and consumption patterns [68]. Data from Jordan show that urbanization has had a negative impact on the health and nutritional status of Bedouin children (a group of nomadic pastoralists) [69]. It is proposed that reduced livestock herding has resulted in the loss of a source of milk and meat, and that families' modest income is insufficient to purchase these and other nutritious food items from the market.

Despite the known high nutritional value of poultry meat and eggs, few studies have been undertaken to determine how interventions can affect consumption patterns in low-income food-deficit countries [70]. It is evident that work is needed to address the lack of information on how improvements to family poultry production can translate into improved nutritional outcomes, by establishing guidelines for the incorporation of poultry products into existing diets in resource-poor settings.

Gender and Cultural Aspects

Gender (denoting the social roles and identities associated with being a man or a woman [71]) is known to influence the type of involvement a person has in agricultural activities, constraints to their productivity, division of labour, and access, control and benefits from resources [72]. Limited access to opportunities and resources prevents women from making productive use of their time, resulting in less efficient farming compared with their male counterparts. A 20–30% increase in agricultural yields is predicted, if women were granted the same access to productive resources as men: translating to a 2.5–4% increase in the total agricultural output of developing countries and a 12–17% reduction in the number of hungry people in the world [14].

There is widespread consensus that successful efforts to improve household food security should consider women's social status, empowerment, time allocation, and health and nutritional status [33]. A mother's education is considered to be a better predictor of young children's health and nutrition than land ownership, household assets, or a father's education [73]. For each year a mother stays in school, the odds of having a stunted child decrease by 4–5% [74] Several recent meta-analyses of homestead food production systems confirm that nutritional effects are more likely when interventions target women, by improving their knowledge and skills or promoting their control over income generated from the sale of targeted products [20, 75].

Although participation of the entire family is common, women tend to have greater responsibility for the care of poultry, particularly when kept in low numbers [76], and are widely recognized as the key players in family poultry production [14, 77–80]. They are largely responsible for the day-to-day management of chickens, with men and boys involved in the marketing of birds and construction of housing [4]. It has been noted that moving from a scavenging system to a commercial enterprise is likely to result in poultry production being taken over by a male household member [65].

Appreciating gender roles in family poultry production has been identified as central to any successful engagement with this sector [4, 81]. Bagnol [80] identifies a predominance of male veterinarians and extension staff, who tend to work largely with more prosperous farmers on issues relating to crops and ruminant production systems and often lack an understanding of how to deal with women and poor farmers. Experiences from work to control ND and highly pathogenic avian influenza (HPAI) in village poultry illustrate the importance of understanding the roles, interests and needs of women for interventions to be effective [80]. Bagnol reports that although the segregation of flocks may be an effective strategy to improve biosecurity in family poultry systems, it tends to result in an increased workload for women, who are faced with the tasks of cleaning out enclosures and providing feed and water. Programmes aiming to improve village poultry production should include a particular focus on women, with consideration given not only to gender but also to age, wealth and marital status [80–82].

Beyond their contribution to household diets and income generation, poultry hold considerable social and cultural significance in many countries. Significant value is placed on livestock as an indicator of social importance within the community and as a means of creating social goodwill [27], with poultry often given as gifts or served in meals for distinguished guests [24]. In many African countries, cockerels are the most common sacrificial animal for religious ceremonies [83]. The importance assigned to this role is reflected in the differential prices received for birds of specific feather colour and sex used for distinct purposes, such as seeking a good harvest, rainfall or protection from disease or war. In some areas, village poultry are said to also have a mystical function. There is a belief among poultry farmers in Senegal that bad spirits can be diverted away from family members into chickens. Such spirits may be implicated in cases of ND where affected birds display neurological signs which manifest as strange movements, and this belief partially explains why there is a strong wish for there to be at least one village chicken flock in each village [7].

Policy Aspects

Reports exploring pathways to sustainably improve food and nutrition security highlight the need for coordinated efforts across multiple sectors. Over the past 50 years, the development agenda has been dominated by agricultural agencies focusing on energy-rich, nutrient-poor staples and large-scale livestock production, and human health-related agencies supporting the specific micronutrient fortification and supplementation programmes [84, 85]. The long-term sustainability and effectiveness of these isolated policies and programmes at achieving poverty-alleviating and nutritional goals is questionable [86], and they do not necessarily have the capacity to translate into improved food and nutrition security for households of lower socioeconomic status.

The importance of targeted, context-specific policies that particularly benefit the poor has been recognized in recent years, with a growing focus on smallholder producers [85]. Policies which target family poultry enable their keepers to maximize the nutritional, financial, gender-empowering and food-securing benefits of their small flocks [4, 87]. Such policies can be shaped around the construction and continued support of an effective livestock extension service to deliver poultry health and husbandry information, facilitate ND vaccination and provide supplemental feeds or knowledge of locally available supplements to improve feed quality [4]. To be effective, these extension services should increase rural education and local capacity-building, reach dispersed rural communities and be accessible by women [88]. Encouragement of public-private partnerships that aid poultry development may be an incentive to farmers to adopt husbandry changes [84]. As production increases, improving market access or supporting the development of co-operatives provide producers with a means to increase the contribution of their poultry to their livelihood [84, 88].

While nutritional status itself may be seen as an 'individual-level attribute', contributing factors extend far beyond the individual and their household [89]. A One Health approach, based around the inextricable links between the health and wellbeing of humans, animals and ecosystems, has recently been applied to the area of infectious disease, but also offers many opportunities to effectively improve food and nutrition security. It is suggested that there is a role for policies which work within the context of what is locally available and respond to the combined recommendations of agricultural and livestock specialists, human nutritionists, maternal and child health specialists, economists and social anthropologists [90].

Conclusions

As the 2015 target date of the Millennium Development Goals approaches, it is clear that there is still significant progress needed in poverty reduction and improvements to health, education and gender equality; particularly in sub-Saharan Africa, where the prevalence of childhood stunting has remained largely unchanged since 1990 [91]. Alongside their contributions to livelihood and social activities, family poultry (widely owned by the poor, landless, female and poorly educated members of rural and peri-urban communities) offer a potential source of high-quality protein and micronutrients to complement cereal-based diets and alleviate seasonal food shortages. Improving the productivity of family poultry, traditionally under the control of women, has the potential to empower women as smallholder farmers and deliver nutritional benefits to children. There is a need for the implementation of policies aimed at increasing the productivity of family poultry systems, through effective extension services and disease control programmes, to form part of a multi-disciplinary approach to tackling global undernutrition in a sustainable manner.

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Chapter 4. Testing associations between Newcastle disease vaccination and village chicken flock size

Chapter 4 evaluates data following the implementation of community-based vaccination programs against Newcastle disease in village poultry in Sanza and Majiri Wards in Tanzania. Building on the previous chapter, which identifies Newcastle disease as a key constraint to village poultry production, the uptake of a fee-for-service vaccination program across the study population is reported and levels of chicken ownership and mean flock size presented over a two-year period.

This chapter identifies a bi-directional relationship between Newcastle disease vaccination and chicken numbers at a household level, and a significant increase in flock size with regular vaccination. In order to sustainably strengthen food and nutrition security, there is a need to consider how to support the participation of vulnerable households in poultry vaccination programs and how to encourage continued vaccination throughout the year.

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Image 4. A community vaccinator practises administering an eye-drop to a chicken during a training workshop in Majiri Village. A participatory training program, combining theoretical and practical sessions over three half-days in the village setting, has been used to equip local people to conduct regular vaccination campaigns using the I-2 Newcastle disease vaccine.

Photo credit: Julia de Bruyn, 2015.

RESEARCH ARTICLE

The chicken or the egg? Exploring bi-directional associations between Newcastle disease vaccination and village chicken flock size in rural Tanzania

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Abstract

Newcastle disease (ND) is a viral disease of poultry with global importance, responsible for the loss of a potential source of household nutrition and economic livelihood in many low-income food-deficit countries. Periodic outbreaks of this endemic disease result in high mortality amongst free-ranging chicken flocks and may serve as a disincentive for rural households to invest time or resources in poultry-keeping. Sustainable ND control can be achieved through vaccination using a thermotolerant vaccine administered via eyedrop by trained "community vaccinators". This article evaluates the uptake and outcomes of fee-for-service ND vaccination programs in eight rural villages in the semi-arid central zone of Tanzania. It represents part of an interdisciplinary program seeking to address chronic undernutrition in children through improvements to existing poultry and crop systems. Newcastle disease vaccination uptake was found to vary substantially across communities and seasons, with a significantly higher level of vaccination amongst households participating in a longitudinal study of children's growth compared with non-participating households (p = 0.009). Two multivariable model analyses were used to explore associations between vaccination and chicken numbers, allowing for clustered data and socioeconomic and cultural variation amongst the population. Results demonstrated that both (a) households that undertook ND vaccination had a significantly larger chicken flock size in the period between that vaccination campaign and the next compared with those that did not vaccinate (p = 0.018); and (b) households with larger chicken flocks at the time of vaccination were significantly more likely to participate in vaccination programs (p < 0.001). Additionally, households vaccinating in all three vaccination campaigns held over 12 months were identified to have significantly larger chicken flocks at the end of this period (p < 0.001). Opportunities to understand causality and complexity through quantitative analyses are limited, and there is a role for qualitative approaches to explore decisions made by poultry-keeping households

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and the motivations, challenges and priorities of community vaccinators. Evidence of a bi-directional relationship, however, whereby vaccination leads to greater chicken numbers, and larger flocks are more likely to be vaccinated, offers useful insights into the efficacy of fee-for-service animal health programs. This article concludes that attention should be focused on ways of supporting the participation of vulnerable households in ND vaccination campaigns, and encouraging regular vaccination throughout the year, as a pathway to strengthen food security, promote resilience and contribute to improved human nutrition.

Introduction

Small flocks of poultry are kept by rural and periurban households throughout low-and middle-income countries, where their contributions span income generation, resilience in times of financial need, provision of animal-source foods, female empowerment and sociocultural activities [1–5]. These genetically-diverse chickens are well-suited to low-input production systems: scavenging for feed, hatching eggs, raising chicks, and sometimes roosting in trees overnight. Constraints to village poultry production include high mortality rates due to disease and predation, and a reliance on available environmental food resources [6].

Newcastle disease (ND) is a viral disease of poultry with global importance, responsible for the loss of economic livelihood and a potential source of household nutrition in many resource-poor settings [7]. Periodic outbreaks result in high mortality amongst free-ranging flocks and serve as a disincentive for poultry-keepers to invest time or resources in their birds. Since opportunities for biosecurity approaches are limited in village settings, where chickens commonly move through the village environment, pass through markets and are given to visiting guests, ND control in village poultry systems is heavily reliant on vaccination.

A successful ND vaccination program has been proposed to require a minimum of 85% of a flock to receive an adequate dose and respond appropriately to the vaccine, in order to achieve herd immunity [8]. This is yet to be validated in village settings, where suboptimal conditions may include nutritional deficiencies, stress, immunosuppression and repeated viral challenges [9]. Amongst the spectrum of ND vaccines currently available and under evaluation, live vaccines developed from low-virulence viral strains remain the mainstay of ND control in many rural communities of Africa. Of these, the I-2 ND vaccine has advantages of increased thermotolerance (an important characteristic in the absence of a reliable cold chain), being safe to administer to birds of all ages including day old chicks, and safe when administered in excess of the recommended dose. The I-2 ND vaccine master seed has been made freely available to low- and middle-income countries to allow a vaccine suitable for use village poultry flocks to be produced locally [10].

Efforts to achieve sustainable ND control in resource-poor settings have included the development of a "community vaccinator" model, whereby a participatory training program and culturally-appropriate extension materials are used to equip local people to offer fee-for-service vaccination through coordinated four-monthly campaigns [11]. Community-based approaches have been central to the delivery of human health care [12, 13] and conservation programs [14–16] for many years, however their use in animal health is less common. Although village poultry systems pose specific challenges to disease control, the community structure of rural African villages is recognised as being conducive to collective action–such as programs to improve chicken health and production–in a way which is less possible in high-income, urban settings [17].

This article presents findings following the implementation of community-based ND vaccination programs using the I-2 ND vaccine in rural communities in Tanzania [18]. It represents part of a nutrition-sensitive program, exploring opportunities to strengthen household nutrition through improvements to existing poultry and crop systems, with a focus on assets controlled and managed by women. In this paper, we describe levels of chicken ownership and chicken flock size over a two-year period and explore levels of vaccination uptake (across all households, and within a randomly selected subset participating in a longitudinal study assessing children's height-for-age). We test associations between the availability of vaccination at a village level and chicken flock sizes, and test bi-directional associations between chicken numbers and vaccination at a household level.

Methods

Ethics approval

The study design, protocols and research instruments for this program were approved by the National Institute for Medical Research ethics committee (NIMR/HQ/R.8a/Vol.IX/1690) in Tanzania, The University of Sydney Human Research Ethics Committee (2014/209) and The University of Sydney Animal Ethics Committee (2013/6065). All participants provided informed consent prior to participating in the study, with assurance of confidentiality, anonymity, voluntary participation and no adverse effects in case of refusal.

Study area and population

This longitudinal study comprises eight rural villages in two adjoining wards of Manyoni District in the semi-arid central zone of Tanzania, and represents a subset of a cluster randomised controlled trial evaluating the impact of village poultry vaccination programs and strategic improvements to crop systems on levels of chronic undernutrition in children [18]. Study sites were selected based on recommendations of in-country partners, according to levels of child stunting and the absence of existing human nutrition or poultry vaccination programs. Within the district, a unimodal pattern of rainfall is expected between November and April, with long-term data indicating mean annual rainfall of 624 mm (SD = 179 mm) and a mean number of rain days of 49 (SD = 15) [19].

A ward census was conducted by the project in April 2014 in Sanza Ward and October 2014 in Majiri Ward, with enumerators registering details of all household members, ownership of chickens and interest in chicken-keeping. Eligibility criteria for inclusion in the longitudinal study included the presence of a child under 24 months of age, and either current ownership of chickens or an intention to keep chickens within a two-year period. Few households were excluded based on the latter criterion.

Two-stage sampling was used to give a total of 240 households in Sanza Ward and 280 in Majiri Ward: by first enrolling all eligible households with a child under 12 months of age, and then using random selection to enrol additional households with a child aged 12–24 months. Baseline data collection was completed for 229 households in Sanza Ward in May 2014 and 274 households in Majiri Ward in November 2014, as part of the staged implementation within the larger project design. An overview of administrative units within the study and the number of enrolled households at a village, ward and district level are shown in Fig 1.

Study intervention

Newcastle disease (ND) control programs using the thermotolerant I-2 ND vaccine, administered via eyedrop [20] were established within the project sites, beginning in May 2014 in the

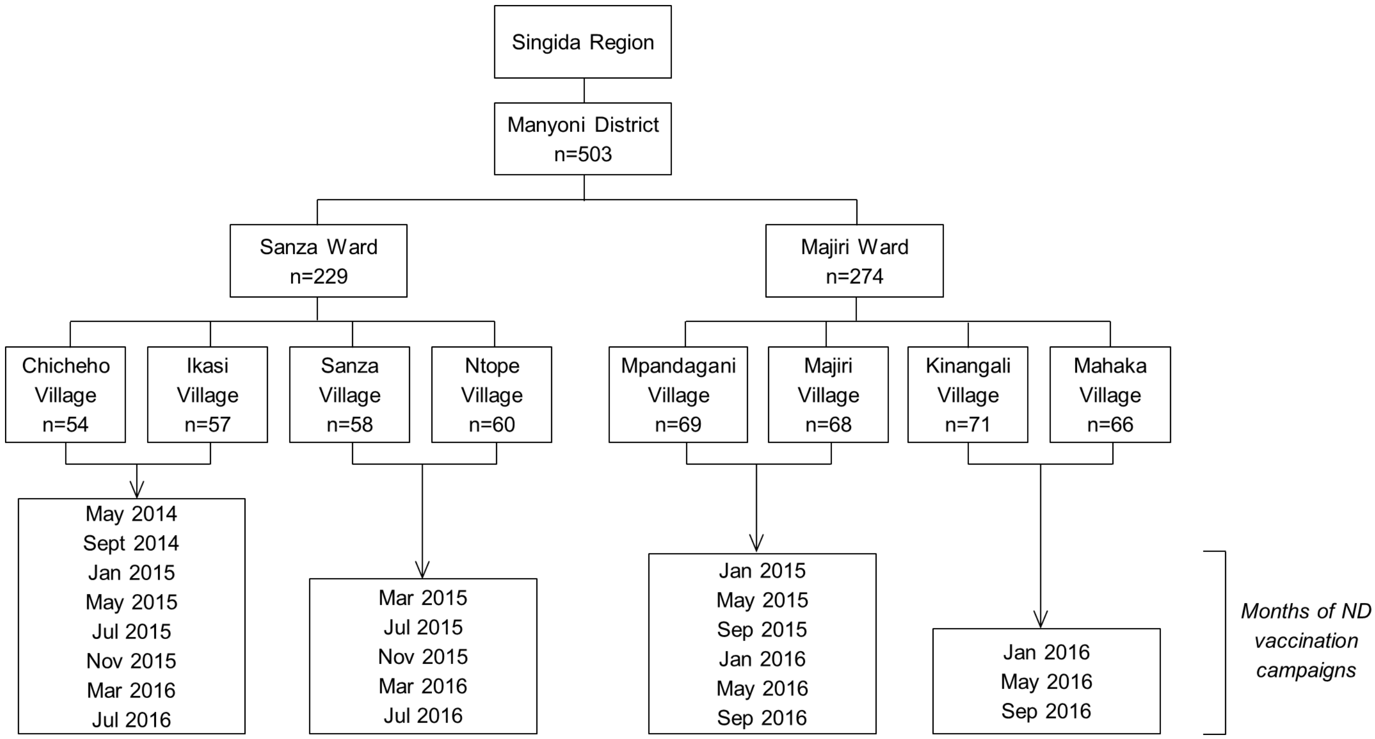

Fig 1. Overview of administrative units in study population, with the number of enrolled households in each of eight villages, and aggregated at ward and district levels. The timing of vaccination campaigns is shown.

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first two of the eight villages (Fig 1). Local candidates for the role of "community vaccinator" were identified in consultation with village leaders. Training workshops were conducted using materials developed for and pre-tested in resource-poor settings [21]. These included both theoretical and practical components to cover aspects of chicken health and disease, principles of ND transmission and control, vaccine storage and handling, and logistical aspects of implementing community-wide vaccination campaigns.

In addition to the six-month delay between commencement of research activities between the two wards, there was a staggered start to ND vaccination programs within wards. At ward-level meetings in both Sanza and Majiri, village representatives drew pieces of paper at random to designate their village for immediate or delayed introduction of ND vaccination, with a delay of three campaigns between the two groups (Fig 1). Prior to each campaign, community vaccinators visited households to register chicken numbers and establish chicken-keepers' interest in fee-for-service vaccination, allowing an appropriate quantity of vaccine to be ordered. The cost of vaccination was initially set at 50 Tanzanian Shillings (TZS) per bird in all villages, and was increased to 100 TZS per bird in Majiri Ward in 2016 based on local consensus.

The months of vaccination campaigns within the eight villages is shown in Fig 1. Studies on the epidemiology of ND in village chickens are limited, however general information from Veterinary Investigation Centres across different agroecological zones of Tanzania [22] suggests a heightened risk of ND outbreaks between July and November each year, during the dry season. Accordingly, initial recommendations were that vaccination campaigns be held in January, May and September. This timing was followed in Majiri Ward throughout the study. In Sanza Ward, vaccination months were changed to March, July and November in the second year of implementation. This transition was made both to reflect the perceived risk of outbreaks within the community, and to accommodate changes to the Tanzanian financial year in Tanzania and associated logistical challenges of distributing vaccine in January.

Although it is considered prudent to conduct two ND vaccination campaigns prior to the high-risk period for disease outbreaks [23], delays in project inception led to the first campaign (in Chicheho and Ikasi villages) being held in late May 2014. This coincided with reports of illness and mortality in a small number of chickens within the area, suggesting the potential presence of a disease compatible with ND. A decision was made to proceed with the campaign, given it was considered a minor risk that chicken-keepers might attribute post-vaccination illness or mortality in their chickens either to the inefficacy of the vaccine or as a direct outcome of vaccination. In addition to hand-washing between each household visited, payment was postponed to a follow-up visit as an additional measure to reduce the potential for disease transmission, with the transfer of money identified as a potential pathway for viral transmission.

Data sources

Information used for this analysis falls into two broad categories: (1) relating to all households to which ND vaccination was made available, and (2) relating to the subset of households enrolled in the longitudinal study of children's growth (hereafter referred to as "enrolled households"). In the former category, the total number of households was derived from initial census data collected by the project, and the number of households vaccinating their chickens in each campaign was determined from community vaccinators' records. Daily rainfall data were recorded from a rain gauge with 1 mm graduations, located at the village office in Ikasi Village, Sanza Ward and Kinangali Village, Majiri Ward.

Information on study participants was drawn from two questionnaires, collected through interviews by local enumerators recruited and trained within each ward. One questionnaire (applied at six-monthly intervals to mothers of enrolled children), focussed on maternal and child health and nutrition, while the other (applied annually to an intended equal number of male and female household members; actual sample comprised 60.5% female respondents of 1,354 completed questionnaires) encompassed demographic data, socioeconomic factors, livelihoods and chicken-keeping practices. Additionally, two representatives from each village (one male, one female) were employed as "Community Assistants" to collect ongoing data from enrolled households. The number of chickens owned, categorised by age (i.e. under or over two months) and participation in each vaccination campaign were recorded during twice-monthly household visits.

Data analysis

Defining variables. Socioeconomic status of enrolled households was determined using a modified version of a "household domestic assets index" (HDAI), developed for use in sub-Saharan Africa [24]. The index assigns a weight to livestock and non-livestock assets according to their equivalent value. It is acknowledged that the relative value of assets will vary between settings, however the reference's weighting system was considered adequately appropriate for the study sites to provide a reasonable estimate of enrolled households' wealth. Given that some of the information involved in index construction (such as the size of land ownership and the age of assets) was not collected within this study, a modified index was formed based on livestock species and household items owned. Chicken numbers were excluded from these calculations, in order to evaluate their influence on vaccination uptake separately to their general contribution to household wealth.

Language group, as a proxy for ethnicity and cultural practices, was also considered as a potential determinant of chicken ownership and vaccination uptake, based on observed and documented differences in household dynamics, diets and the practice of agropastoralism in this setting [25, 26]. Questionnaire responses for the "first language" of both the mother and father of children participating in the study were combined with information on the gender of the household head to determine the dominant language group of each household, likely to influence agricultural and dietary practices.

The number of chickens owned by households was recorded at two-weekly intervals. While chickens of all ages were included in descriptive summaries, the number of chickens over two months of age was used as a predictor and outcome variable in inferential analyses. This distinction was made based on documented high rates of mortality amongst chicks in village settings from causes other than ND, such as predation, harsh weather conditions and poor nutrition [27, 28].

Descriptive statistics. Percentages were determined for categorical variables and means and standard deviations or medians and interquartile ranges (IQR) calculated, for normally and non-normally distributed continuous variables, respectively. Records of chicken numbers in enrolled households were aggregated at village and ward levels for twice-monthly intervals over a two year period in both wards (beginning in July 2014 in Sanza Ward, and November 2014 in Majiri Ward). Graphical summaries were assembled for the percentage of enrolled households owning chickens and the average chicken flock size over time. In recognition of fluctuating levels of village chicken ownership, the percentage of households owning chickens consistently over a twelve-month period, and those owning chickens intermittently or not at all, were evaluated for each ward.

Levels of vaccination uptake were determined for all households in a village, and amongst households enrolled in the study. In the former case, given the absence of information on chicken ownership across the whole village, vaccination levels were calculated relative to the total number of households recorded in the census (a proportion of which it is noted would not be keeping chickens). For the enrolled subset, households owning chickens were categorised as vaccinating or non-vaccinating according to their participation in each campaign.

Univariable and multivariable models. Depending on the type of response variable, linear mixed models (for quantitative variables) or generalised linear mixed models (for binary and count variables) were used, with the mixed model approach to allow for geographical clustering. For all analyses, univariable models were first used to test unconditional associations between predictor variables of interest (including socioeconomic and demographic characteristics and temporal factors) and the two outcomes of interest: chicken flock size and vaccination uptake. In the case of chicken numbers and asset scores, log-transformations were used to minimise the excessive influence of very large numbers. Variables with p-values under 0.1 were included in multivariable models, and a manual backwards elimination approach used with variables being retained if they were significant at the 5% level. All multivariable models included ward, village, subvillage and household identification as random effects, to allow for clustered data.

Initial analyses explored: (a) longitudinal associations between enrolment in the study and participation in ND vaccination campaigns, and (b), for enrolled households, associations between the timing of commencement of vaccination (immediate or delayed) and levels of participation in the first campaign. The relationship between chicken numbers and ND vaccination was recognised as having the potential to be bi-directional: (1) with lower mortality amongst vaccinated birds resulting in increased chicken flock size, and / or (2) with households owning more chickens being more likely to invest in vaccination. Schematic diagrams of analyses conducted, including the relevant time frames to explore causality, are shown in Fig 2.

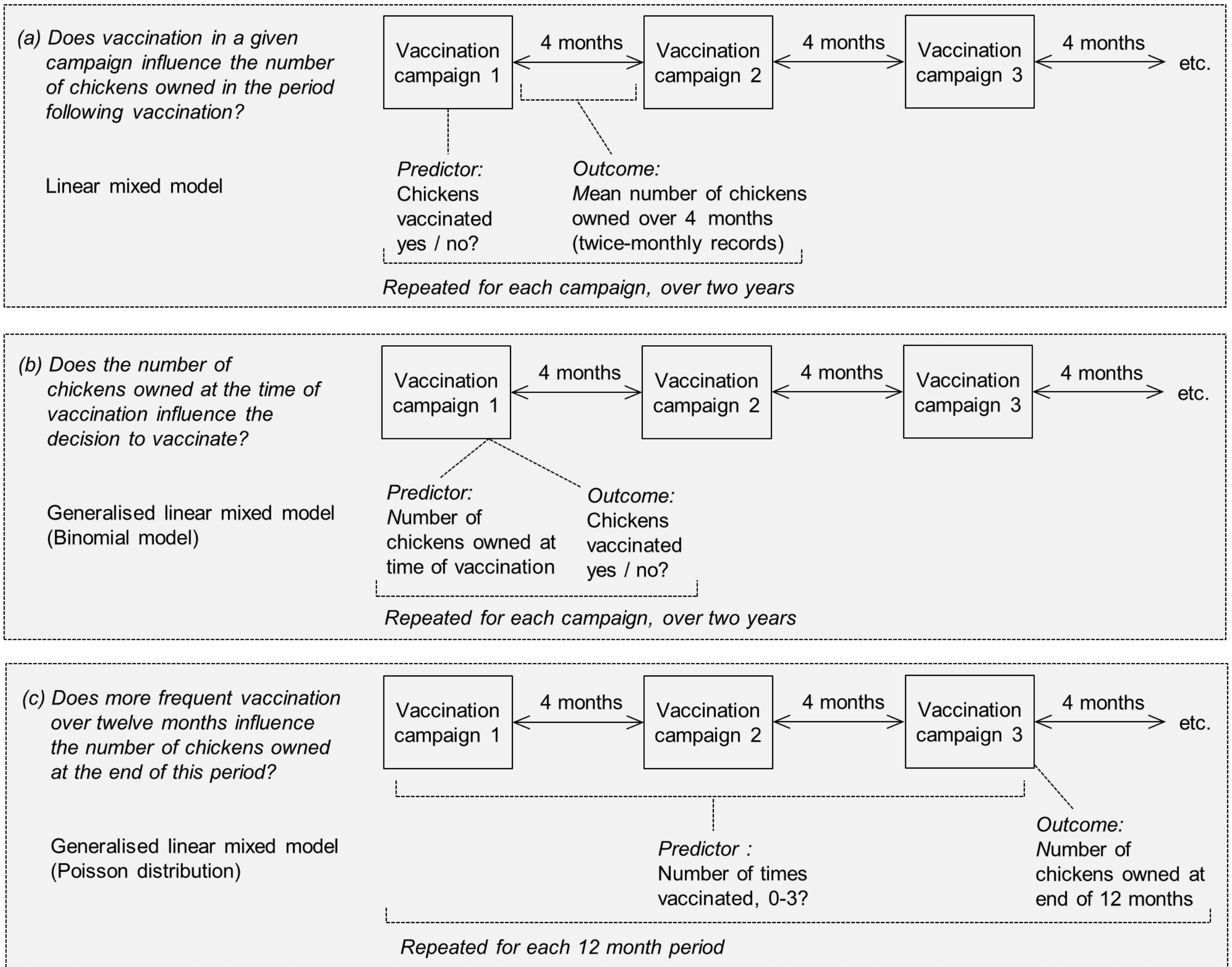

Fig 2. Overview of analyses exploring associations between chicken vaccination and chicken numbers, with time periods for relevant predictor and outcome variables. All were within multivariable models.

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Vaccination in a given campaign was evaluated as a predictor of chicken flock size in the period following vaccination, by considering the mean number of chickens owned between one campaign and the next (Fig 2A; linear mixed model). To explore the alternative causal pathway, associations between chicken flock size and the decision to vaccinate were tested using the number of chickens owned at the time of vaccination (Fig 2B; generalised linear mixed model (binomial model)). Finally, the significance of participation in multiple vaccination campaigns over twelve months was tested as a predictor of the chicken flock size at the end of this period (Fig 2C; generalised linear mixed model (Poisson distribution)). The fit of the mixed models was assessed using standard residual diagnostic plot methodologies. All analyses were conducted using GenStat Release 18 (https://www.vsni.co.uk/).

Results

Characterising the study population

Demographic and socioeconomic characteristics of enrolled households were compiled using baseline data from each of the two wards (Table 1). The percentage of households identifying

Table 1. Overview of household characteristics, by ward.

	Sanza Ward	Majiri Ward
Baseline data collection	May 2014	November 2014
Enrolled households (*n*)	229	274
Female-headed households (%)	30.2[a]	16.4[a]
Household size		
Mean (SD)	5.4 (1.9)	5.5 (2.6)
Range	2–11	2–21
Language group (%)		
Gogo	78.2[a]	74.8[a]
Sukuma	6.1[a]	14.6[a]
Other	4.4	2.6
Unspecified	11.4[a]	8.0[a]
Household Domestic Assets Index		
Median (IQR)	12 (5–50)[b]	26 (7–115)[b]
0–49 (%)	74.7	59.6
50–99 (%)	10.7	13.1
≥100 (%)	14.7	27.3
Livestock ownership at baseline (%)		
Cattle	26.7[a]	36.2[a]
Sheep or goats	27.1[a]	47.8[a]
Chickens	51.1[a]	42.1[a]
Number of livestock[c], median (IQR)		
Cattle	4 (2–17)[b]	10 (4–20)[b]
Sheep or goats	14 (7–20)	12 (5–25)
Chickens	7 (2–13)	8 (5–13)

Significant differences between wards ($p < 0.05$), as determined by

[a] Chi-square tests and

[b] t-tests.

[c] Amongst households keeping livestock, for each category

https://doi.org/10.1371/journal.pone.0188230.t001

as having a female household head varied significantly between wards ($p < 0.001$), from 16.4% in Majiri to 30.2% in Sanza. Household size ranged from two to 21 people across the study sample, with a median of five household members in both wards. Fourteen language groups were represented, based on questionnaire responses for the "first language" of both the mother and father of enrolled children. Gogo constituted the most common language group ($n = 381$), with Sukuma the second most common ($n = 46$).

The modified HDAI, based on the sum of weighted livestock and non-livestock assets, suggested a wide variation in socioeconomic status amongst study participants. The range of HDAI scores extended from zero to 1,010, with a prominently positively-skewed distribution. Significant variation was seen between wards ($p = 0.002$), from a median HDAI of 12 in Sanza and 26 in Majiri. The percentage of households owning ruminants also varied significantly between wards ($p = 0.024$ for cattle, $p < 0.001$ for sheep and goats), and cattle herds were significantly larger in Majiri Ward ($p = 0.012$). Chickens were identified to be owned by 51.1% of enrolled households in Sanza Ward and by 42.1% in Majiri Ward at the time of baseline data collection. The known seasonality of village chicken numbers and differing months in which baseline assessments were conducted prevents conclusions being drawn about significance of differing levels of chicken ownership using this data.

Chicken ownership and flock size in enrolled households

Twice-monthly records of chicken numbers in enrolled households were aggregated at the village and ward level, to evaluate trends in chicken ownership and chicken flock size over a two-year period beginning in July 2014 in Sanza Ward and November 2014 in Majiri Ward (Fig 3). Flock size was evaluated both in terms of the total number of chickens (Fig 3B and 3E), and

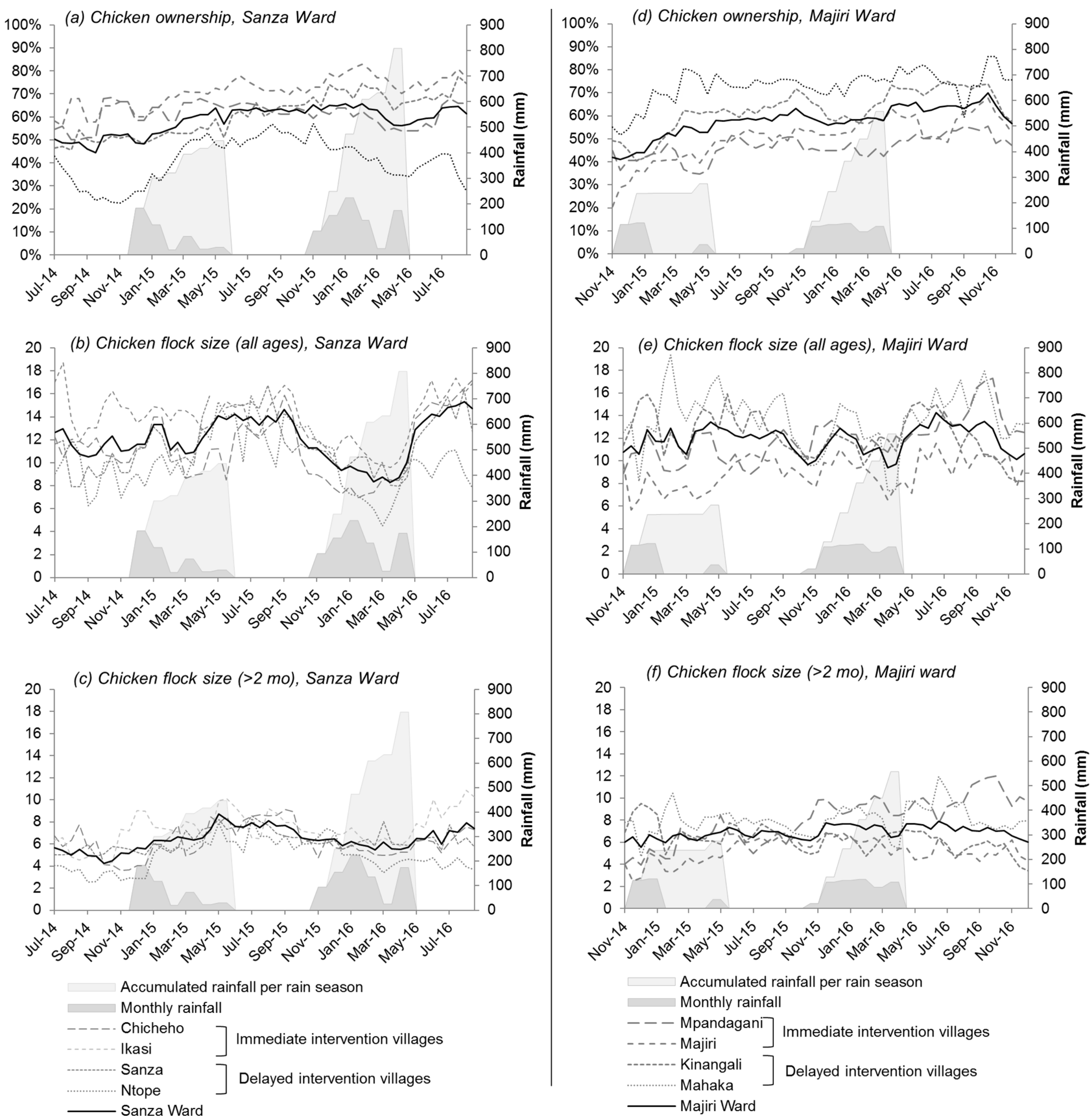

Fig 3. Percentage of enrolled households owning chickens (a, d) and mean flock size per household, including chickens of all ages (b, e) and restricted to chickens over two months of age (c, f), with monthly and accumulated rainfall per year.

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the number older than two months of age (i.e. excluding chicks; Fig 3C and 3F). Daily rainfall data are shown as monthly and accumulated totals for each rain season, to reflect seasonality within the agricultural calendar in the study sites.

There was a mild increase in the percentage of enrolled households keeping chickens in Sanza Ward (from 50.2% to 59.3% over 24 months; Fig 3A), with considerable variation between villages. Levels of chicken ownership increased in two villages (from 58.3% to 71.4% in Ikasi, and 46.4% to 68.6% in Sanza), but remained relatively unchanged in the other two. The most marked variation during the data collection period was seen in Ntope Village, one of the delayed vaccination villages, where chicken ownership levels dropped to 22.6% in November 2014, rising to 56.9% by November 2015, before falling to 34.7% in April 2016.

In Majiri Ward, an upward trend in levels of chicken ownership amongst enrolled households was evident (from 42.0% to 66.2% over 24 months; Fig 3D). At a village level, fewer households kept chickens in the immediate vaccination communities, compared to the delayed vaccination communities, both at the time of commencement of project activities and throughout the period of data collection. Levels of chicken ownership were highest in Mahaka Village, while Majiri Village recorded the lowest levels, but the greatest increase, over 24 months (from 20.6% to 65.0%). Fluctuations in levels of chicken ownership within villages of Majiri Ward were less prominent than in Sanza Ward, during the respective data collection periods.

In November 2014, the first point at which information is available for both study sites, comparable mean flock sizes were documented in the two wards (11.0 in Sanza vs 10.8 in Majiri, total chicken numbers). Although limited to a 24 month period, data from Sanza Ward suggests the possibility of a seasonal pattern in chicken numbers, with a decrease in the mean flock size through the dry season and an increase through the wet season. A particularly marked decline in overall chicken numbers was seen between September 2015 and March 2016 (from a mean flock size of 14.6 to 8.3). Ikasi village, in which the percentage of chicken-owning households was highest, also recorded the greatest mean chicken flock size in Sanza Ward.

There was no suggestion of a seasonal or temporal effect on chicken numbers in Majiri Ward, where ward-level data showed a moderately stable flock size over the data collection period (range of 6.0–7.9 chickens above two months of age, over 24 months). As in Sanza Ward, the village with the highest level of chicken ownership in the ward, Mahaka, also had the largest mean number of chickens per household. Although only a relatively mild increase in the percentage of chicken-owning households was seen in Mpandagani village (from 44.9% to 53.7% of enrolled households, over 24 months), a marked increase in chicken flock size was recorded (from 4.0 to 12.0 chickens above two months of age).

In both study sites, more substantial fluctuations in mean flock size were evident when chicks (i.e. chickens under two months of age) were included in calculations (Fig 3B and 3E, cf. Fig 3C and 3F). The inclusion of chicks in graphical summaries serves to illustrate the variability in flock size which accompanies the hatching of clutches of eggs and subsequent loss of some chicks to the hazards of predation, disease or poor nutrition in a village setting.

For all enrolled households with twice-monthly records available, the regularity with which chickens were kept was also considered. The percentage of households owning chickens consistently, intermittently and not at all, over consecutive twelve-month periods in each ward is presented in Fig 4. The percentage not keeping chickens has remained relatively stable over the two years evaluated (24.2% to 23.2% in Sanza Ward, 24.6% to 22.7% in Majiri Ward), however a moderate increase has been seen in the percentage of households consistently keeping chickens between one year and the next (24.7% to 36.4% in Sanza Ward, 22.1% to 35.2% in Majiri Ward). Of the relatively stable proportion of enrolled households owning chickens, it

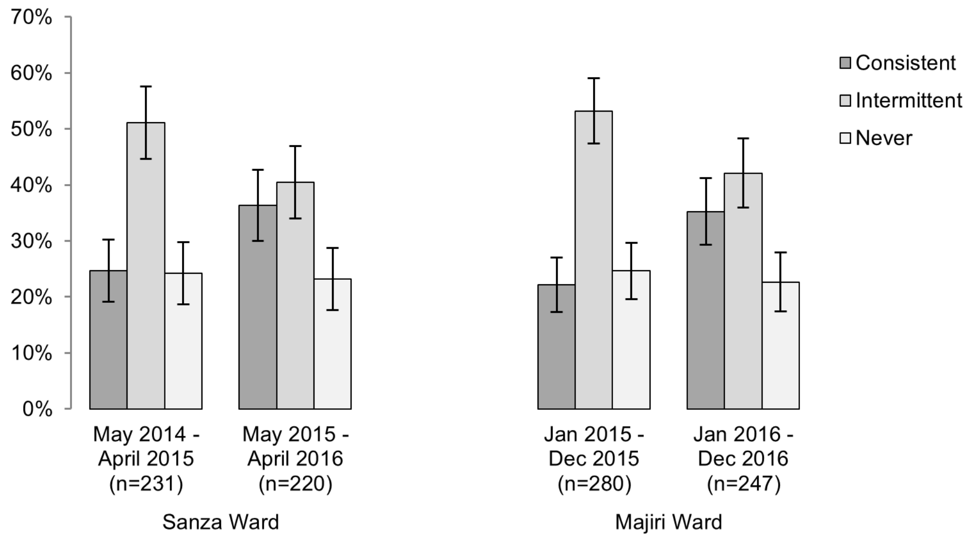

Fig 4. Percentage of enrolled households keeping chickens consistently, intermittently or not at all, during two consecutive twelve-month periods in Sanza and Majiri Ward. 95% confidence intervals are shown.

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became more common to keep chickens consistently throughout the year during the second twelve-month period.

Newcastle disease vaccination uptake

Levels of uptake of ND vaccination varied substantially across wards, villages and campaigns. The percentage of households participating in each campaign has been evaluated across all households (Fig 5A and 5B), and amongst the subset of households enrolled in the longitudinal study (Fig 5C and 5D). Levels of chicken ownership across all households are not known, but for enrolled households, the percentage of households owning but not vaccinating chickens is also shown.

Vaccinator records indicate the first campaign in Sanza Ward, in May 2014, to have involved almost three-quarters of all households (72.4%) across the two intervention villages, but this reduced dramatically to around one-fifth of all households in the two subsequent campaigns (20.4% and 19.1% for September 2014 and January 2015, respectively). In the delayed intervention villages in Sanza Ward, around half of all households (52.1%) participated in the first campaign, in March 2015. At a ward level, vaccination levels have stabilised at just under one-third of all households for the four most recent campaigns evaluated (ranging from 30.9% in July 2016 to 32.9% in March 2016), with some fluctuation at a village level between one campaign and the next.

In Majiri Ward, vaccination uptake has been lower on average, compared to Sanza Ward (22.5% of all households versus 37.5%, across a two-year period in each ward), and with less marked variation at a ward level between campaigns (20.3–29.2%). Within both of the two years evaluated in Majiri Ward, the highest level of participation was recorded in the May campaign. Uptake of vaccination varied substantially between villages, with almost three times more households vaccinating in Kinangali compared to Mpandagani over the three campaigns in 2016 (30.8% versus 10.7%).

In the first campaign of the study, implemented in Chicheho and Ikasi villages in Sanza Ward in May 2014, comparisons between vaccination levels amongst enrolled households and

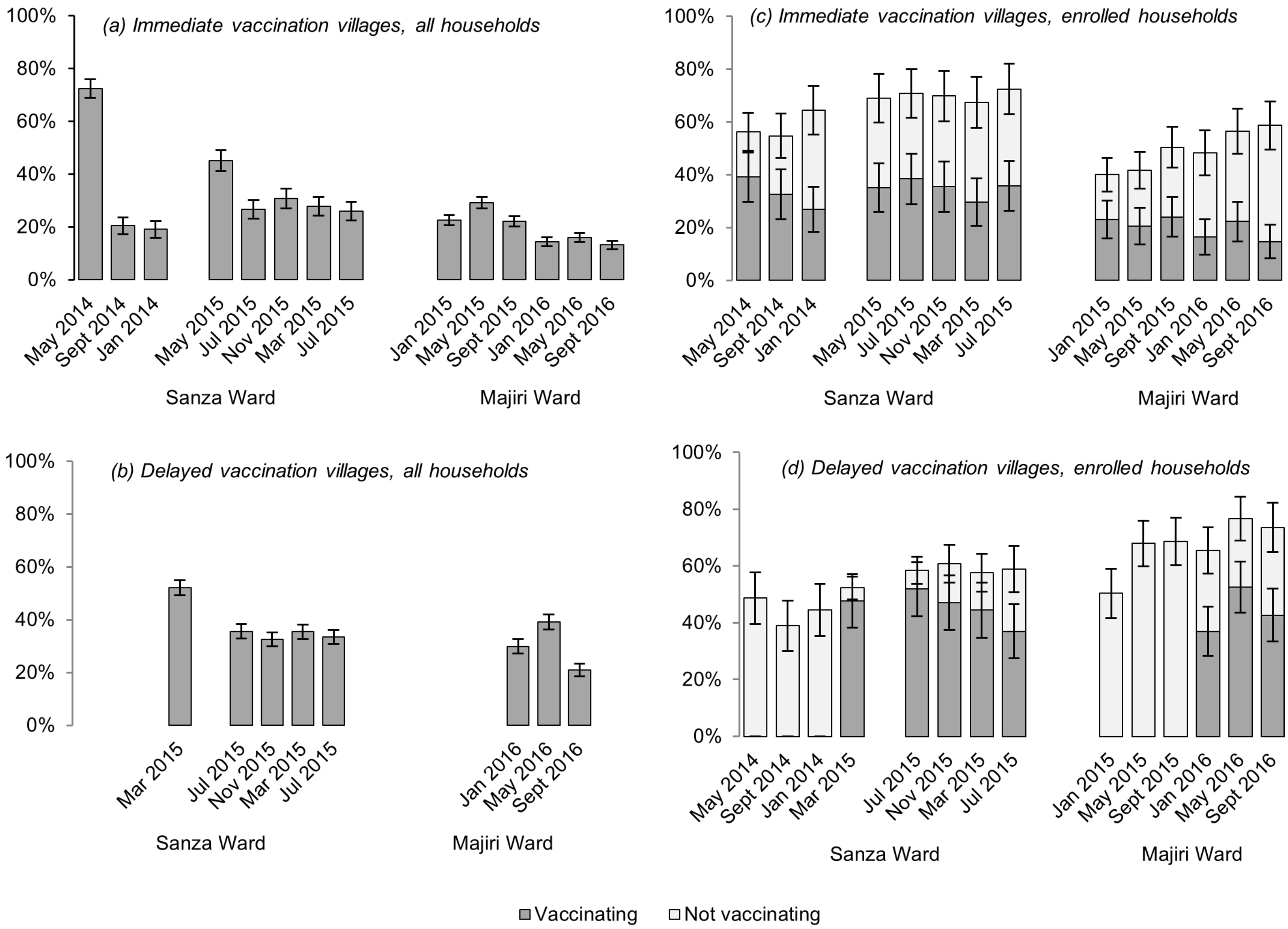

Fig 5. Percentage of households participating in each campaign (dark grey shading), according to intervention group: across all households (a and b), and amongst enrolled households (c and d). For enrolled households, the percentage owning chickens but not vaccinating is included for each campaign (light grey shading). 95% confidence intervals are shown.

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across the broader community reveal a contrasting situation in the two intervention villages. In Ikasi village, similar uptake was seen in the two groups (52.1% vs. 50.9%) while in Chicheho, available data indicates 23.2% of enrolled households to have vaccinated chickens, compared to 87.7% of the wider community. This apparent under-representation of enrolled households has not been repeated in subsequent campaigns or alternative locations. In Majiri Ward, the most prominent difference between vaccination uptake was seen in Kinangali village in September 2016 (53.8% enrolled households vs. 26.1% in overall village).

To test the association between enrolment in the longitudinal study and vaccination of chickens, the number of enrolled households (vaccinating and total) was subtracted from community-wide data to give the number of "non-enrolled households" (vaccinating and total). In the May 2014 campaign in Chicheho village, records indicate the number of non-enrolled households vaccinating chickens to have *exceeded* the total number of non-enrolled households in the village. Excluding this campaign (for reasons elaborated in the Discussion), enrolment in the longitudinal study was identified as a significant predictor of chicken vaccination ($p = 0.009$). Controlling for variation between campaigns and clustering at the ward and village level, model-based predictions for vaccination participation were 36.2% (SE 3.9%) for enrolled households and 30.1% (SE 3.0%) for non-enrolled households.

The effect of the delay to the introduction of vaccination programs in some villages on participation in the first campaign was also explored using household-level data. Amongst enrolled households owning chickens during the month of vaccination, generalised linear mixed model analysis which included ward, village and subvillage locations as random effects indicated no significant difference in the probability of vaccinating in the first campaign where the vaccine was available immediately or those with a twelve month delay ($p = 0.55$).

Linking Newcastle disease vaccination and chicken numbers

Relationships between ND vaccination and chicken numbers at a household level were explored using two years of data from enrolled households in villages where vaccination was available. The potential for differences between male- and female-headed households was considered in all models, but no significant associations were identified.

Firstly, a linear mixed model was used to test associations between vaccination in a given campaign and the mean number of chickens owned in the period following vaccination (in most cases, the four month period between campaigns). Controlling for the influence of language group (with a predicted mean flock size of 10.8 (SE 1.6) chickens for Sukuma households, compared to 6.4 (SE 0.6) chickens for other language groups; $p < 0.001$) and HDAI score ($p = 0.007$), ND vaccination in a given campaign was significantly associated with greater chicken numbers in the period following vaccination ($p < 0.001$). The introduction of an interaction term to the model demonstrated that the association between vaccination and chicken flock size varied between campaigns ($p = 0.025$; Fig 6). Statistically significant differences between vaccinated and non-vaccinated flock sizes were demonstrated for the campaigns held

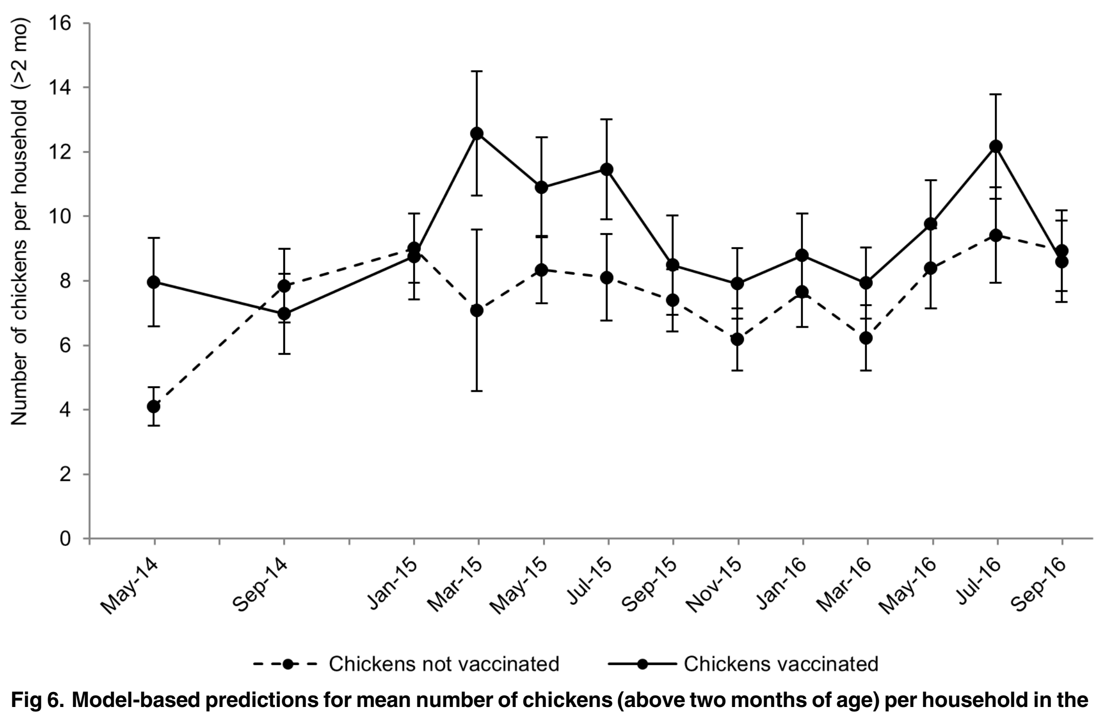

Fig 6. Model-based predictions for mean number of chickens (above two months of age) per household in the period between one vaccination campaign and the next, according to households' participation in a given campaign ($p = 0.025$), based on multivariable analysis of enrolled households (controlling for language group and asset score).

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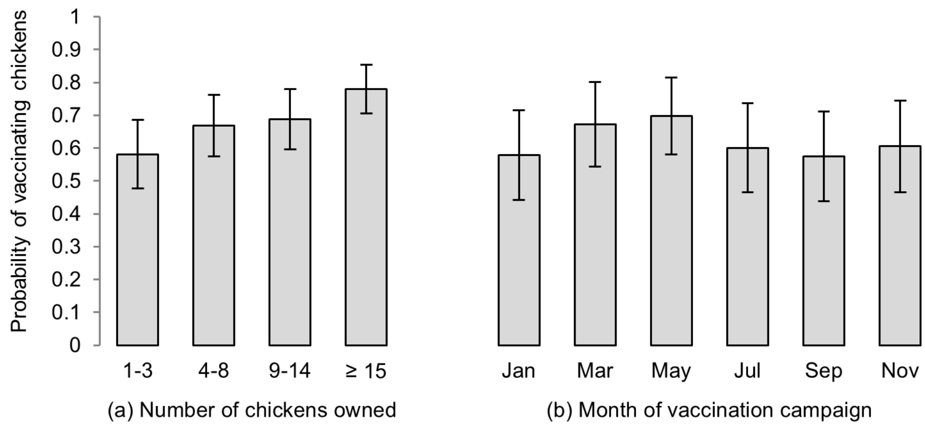

Fig 7. Probability of enrolled households participating in Newcastle disease vaccination campaigns, according to (a) quartiles of chicken flock size (above two months of age) at the time of vaccination ($p < 0.001$), and (b) the month of vaccination campaigns ($p = 0.044$).

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in May 2014, March 2015 and July 2015. It is considered likely that limited statistical power prevented this same effect being demonstrated in other vaccination campaigns.

Secondly, a binomial generalised linear mixed model was used to evaluate associations between the number of chickens owned by an enrolled household during the month of vaccination and the uptake of vaccination by that household. Allowing for variation between campaigns and geographic clustering within the dataset, a strong association was identified between larger flock size and vaccination uptake ($p < 0.001$). This was evident both considering chicken numbers as a continuous predictor variable, and evaluating quartiles of chicken flock size (Fig 7A). The latter approach, which demonstrates the majority of chicken flocks to be of a modest size, predicts a household with 15 or more chickens to have 2.6 times greater odds of vaccinating than a household with less than four chickens (0.792 probability of vaccinating vs. 0.598).

Within the same model, the probability of participating in a vaccination campaign was also shown to be significantly associated with the month of year ($p = 0.044$; Fig 5B). Although wide standard errors were associated with the model-based means based on this limited period of data collection, households were suggested to be most likely to vaccinate in the months of March and May, in Sanza and Majiri Wards, respectively.

A final component of the analysis explored the influence of participating in multiple vaccination campaigns on chicken flock size. Using two years of data from each of the two wards, the number of campaigns in which a household's chickens were vaccinated over a twelve-month period (0–3) was evaluated as a predictor of the number of chickens owned at the end of this period. In a multivariable generalised linear mixed model, controlling for the influence of HDAI ($p < 0.001$), frequency of vaccination was significantly associated with chicken numbers ($p < 0.001$; Fig 8). Model-based predictions indicated households vaccinating in all three campaigns in a given twelve-month period to have almost twice as many chickens at the end of that period, as households vaccinating once, twice or not at all, for which predicted mean flock size did not differ significantly.

Discussion

This study was devised with the aim of evaluating outcomes of a fee-for-service ND vaccination program on (i) vaccination uptake across the project area, and (ii) on levels of chicken

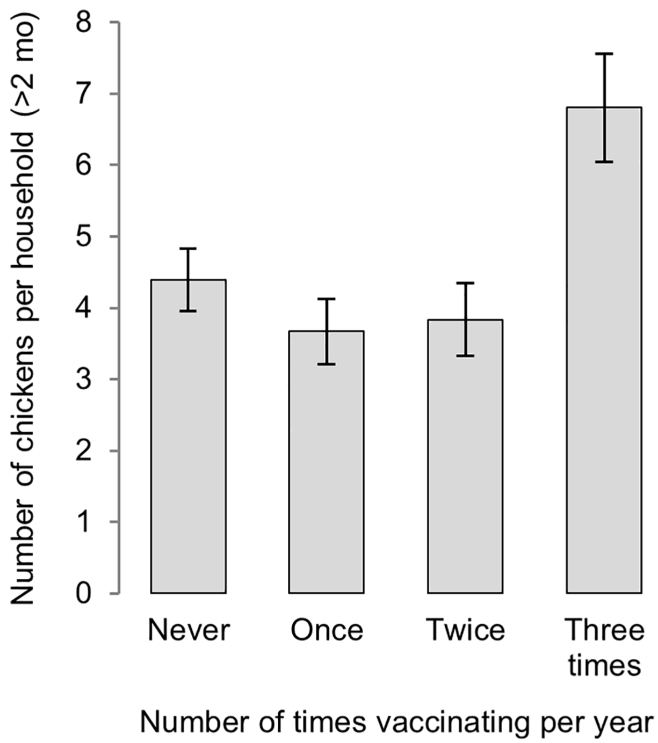

Fig 8. Model-based predictions for mean number of chickens (above two months of age) per household according to the number of campaigns in which chickens were vaccinated in the previous twelve months ($p < 0.001$), based on multivariable analysis of enrolled households (controlling for asset score).

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ownership and flock sizes amongst enrolled households. This was considered in the context of a potential pathway to influence food security and the nutritional adequacy of diets for women and children within those households. Using a nationally-produced thermotolerant vaccine of known efficacy [29] and a "community vaccinator" model applied successfully elsewhere in the region [30], the emphasis of this work was on documenting the results of a cost-recovery chicken vaccination program on poultry flocks in rural communities of Tanzania.

The delayed project inception which led to the commencement of vaccination activities on the cusp of a high-risk period for ND outbreaks was a significant challenge. For chickens already harbouring the virus or suffering immunosuppression (due to high parasite burdens, poor diets or intercurrent disease) to fail to respond effectively to the vaccine and subsequently die would have severe implications for ongoing vaccination efforts in this ward. The decision to postpone payment in this first campaign was intended to minimise the potential for disease transmission via the handling of money, at a time when ND virus might be present within the community. It did, however, set a precedent of payment being delayed or being contingent on the ongoing good health of vaccinated birds, which has been difficult to overcome in some villages.

In the May 2014 campaign in Chicheho Village, of households not enrolled in the longitudinal study, the number recorded as having been vaccinated fractionally *exceeded* the total number of households in the village identified in the census (286 vaccinated, 285 households in total). Although levels of chicken ownership across the non-enrolled segment of the village is not known, only around half of the enrolled subset in Chicheho village (54.7%) kept chickens at this time. The deferred payment system and the commencement of activities in an area rarely visited by research or development programs in the past may have contributed to an elevated vaccination uptake, however it is unlikely that all non-enrolled households in the village might have owned chickens, let alone taken up the vaccination service in this first campaign.

Aside from the possibility of recording errors by newly-trained vaccinators, it is theorised that the apparently high vaccination rates in this village may reflect vaccination of households from outside the intervention area. Although distances between villages are not inconsequential, the potential that vaccinators may have travelled by bicycle or motorcycle to pursue income-earning opportunities further afield cannot be ruled out. The percentage of households keeping chickens and the mean flock size in the neighbouring village of Sanza are noted to have remained relatively stable during the high-risk period for ND outbreaks in this first year, in contrast to the fall in both ownership and chicken numbers in the other delayed intervention village of Ntope.

Signficantly higher levels of ND vaccination were observed amongst households enrolled in the longitudinal study, compared to others within the community ($p = 0.009$). This might be explained by either a higher supply or demand for the vaccination service amongst enrolled households. In terms of demand, Community Assistants' twice-monthly documentation of the number of chickens owned, and a series of questions about chicken ownership and the consumption of chicken meat and eggs during six-monthly questionnaires, are likely to have generated greater interest in poultry-keeping amongst this subset–and potentially a greater likelihood of investing in vaccination. The targeted inclusion of enrolled households in extension activities and the provision of small gifts as tokens of appreciation for their involvement in the study are recognised as likely to have contributed to the increased uptake of vaccination, relative to non-enrolled households of equivalent economic capacity and language group. Additionally, on the supply front, close interactions between Community Assistants and chicken-vaccinators may have resulted in an increase in the vaccination service being offered to enrolled households.

Deeper exploration of factors influencing vaccination uptake and economic analyses of this ND control program (including the influence of an increase in the cost of vaccination in Majiri Ward in 2016) are beyond the scope of this article. Rather, in this paper, we seek to evaluate associations between vaccination at a household level and chicken flock size. When reviewing summaries of chicken ownership and mean flock size across enrolled households over a two-year period in the absence of information on the sale and consumption of chickens, outcomes attributable to the introduction of the ND vaccine are difficult to detect. This is unsurprising, in the early phase of an animal health program which requires households to pay for a novel technology and when a reduction in chicken mortality may be countered by their more frequent sale to meet household needs in times of climate variability, crop failure and a scarcity of staple foods. Rainfall in the first year of data collection was particularly poor, with a total rainfall of 447 mm (30 rain days) in Sanza Ward and 275 mm (21 rain days) in Majiri Ward, falling short of the long-term mean annual rainfall of 624 mm (49 rain days) for Manyoni District [19]. While not documented within this study, increased sale of chickens to meet household needs is likely to have occurred.

Despite limitations in the ability to capture a household's socioeconomic status effectively using an index which has not been validated in the study setting, significant associations between increasing asset score and increasing chicken flock size were found. Chicken flocks were also shown to be significantly larger for households identifying as belonging to the Sukuma language group, compared to others within the study population. Controlling for variation due to socioeconomic status and language group, households vaccinating their chickens in a given campaign were identified to have larger chicken flocks in the period following vaccination. This finding is not only contingent on vaccine efficacy and its appropriate storage, handling and administration, but also on the fact that households within the study have an interest in increasing their chicken flock size–and that reduced mortality due to ND will not immediately be met by increased sale and consumption of chickens.

Determining causality is difficult through such analyses, and the possibility that households with larger chicken flocks have greater interest and financial capacity to invest in ND vaccination must also be considered. This additional hypothesis, that chicken flock size is a determinant of vaccination uptake, was also tested. The finding that households with larger flocks during the month of the vaccination campaign were more likely to have their chickens vaccinated may reflect the fact that community vaccinators preferentially offer their service to households with larger flocks. If payment is received for each bird vaccinated and distances between households substantial, there is an incentive for vaccinators to focus their efforts on households with a greater number of chickens. Previous findings from Malawi, Mozambique and Tanzania have highlighted the adequate compensation of vaccinators as being fundamental to the success of ND control programs [31].

Alternatively, there may be an increased demand for vaccination amongst households with more chickens, for whom poultry-keeping may be more likely to be seen as a viable livelihood strategy and who may be more willing or able to pay for the service. Suggested seasonal patterns in the probability of vaccinating are consistent with both the availability of income from crop sales and the reported patterns of ND outbreaks in this area. Higher levels of vaccination in the months of March and May reflect a time of greater income availability following the harvest of crops, and heightened awareness of the risk of ND outbreaks in the following months. In November and January, the lower perception of disease risk and scarce disposable income may explain the lower likelihood of households choosing to vaccinate their flocks.

The finding of significantly higher chicken flock size ($p < 0.001$) amongst households participating consistently in vaccination campaigns, compared to those vaccinating intermittently or not at all, reinforces the merit of the four-monthly vaccination protocol advocated for using the I-2 ND vaccine in village settings [21]. Although seasonal patterns exist for high-mortality ND outbreaks, benefits of regular vaccination include maintaining ongoing and adequate immunity to reduce the incidence of disease at other times of year, and contributing to herd immunity to protect chicks which are hatched between campaigns [20, 29].

Conclusions

Animal health programs–and development programs more broadly–that involve the voluntary investment of funds by local households offer a sustainable pathway to food and nutrition security, which avoids a reliance on ongoing support from governments or donor agencies. Village chickens, ubiquitous throughout rural communities of sub-Saharan Africa, are a worthy target of efforts to alleviate poverty and enhance diet quality. Within this study, the finding of greater flock size following Newcastle disease vaccination provides assurance of the vaccine being handled and administered effectively by local vaccinators. Increased thermotolerance of the I-2 ND vaccine removes the need for a continuous cold chain, but requirements for appropriate storage, transport and ensuring opened vaccine vials are used within an appropriate time period remain important.

Equally central to a successful ND control program is the awareness-raising and educational role of the vaccinator within their community. Tanzanian poultry-keepers are familiar with clinical signs and patterns of disease amongst their birds, and, although formal diagnosis is rare, illness and mortality compatible with Newcastle disease (*Mdondo* in Swahili) is a known entity. Despite this, when financial reserves are scarce, climate patterns unpredictable, available environmental feed resources limited and the threat of predation and theft common, poultry-keepers may be initially reluctant to invest in ND vaccination programs. This study's finding of increased vaccination uptake by households to whom questions about chicken ownership, management and consumption were posed on a regular basis supports the idea of awareness generating demand for vaccination.

As per the age-old "chicken or the egg" conundrum, linkages between vaccination and poultry flock size are confirmed to be bi-directional: vaccination leads to increased flock size, and larger flocks are more likely to be vaccinated. The real dilemma is how to encourage vaccination amongst households with fewer chickens and to support chicken-keepers to vaccinate regularly. One targeted program in Mozambique has involved the distribution of both chickens and ND vaccination vouchers to households affected by HIV/AIDS, allowing community vaccinators to collect payment for their service from two local non-governmental organisations during the first year of a newly introduced ND vaccination program [32]. Opportunities for a similar subsidised vaccination service for vulnerable households elsewhere in Africa, perhaps integrated with existing or future social welfare programs, warrants further exploration. Qualitative approaches to explore household decision-making around chicken health and management, allocation of income, and motivations, challenges and priorities of community vaccinators will be central to the identification and addressing of barriers to broader vaccination coverage.

Findings which link chicken flock size with households' socioeconomic status affirm the value of integrated approaches to poverty alleviation in efforts to enhance food and nutrition security. There is scope for greater economic and nutritional contributions of village chickens, but this may be accelerated when other strategies to increase the household income are in place. In the context of the broader interdisciplinary nutrition-sensitive program of which this study forms a part, the synergistic outcomes of improved crop production and poultry health are proposed to contribute to increased household income, less vulnerability to extreme weather events, greater willingness and capacity to invest in crop and poultry production and, ultimately, improved human nutrition outcomes.

Supporting information

S1 Table. Output from linear mixed model for mean chicken flock size in the period between one Newcastle disease vaccination campaign and the next.
(DOCX)

S2 Table. Output from generalised linear mixed model (binomial) for participation in a given Newcastle disease vaccination campaign.
(DOCX)

S3 Table. Output from generalised linear mixed model (Poisson distribution) for chicken flock size at the end of a twelve month period.
(DOCX)

S1 Dataset. Data used for analyses in this manuscript.
(XLSX)

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Chapter 5. Evaluating available data on the nutrient content of village chicken meat and eggs in sub-Saharan Africa

Chapter 5 reviews current food composition data resources available for use in Tanzania and across the sub-Saharan African region. It identifies a lack of locally-derived data on the nutrient content of animal-source foods, and discusses the limitations of borrowing data from geographically remote high-income countries, and from analyses conducted many decades previously.

As Newcastle disease vaccination programs support an increase in chicken flock sizes, households will be presented with greater opportunities to sell and consume poultry products. For sound recommendations about the inclusion of chicken meat and eggs in diets in resource-poor settings, accurate information which reflects locally-available resources is vital.

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Image 5. A tray of village chicken eggs awaiting preparation in a local restaurant in Ntope, Sanza Ward. In the absence of Newcastle disease control programs, poultry-keepers often prioritise the hatching of eggs to maintain chicken flock size in the face of regular disease outbreaks, and home consumption of these nutrient-rich food items is uncommon.

Photo credit: Julia de Bruyn, 2017.

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Food composition tables in resource-poor settings: exploring current limitations and opportunities, with a focus on animal-source foods in sub-Saharan Africa

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Abstract

Animal-source foods (ASF) have the potential to enhance the nutritional adequacy of cereal-based diets in low- and middle-income countries, through the provision of high-quality protein and bioavailable micronutrients. The development of guidelines for including ASF in local diets requires an understanding of the nutrient content of available resources. This article reviews food composition tables (FCT) used in sub-Saharan Africa, examining the spectrum of ASF reported and exploring data sources for each reference. Compositional data are shown to be derived from a small number of existing data sets from analyses conducted largely in high-income nations, often many decades previously. There are limitations in using such values, which represent the products of intensively raised animals of commercial breeds, as a reference in resource-poor settings where indigenous breed livestock are commonly reared in low-input production systems, on mineral-deficient soils and not receiving nutritionally balanced feed. The FCT examined also revealed a lack of data on the full spectrum of ASF, including offal and wild foods, which correspond to local food preferences and represent valuable dietary resources in food-deficient settings. Using poultry products as an example, comparisons are made between compositional data from three high-income nations, and potential implications of differences in the published values for micronutrients of public health significance, including Fe, folate and vitamin A, are discussed. It is important that those working on nutritional interventions and on developing dietary recommendations for resource-poor settings understand the limitations of current food composition data and that opportunities to improve existing resources are more actively explored and supported.

Key words: Food security: Under-nutrition: Animal-source foods: Food composition tables: Nutrition-sensitive interventions

Under-nutrition remains a pervasive issue of the current century, with profound implications for individual growth, development and survival, incidence of acute and chronic diseases, and national economic productivity and wealth[1]. The latest global estimates suggest 795 million people to be chronically under-nourished, with substantial geographic variation in progress towards international development goals[2]. The spectrum of nutrition-related disorders includes wasting, stunting and micro-nutrient deficiencies, with the prevalence of stunting being a critical indicator of progress in child survival, reflecting long-term exposure to suboptimal health and nutrition[3]. An increasing incidence of overweight, obesity and non-communicable diseases is also emerging in many low- and middle-income countries (LMIC), where the coexistence of under- and over-nutrition now occurs and is termed the 'double burden of malnutrition'[4].

There is an increasing focus on the role of nutrition-sensitive interventions, including food-based approaches, which use locally available and culturally acceptable products, to achieve sustainable improvements in human nutrition. Animal-source foods (ASF) are known to provide protein of high biological value and micronutrients such as Fe, Zn and vitamin B_{12} that are difficult or impossible to obtain in adequate amounts from

Abbreviations: ASF, animal-source food; FCT, food composition table; INFOODS, International Network on Food Data Systems; LMIC, low- and middle-income countries.

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plant-source foods alone[5,6]. Despite concern by some about the environmental and nutritional implications of increased ASF consumption predicted to accompany population and income growth, there is scope for ASF to enhance the nutrient adequacy of traditional diets based on cereals and tubers in resource-poor settings[5–8]. The inclusion of ASF in the diet has been shown to promote growth and improve cognitive function, physical activity and health[9–11], and among pregnant women it has been shown to support fetal growth and development and enhance maternal nutrition in preparation for lactation[12].

The development of meaningful food-based recommendations for dietary improvement relies on an assessment of existing diets, an understanding of the food resources accessible to a given population, the population's nutrient requirements and accurate data on the nutrient content of available food items[13]. Measurement error or incorrect assumptions occur at all stages of dietary assessment, including misreporting habitual food intakes, elevated nutrient requirements due to high levels of infection and errors in food composition data. In this article, we focus on systematic errors present in food composition databases that may result in incorrect estimations of dietary adequacy, especially in LMIC populations where the intakes of ASF are increasing[14]. The merits and limitations of various food security and nutrition indicators and their implications for understanding the nutritional status of individuals and communities[15] should be recognised, but are beyond the scope of this article.

Information on the macronutrient and micronutrient content of food items is used both to estimate the nutrient content of current diets and to formulate guidelines for increasing dietary adequacy. Food composition data are available through national and regional food composition tables (FCT) and, increasingly, in electronic formats. Although such resources have value in understanding the effects of diets on health, growth and development and devising diets for individuals and populations, their limitations need to be understood[16]. In a comparison of three different commonly used data sources of the macronutrient content of foods consumed in Uganda, Baingana[17] draws attention to the marked variation in results obtained, and contends that inappropriate food composition data have the potential to 'undermine or misdirect research or nutrition efforts'.

The International Network on Food Data Systems (INFOODS), led by the FAO, has been tasked with coordinating efforts to improve the quality of food composition data globally. Many LMIC currently lack capacity for nutrient analysis, which limits the availability of country-specific food composition data. It is among the aims of INFOODS to ensure that the large body of available food composition data is of sufficient quality to be combined with directly analysed values. To achieve this, the FAO[16] proposes ten criteria for a comprehensive food composition database. The data should be (1) representative, (2) of sound analytical quality, including comprehensive coverage of both (3) foods and (4) nutrients, with (5) clear food descriptions and (6) data should be presented in a consistent, unambiguous manner, (7) showing origins of data at a nutrient level, (8) in an easy-to-use format, which is (9) compatible with existing international standards and (10) has few missing data.

As biological materials, foods exhibit variations in composition. Differences in the nutrient content of a given item may be due to environmental conditions, crop variety or animal breed, stage of maturity, processing methods and cooking techniques[16,18]. In the case of ASF, the composition of products derived from intensively raised animals of commercial breeds may differ from those of indigenous livestock in resource-poor settings, which are typically reared in low-input production systems, sometimes on mineral-deficient soils and commonly not receiving balanced feed. A crucial shortfall of many national or regional food composition databases, including those released in recent years, is their reliance on a small number of existing data sets – often from more high-income nations and sometimes from analyses conducted decades previously.

This article reviews selected FCT currently in use within sub-Saharan Africa, first examining the spectrum of ASF reported and then considering the source of data for each item. Of criteria for reliable composition data proposed by the FAO[15], this study focuses primarily on whether databases are representative of national or regional diets and whether data may be considered of sound quality for the context in which they are intended to be used. Using poultry products as an example, comparisons are made between compositional data from three high-income nations, and the implications of using data from different sources are discussed. Focus is given to three micronutrients because their content in ASF items differed markedly between references: vitamin A, which is relevant because of the widespread occurrence of deficiency globally; vitamin B_{12}, found naturally only in ASF; and folate, which is of particular relevance to women of reproductive age because of its role in preventing neural tube defects during embryonic development in early pregnancy.

Methods

The FAO INFOODS directory provides details of available food composition data according to geographic location, as well as international databases. Many of the resources listed are no longer in print and are difficult to access. For the purposes of this analysis, national and regional food composition data for sub-Saharan Africa accessible online in the English language were examined. Databases meeting criteria for inclusion (in reverse chronological order of publication date, from 2012 to 1989) were as follows: *West African Food Composition Table*[19], *A Food Composition Table for Central and Eastern Uganda*[20], *Food Composition Table for Use in The Gambia*[21], *Food Composition Tables for Mozambique*[18], *Tanzania Food Composition Tables*[22], *Lesotho Food Composition Table*[23] and 'Nutritive value of foods of Zimbabwe'[24]. Data from the *Food Composition Table for Use in Africa*[25] were also reviewed, but owing to large sections of missing nutrient information they were deemed insufficiently complete for inclusion in the comparative analysis.

Lists of ASF were compiled from each of the selected databases. Meat and meat products, fish and shellfish, milk, eggs and insects were included in both raw and, where available, cooked or processed forms. FCT entries based on recipes that include ASF as an ingredient (e.g. 'fish relish with coconut milk') and commercially processed meat-based entries (e.g. sausages, canned tuna) were excluded from this analysis.

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ASF items from each reference were divided into seven categories: *meat flesh*, defined as skeletal muscle with any attached fat, connective tissue, nerves, vessels, blood and skin[26]; *offal* including blood, brain, heart, intestines, kidneys, pancreas, spleen, thymus, tongue and tripe, but excluding meat flesh, bone and bone marrow[26]; *other carcass components*, covering entries that include bone, such as chicken heads and feet; *fish and shellfish*; *milk*; *eggs*; and *insects*.

National food balance data corresponding to the year of publication of each database were collated for evaluating how effectively the range of ASF items matched the reported food supply[27]. In the absence of comprehensive national food consumption survey data, food balance sheets are recognised to provide guidance on the domestic availability of foods and their contribution to diets during FCT compilation[16]. Although the supply of an ASF category will not always be expected to correspond to the number of FCT entries (for example, milk might be widely consumed but represented in a small number of entries), comparisons have been made between the availability of food and its inclusion in FCT lists.

In a second aspect of the analysis, ASF entries were classified according to the data source for each food item, on the basis of types of compositional data as defined by Greenfield & Southgate[16]. These include *original analytical values*, derived from the published literature or unpublished laboratory reports based on valid methodology and local food items; *imputed values*, whereby data are estimated from analytical values for a similar food or for another form of the same food; *calculated values*, which apply accepted yield factors and nutrient retention factors for the relevant cooking methods to data from other sources; *borrowed data*, drawn from other tables or databases where reference to original sources may or may not be provided; and items of *unspecified* source.

Entries have been further categorised according to the region from which compositional data originated: Africa, the USA, the UK, Europe or Asia. For data borrowed from other FCT, the original sources have been consulted where possible, and it is indicated where this has not been possible. Many of the ASF items listed in the Gambian and West African databases have been compiled from multiple sources, and the degree to which each source has contributed to an entry is often not evident. In order to summarise the origins of data in these cases, all countries contributing to a database entry have been given equal weighting (e.g. 0·5 each if two data sources, 0·33 each if three data sources), and the total number of items from each region has been rounded to whole numbers.

On the basis of a predominance of data from UK and US sources, a third exercise was undertaken comparing nutrient content of selected poultry products in the most recent food composition databases from these two countries with a third data set, from Australia. Data were drawn from the UK's recently updated *McCance and Widdowson's: The Composition of Foods Integrated Dataset*[28], the 28th release of the United States Department of Agriculture National Nutrient Database[29] and the Australian Food, Supplement and Nutrient Database[30]. The three sets of published values for macronutrients and selected micronutrients (vitamin A, vitamin B_{12}, folate, vitamin E, Fe, Zn and Se) were compared per 100 g edible portion of light and dark chicken meat, chicken liver and whole chicken eggs, in their raw forms.

Results

Spectrum of animal-source foods

The databases examined varied substantially in the number of food items included. The comparatively more extensive FCT for West Africa and Central and Eastern Uganda contain 113 and 126 ASF entries, respectively, whereas the Gambian reference includes only thirteen. The Gambian database has a strong emphasis on local recipes and prepared dishes, and reports only a very limited number of individual food items. There is also a notable lack of detail in the description of food items in this reference, such as 'egg' and 'meat, boiled', both of unspecified livestock species.

Differences can be seen in the number and relative proportion of entries in the seven ASF categories in each of the databases, as outlined in Table 1a. Fish and shellfish constitute a substantially higher proportion of ASF in databases for The Gambia (69·2 %, *n* 9) and Mozambique (55·6 %, *n* 20), compared with Zimbabwe (5·6 %, *n* 3) and Lesotho (*n* 0). In Lesotho, the number of meat flesh entries is matched by the number of offal entries (both 35·3 %, *n* 18), whereas in all other databases there are two or more times more meat flesh than offal entries. Other carcass components, which include chicken heads and feet of chicken, cattle and small ruminants, are only found in the tables for Uganda (5·6 %, *n* 7) and Lesotho (7·8 %, *n* 4).

Table 2 presents national food balance data for ASF from the year of compilation of each database[27]. High reported levels of offal supply in Lesotho and Uganda (2·06 and 1·51 kg/capita per year, respectively) are matched by high numbers of offal FCT entries (*n* 18 and *n* 23, respectively), whereas the low reported offal supply in Mozambique and The Gambia (0·58 kg/capita per year for both) is also reflected in their national FCT databases (*n* 1 and *n* 0, respectively). Similar patterns are seen for fish and shellfish, where both the high per capita supply in West Africa and Uganda and the low supply in Lesotho and Zimbabwe are reflected in the number of related FCT entries.

The range of livestock species whose milk is included in the databases varies, from cattle only (Tanzania and The Gambia) to cattle and goats (Lesotho, Mozambique, Uganda and Zimbabwe) and cattle, goats and camels (West Africa). The majority of FCT provide data only for chicken eggs, with only two references including duck eggs (Lesotho and Mozambique) and one including turkey eggs (Lesotho). Insects including termites, locusts, crickets and caterpillars are found in four of the seven databases examined (Tanzania, Uganda, West Africa and Zimbabwe).

The preparation state of ASF entries is listed as the percentage of food items that were raw, cooked or processed in each FCT (Table 1b). The Zimbabwe database, the oldest reference consulted, includes a majority of food items in their raw form (72·2 %, *n* 39), whereas the newer references report a larger number of items in cooked or processed forms, most prominently in the Ugandan FCT (70·6 %, *n* 89). Databases were also examined for the breadth of animal species contributing to the

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Table 1. Animal-source food (ASF) entries in selected African food composition tables, by category, mode of preparation, animal type, nature of data and origin of data
(Number and percentage of total ASF entries)

	Uganda		West Africa		The Gambia		Mozambique		Tanzania		Lesotho		Zimbabwe	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
(a) ASF categories														
Meat flesh	49	38·9	42	37·2	2	15·4	10	27·8	10	30·3	18	35·3	30	55·6
Offal	23	18·3	14	12·4	0		1	2·8	5	15·2	18	35·3	10	18·5
Other carcass components	7	5·6	0		0		0		0		4	7·8	0	
Fish and shellfish	31	24·6	45	39·8	9	69·2	20	55·6	11	33·3	0		3	5·6
Milk	3	2·4	5	4·4	1	7·7	3	8·3	1	3·0	4	7·8	4	7·4
Eggs	7	5·6	3	2·7	1	7·7	2	5·6	4	12·1	7	13·7	3	5·6
Insects	6	4·8	4	3·5	0		0		2	6·1	0		4	7·4
(b) Preparation														
Raw	37	29·4	43	38·1	6	46·2	24	66·7	17	51·5	27	52·9	39	72·2
Cooked, dried or processed	89	70·6	70	61·9	7	53·8	12	33·3	16	48·5	24	47·1	15	27·8
(c) Animal type														
Domestic livestock	89	70·6	61	54·0	4	30·8	15	41·7	20	60·6	51	100	46	85·2
Fish, shellfish	31	24·6	45	39·8	9	69·2	20	55·6	11	33·3	0		3	5·6
Wild foods	6	4·8	7	6·2	0		1	2·8	2	6·1	0		5	9·3
(d) Nature of data														
Original analysis	0		0		0		4	11·1	0		0		0	
Imputed	39	31·0	0		2	15·4*	0		0		0		0	
Calculated	0		65	57·5*	0		8	22·2	0		5	9·8	0	
Borrowed	87	69·0	47	41·6*	11	84·6*	24	66·7	0		45	88·2	0	
Not specified	0		1	0·9	0		0		33	100	1	2·0	54	100
(e) Origin of data														
Africa	6	4·8	24	21·2†	0		15	41·7‡	0		23	45·1§	0	
USA	112	88·9	35	31·1	0		15	41·7	0		18	35·3	0	
UK	0		9	8·1	4	30·8	1	2·8	0		4	7·8	0	
Europe	0		28	24·5	0		0		0		0		0	
Asia	8	6·3	10	8·8	0		0		0		0		0	
Unknown	0		7	6·2	9	69·2‖	5	13·9	33	100	6	11·8	54	100
Total ASF entries	126		113		13		36		33		51		54	

* Multiple data sources for each item.
†‡§ Data from South African databases; original source unable to be traced († 8/24, ‡ 7/15 and § 23/23).
‖ 7/9 Entries include data on Ca, P and Zn contents from The Gambia.

Table 2. National food balance data for animal-source foods (ASF) in selected African countries, corresponding to the year of food composition table publication[34]

	National food balance (kg/capita per year)					
ASF category	Uganda*	The Gambia	Mozambique	Tanzania	Lesotho	Zimbabwe
Meat flesh	12·55	8·65	8·23	8·84	23·2	11·87
Offal	1·51	0·58	0·58	1·14	2·06	1·31
Fish and shellfish	12·95	26·51	8·47	5·09	0·52	2·4
Milk	31·34	59·44	3·12	20·91	16·01	30·37
Eggs	0·97	0·58	1·28	0·67	0·52	1·22

* Food balance data not available for 2012; data for 2011 was used instead.

ASF listed, as presented in Table 1c. Of particular interest was the inclusion of products from non-domesticated animals. No such items are found in resources from The Gambia and Lesotho, but other references, in addition to the aforementioned invertebrates, include entries for rodent (Mozambique), antelope (Mozambique), crocodile (West Africa) and an unspecified 'game animal' (West Africa).

Sources of data

The databases varied in their inclusion of details on the origins of published data, including sampling methodology, analytical techniques and the source of borrowed nutrient values; five of the seven tables (those of Lesotho, Mozambique, The Gambia, Uganda and West Africa) provided an indication of the data source for individual food entries, whereas the remaining two (for Tanzania and Zimbabwe) provided only general information about the data compilation process and a list of references used.

In the Ugandan database, 69·0 % (*n* 87) of the ASF entries have been borrowed directly from other databases, and the remainder have been calculated by applying conversion factors to borrowed values for food items in their raw form, to reflect changes in moisture content and nutrient losses due to cooking. Of all ASF entries, 88·9 % (*n* 112) are from the USA. In the West African FCT, directly-borrowed values constitute 41·6 % (*n* 47) and calculated values constitute 57·5 % (n 65) of all compositional data. Sources of data are given at the nutrient level, with a majority of ASF entries having been compiled from multiple sources. Approximately 31·1 % of data were derived from the USA, 24·5 % from European sources and 21·2 % from within the African continent. ASF entries in the Gambian database also include those composed of multiple data sources. Of the limited number of ASF reported (n 13), the vast majority are borrowed (84·6 %, n 11), with relatively balanced input from British databases, Gambian literature sources and Platt's 1962 reference for foods 'commonly used in tropical countries'[31]. Data sources for this last reference are not readily available, but are indicated to include a combination of primary analysis, published literature and alternative international databases. The Lesotho database identifies six of its total 283 entries to have been analysed directly, none of them ASF. This reference also has a strong reliance on data from alternative databases (88·2 %, n 45), with a predominance of ASF entries coming from South African (45·1 %, n 23) and US (35·3 %, n 18) references.

The Mozambique FCT is the only database examined to include ASF data from primary analysis of local foods (11·1 %, n 4). Dried forms of four species of fish (*pendhe*, *mirosse*, *sarabuanha* and *madambane*) were sourced from Mozambican markets in December 2008 and transported to Finland for analysis. A further four entries in the database have been calculated using these values.

The Tanzanian FCT does not report the sources of data for individual food items. The reference was developed using the World Food Dietary Assessment System, whereby information is imported from a series of six databases, considered representative of foods consumed in developing countries. The Kenyan database, which serves as the primary source for the Tanzanian FCT, uses nutrient values from references published in the 1960s[25,31]. Additional food items have been imported from databases from Egypt, India, Indonesia, Mexico and Senegal, as well as from US, UK and South African sources. There is no mention of data from in-country analysis.

Comparison of nutrient content for poultry products

Compositional data from the UK[28], USA[29] and Australia[30] were reviewed for selected poultry products. Differences were noted in the listing of food items in raw or cooked forms, the differentiation of various meat components of a carcass and, importantly, the inclusion of skin or fat. Table 3 details published values for proximates and selected micronutrients (vitamin A, vitamin B_{12}, folate, vitamin E, Fe, Zn and Se) in raw forms of dark and light chicken meat, chicken liver and whole eggs.

Beyond the expected variability between results of any two analyses, prominent and inconsistent differences were noted in a number of nutrients. Vitamin A levels in chicken liver varied widely between references, with retinol activity equivalents ranging from 3296 μg in the US database, to 9700 μg in the UK and to 12 007 μg in Australia. Variation was also seen in folate content of liver, with the UK and Australian references reporting levels 1·7 and 2·5 times higher than the US reference value, respectively. Vitamin B_{12} levels also varied across databases with the content in eggs reported to be 1·5 times higher in Australia and three times higher in the UK, compared with US values. In chicken liver, Australia- and US-reported levels of vitamin B_{12} were equivalent but less than half of the levels in the UK reference.

The implications of reported differences in nutrient content may be considered in terms of their contribution to an individual's daily requirements. Reference nutrient intakes (RNI) for vitamin A, vitamin B_{12} and folate[32] have been used to determine the contribution of a whole hard-boiled chicken egg to daily nutrient targets for people of various ages and physiological states, as presented in Table 4. Some figures are less relevant in a practical sense, but considerable variation can be seen in calculations using different data sources. US data indicate that a single egg would provide 20·5 % of the daily vitamin A requirements of a child aged 1–3 years, compared with 5·4 % using Australian data. For a pregnant woman, an egg represents 15·2 % of the RNI for folate using Australia-reported values, compared with 5·5 % according to the British database.

Table 5 presents the required intake of fried chicken liver to meet RNI for these same three nutrients. Although not recommended for pregnant women in countries where vitamin A intakes commonly exceed RNI because of concerns about potential teratogenic effects, liver represents a rich dietary source of vitamin A in resource-poor settings. Consumption of a single fried chicken liver (approximately 42 g[33]) would meet the vitamin A requirements of a child aged 1–3 years for 13 d based on Australian reference values, compared with 4 d using US data. A breast-feeding mother's daily folate needs are reported to be contained in 17 g of liver in Australia and 45 g in the USA.

Discussion

Among the objectives of compiling national or regional FCT is the creation of reliable resources to meet the needs of users, which might include 'government agencies, nutrition scientists, health and agriculture professionals, policymakers and planners, food producers, processors, retailers and consumers'[34]. In the international development arena, such tools are of particular value to those involved in programmes seeking food-based solutions to nutritional challenges. To assess the validity of existing references and establish their role in guiding efforts to improve food and nutrition security, this article considers (a) whether databases reflect the spectrum of foods consumed within a given country or region, (b) whether the origins of published data and details of the foods analysed make them appropriate for use in the intended area and (c) the reliability of original data sources.

Patterns in ASF consumption change over time, according to availability, access and a broad range of socio-economic and cultural factors. Short-term variation in diets may be seen between seasons, as well as longer-term variation according to climatic factors. Rigorous approaches to understanding diets, which consider the impact of seasons, agro-ecological zones, sex and socio-cultural factors, should underpin any national or regional food composition database. Introductory remarks to

Table 3. Published values from the UK, US and Australian food composition databases for selected nutrients in raw poultry products, per 100 g edible portion

		Food composition table		
	Units	UK	USA	Australia
(a) Whole egg, chicken (raw)		*Ref. 12-937*	*Ref. 01123*	*Ref. 03A10075*
Water	g	76·8	76·2	76·1
Energy	kJ	547	599	533
Protein	g	12·6	12·6	12·6
Lipids, total	g	9·0	9·5	8·5
Carbohydrates	g	Trace	0·7	0·3
Vitamin A, RAE	µg	126	160	130
Vitamin B_{12}	µg	2·7	0·9	1·4
Folate, DFE	µg	47	47	110
Vitamin E	µg	1·3	1·1	2·2
Fe	mg	1·7	1·8	1·9
Zn	mg	1·1	1·3	1·1
Se	µg	23	31	26
(b) Chicken liver (raw)		*Ref. 18-411*	*Ref. 05027*	*Ref. 08D10194*
Water	g	76	76	75
Energy	kJ	386	496	466
Protein	g	17·7	16·9	16·9
Lipids, total	g	2·3	4·8	4·8
Carbohydrates	g	Trace	1	0
Vitamin A, RAE	µg	9700	3296	12 007
Vitamin B_{12}	µg	35·0	16·6	16·6
Folate, DFE	µg	995	588	1450
Vitamin E	µg	0·6	0·7	0·4
Fe	mg	9·2	9·0	9·8
Zn	mg	3·7	2·7	3·6
Se	µg		54·6	54·6
(c) Chicken, light meat (raw)		*Ref. 18-290*	*Ref. 05039*	*Ref. 08C10431*
Water	g	74	75	75
Energy	kJ	449	477	438
Protein	g	24	23	22
Lipids, total	g	1·1	1·7	1·6
Carbohydrates	g	0	0	0
Vitamin A, RAE	µg	Trace	27	8
Vitamin B_{12}	µg	Trace	0·4	0·7
Folate, DFE	µg	14	4	0
Vitamin E	µg	0·1	0·2	2·2
Fe	mg	0·5	0·7	0·4
Zn	mg	0·7	1·0	0·7
Se	µg	12	18	25
(d) Chicken, dark meat (raw)		*Ref. 18-289*	*Ref. 05043*	*Ref. 08C10435*
Water	g	76	76	75
Energy	kJ	459	523	496
Protein	g	21	20	18
Lipids, total	g	3	4	5
Carbohydrates	g	0	0	0
Vitamin A, RAE	µg	20	22	19
Vitamin B_{12}	µg	1·0	0·4	0·7
Folate, DFE	µg	9	10	14
Vitamin E	µg	0·2	0·2	0·6
Fe	mg	0·8	1·0	0·7
Zn	mg	1·7	2·0	1·5
Se	µg	14	14	20

Ref., reference code within database; RAE, retinol activity equivalents; DFE, dietary folate equivalents.

many of the FCT express an intention to present resources that represent local diets. The Gambian database reports an effort to cover foods typically consumed in rural areas, although the focus is on dishes (as prepared by the country's predominant linguistic group, the Mandinka) rather than individual ingredients. The Ugandan resource, developed during a Consultative Group on International Agricultural Research project, includes all food items captured from two dietary intake surveys of women and children aged 6 months to 7 years, from three districts in the country's Central and Eastern regions. Approaches to compiling food lists in other databases are less explicitly described. Although some similarities can be seen between national food supply data and the spectrum of food items in the FCT reviewed, it is unclear whether differences between databases reflect true differences in the types of foods consumed in various African countries.

Table 4. Contribution of a 55-g, hard-boiled, whole chicken egg to reference nutrient intake (RNI, daily amount required to meet needs of 97·5 % of population) for vitamin A, vitamin B_{12} and folate

		% Contribution of one egg to RNI		
	RNI[31] (μg/d)	UK (*Ref. 12-940*)	USA (*Ref. 01129*)	Australia (*Ref. 03A10062*)
(a) Vitamin A				
Child (1–3 years)	400	16·5	20·5	5·4
Female (15–50 years)	600	11·0	13·7	3·6
Pregnant female (15–50 years)	700	9·4	11·7	3·1
Breast-feeding female (15–50 years)	950	6·9	8·6	2·3
(b) Vitamin B_{12}				
Child (1–3 years)	0·5	220·0	122·1	154·0
Female (15–50 years)	1·5	73·3	40·7	51·3
Pregnant female (15–50 years)	1·5	73·3	40·7	51·3
Breast-feeding female (15–50 years)	2·0	55·0	30·5	38·5
(c) Folate				
Child (1–3 years)	70	23·6	34·6	65·2
Female (15–50 years)	200	8·3	12·1	22·8
Pregnant female (15–50 years)	300	5·5	8·1	15·2
Breast-feeding female (15–50 years)	260	6·3	9·3	17·6

Ref., reference code within database.

Table 5. Contribution of fried chicken liver to reference nutrient intake (RNI, daily amount required to meet needs of 97·5 % of population) for vitamin A, vitamin B_{12} and folate

		Required intake (g) to meet RNI		
	RNI[31] (μg/d)	UK (*Ref. 18-412*)	USA (*Ref. 05661*)	Australia (*Ref. 08D10161*)
(a) Vitamin A				
Child (1–3 years)	400	3·8	10·1	3·1
Female (15–50 years)	600	5·7	15·1	4·6
Pregnant female (15–50 years)	700	6·7	17·6	5·4
Breast-feeding female (15–50 years)	950	9·1	23·9	7·3
(b) Vitamin B_{12}				
Child (1–3 years)	0·5	1·1	2·4	2·9
Female (15–50 years)	1·5	3·3	7·1	8·8
Pregnant female (15–50 years)	1·5	3·3	7·1	8·8
Breast-feeding female (15–50 years)	2·0	4·4	9·5	11·8
(c) Folate				
Child (1–3 years)	70	5·2	12·1	4·6
Female (15–50 years)	200	14·8	34·6	13·1
Pregnant female (15–50 years)	300	22·2	51·9	19·6
Breast-feeding female (15–50 years)	260	19·3	45·0	17·0

Ref., reference code within database.

There is a paucity of published data on the range of ASF consumed by African populations, including the breadth of carcass components eaten and the use of products from animals other than domestic livestock. Patterns of offal consumption vary with availability, cost, cultural beliefs, socio-economic attitudes and nutritional knowledge[35]. Although studies from Somalia suggest that many forms of offal are considered inferior meat because of their lower cost and are mainly consumed by women (with the exception of kidney and liver, which have an equivalent cost to muscle meat and are principally eaten by men), offal is reported to be widely consumed and considered both palatable and culturally acceptable[35]. With liver identified as among the best local food sources to improve dietary quality of young children[36,37], there would be great advantage in broadening the range of micronutrient-rich organ meats in FCT to allow their inclusion in dietary recommendations in LMIC.

There has been some interest in the relative importance and nutrient content of edible indigenous plants in supplementing cereal-based diets of rural populations in Africa[38,39]; however, there remains much less reference in the published literature to the consumption of wild foods of animal origin. Although inter-country differences may exist in their availability and cultural acceptability, non-domesticated animals and insects contribute to nutrition security in many resource-poor settings. The harvest of wildlife provides a valuable source of meat for hundreds of millions of rural people living in poverty, often protecting against chronic under-nutrition where alternative sources of ASF are scarce or prohibitively expensive[40,41]. Insects have been an important wild source of protein and other macronutrients and micronutrients for thousands of years, particularly in remote rural areas and in tropical countries with high biodiversity[42], and are the focus of current attention as an environmentally sustainable and nutritious complement to traditional protein sources[43].

Projects seeking to document the food resources accessible by a given population have revealed great diversity in the range of items consumed throughout the year. An ethno-biological inventory of foods in Baringo District, Kenya, identified 226 edible species (thirty-eight ASF)[44] and studies in Lusaka Province, Zambia, found 171 wild food species (eighty-seven ASF) that contribute to local diets[45]. Such findings have been generated from focus group discussions and interviews with community members to develop food lists in local languages, understand seasonal availability and food preparation methods, and working with national research institutions or museums to determine the scientific names and classifications of the food items identified[44,45]. Among the seven databases examined in this article, there is substantial variation in the inclusion of non-domesticated animals and insects. The Mozambican reference includes a single, wild ASF entry (rodent), whereas the West African reference provides data on caterpillars, locusts, winged ants and crickets. A lack of nutrient compositional data on the full spectrum of ASF from which a food-insecure household might benefit is a limitation of several references, as well as restricts the potential for knowledge of available food resources to be translated into guidelines for dietary improvement.

Despite the INFOODS programme's strong focus on improving the quality, availability, reliability and use of food composition data globally, it remains evident that a majority of compositional data – including data published in recently released regional and national references – is drawn from other databases in geographically distant locations. Details of the source of data are sometimes lacking, and it is not always clear whether values are original data or borrowed or imputed from other sources. Of the FCT examined, only one included any original analysis of local ASF items and a large amount of data has been derived from outside Africa, and overwhelmingly from the USA. A lack of funding has consistently been highlighted by the INFOODS African Regional Data Centre (AFROFOODS) as the major obstacle for generating original analytical data[46]. The resulting reliance on existing references is evident in the 2010 Tanzanian FCT, based largely on databases compiled in the 1960s[25,30] despite national capacity for nutrient analysis at institutions such as Sokoine University of Agriculture, the Tanzania Food and Nutrition Centre, Tanzania Veterinary Laboratory Agency and Tanzania Food and Drug Authority.

Even when original analytical and sampling methods are sound, this practice of 'data recycling' overlooks the potential for significant variation in the nutrient content of food items of both plant and animal origin. Introductory notes accompanying the UK database suggest the major source of variation in meat composition to be differing fat content, both as a result of husbandry and food preparation techniques[27]. Most nutrients are said to be affected, due to differences in their distribution in lean meat and associated fat. Elsewhere, genetic strain has been identified as a crucial factor affecting meat quality[47,48]. Such observations affirm the limitations of applying international reference data to indigenous breed livestock raised in low-input systems in resource-poor settings.

Taking chickens as an example, marked physical differences are evident between local breed poultry raised in small free-ranging flocks in rural African communities, typically largely or wholly reliant on environmental feed sources, and those of genetic lines selected for rapid growth and high feed conversion ratios, reared on balanced feed rations in commercial production systems. Among commercial poultry producers, it is recognised that nutrient requirements differ significantly between broiler (meat-producing) and layer (egg-producing) birds and between different stages of the life cycle[49]. Scavenging village chickens may achieve a balanced diet under some conditions, eating crop residues after the harvest and fresh plant material, insects, worms and molluscs during the wet season. In areas with unimodal, irregular or limited rainfall, however, there are likely to be times of environmental food shortage during the dry season, when birds are at risk of inadequate nutrition[50].

Documented changes in the carcass composition and yield of commercial breed chickens over time have been attributed to genetic selection[51], confinement of domestic livestock and provision of high-energy feed[52]. Although poultry has historically been regarded as a lean option compared with red meat[53], the modern broiler chicken has been reported to provide several times more energy from fat than from protein and contains a ratio of n-6:n-3 fatty acids of as high as 9:1 – a shift away from the lower ratio advised for decreasing the risk of CHD[54].

Interest in the impact of livestock production systems on the nutrient content of food products has grown in recent years, as consumer concerns about welfare standards have prompted a shift away from traditional battery cages for hens and indoor housing of pigs towards free-range systems. The effect on nutrient levels remains unresolved, with some studies showing no significant differences[55,56] and others attributing variation to diet[57]. In the case of eggs, such studies have focused on cholesterol and PUFA levels, and not on other micronutrients of public health significance. As for any food, variation in water content is a major determinant of the nutrient density of eggs and relates to both the ratio of yolk:white and the solids content of each component[16,58]. Evaluation of the effect of egg size, hen age and genetic strain on solid content has shown smaller eggs and older hens to be associated with a higher solid content[58]. This might appear to be a favourable finding for the nutrient density of village chickens' eggs, typically smaller and produced by older hens than their commercial counterparts; however, the absence of published data on the nutrient content of poultry products from resource-poor settings remains a major gap.

Also of concern is the variation that exists between compositional data from developed nations, including in micronutrients of public health significance. As databases continue to be revised and updated, individual entries are often comprised of compositional data from multiple analyses conducted years or decades apart. Data on the vitamin A content of raw chicken liver are based on analyses from the early 1980s, 2003 and 2005 for the UK, US and Australian references, respectively. Details of analytical techniques are found in general comments accompanying each database, and suggest no methodological reason for a 3·5-fold difference between US and Australian values. The apparent disparity between nutrient levels in the products of commercially reared chickens from different nations – of similar genetic lines, each receiving feed intended to meet nutritional requirements while minimising excessive nutrient excretion – further highlights the variability that might be expected in the nutrient content of scavenging chickens in resource-poor settings.

Calculations to determine the required daily intake of ASF items to meet specific nutrient requirements may appear to undermine the significance of data variability – for example, when considering the difference between a 7 and 24-g portion of chicken liver to meet a breast-feeding mother's daily vitamin A requirements (using Australian and US references, respectively; Table 4). The equivalent vitamin A intake from plant-based sources would equate to over 700 g of fresh papaya[27], almost 150 g of cooked spinach[27] or approximately 220 g of boiled orange-fleshed sweet potato[20]. In this context, where intakes of vitamin A are marginal or low and even small portions of ASF have the potential to meet an individual's requirements, 2–3-fold differences in compositional data become more relevant. The value of reliable data on locally available resources should not be underestimated.

Conclusion

Access to current, relevant and reliable data on the nutrient content of food items is fundamental for those working to implement sustainable responses to global food and nutrition security challenges. In the African region, several databases released in recent years provide readily accessible sources of compositional data. There are significant limitations, however, when these references do not reflect the full range of food items that might be consumed by members of a food-insecure household, including invertebrates, non-domestic animals, offal and other carcass components, as well as indigenous and non-cultivated plants. New references rarely provide new data, and the volume of information 'recycled' from other databases, which are often from analyses conducted decades previously and sourced from high-income countries, limits their usefulness. In the case of ASF, it is important to acknowledge the variation in the nutrient content likely to be associated with differences in livestock breeds, management systems, diet, seasons and environments. Less recognised is the variation that exists between the nutrient content of equivalent ASF items reported in databases of high-income nations, and the implications for borrowing data from one reference over another.

It is clear that limitations of FCT are not restricted to resource-poor settings. There are global efforts to standardise and harmonise food composition data, including work coordinated by the European Food Information Resource association and the FAO to establish protocols and improve data quality and database searchability[59]. Together with strong partnerships between research institutions, industry bodies and disciplinary areas, these efforts may enable existing data from LMIC (e.g. generated by universities or animal feed companies) to be assessed for quality and integrated into national or regional databases. Research and development projects that use food-based approaches might also be encouraged to undertake analysis of local items of interest, with a view of incremental expansion of national databases.

The INFOODS programme and its regional data centres have done much to raise the profile of FCT activities and support capacity-building through training courses and institutional collaborations; however, there remains a strong need for funding – both through the support of donor agencies and commitment from national governments – to generate new location-specific compositional data. Accurate information on the nutrient content of locally available food items will better guide work in nutrition-sensitive and cost-efficient interventions and enable the development of meaningful guidelines for improving dietary adequacy.

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Chapter 6.
Characterising infant and young child feeding practices and the consumption of chicken meat and eggs

Chapter 6 presents a mixed-methods evaluation of infant and young child feeding practices in the Tanzanian study sites. It integrates sample-wide survey data with targeted in-depth interviews to identify early initiation of complementary feeding as a widespread practice, principally motivated by mothers' perceptions of insufficient breast milk. A novel approach has been used to document the consumption of a target food (chicken meat and eggs) by a target group (women and young children) in a low-literacy setting.

Fundamental to any attempt to influence dietary or caregiving practices is an understanding of existing behaviours, including motivations, priorities and barriers to change. In this study, chicken meat and eggs were infrequently eaten, but close associations between maternal and child consumption patterns suggest the potential for strategies that increase access to these products at a household level to bring nutritional benefits to children.

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Image 6. A woman from the Gogo language group with her twin daughters and younger child, in the remote Chikuyu Bubu subvillage in Sanza Ward, close to the escarpment which forms the western border of the Rift Valley. *Kigogo* is the predominant language spoken in the study communities (including by 76.3% of enrolled households).

Photo credit: Julia de Bruyn, 2017.

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ORIGINAL ARTICLE

Characterising infant and young child feeding practices and the consumption of poultry products in rural Tanzania: A mixed methods approach

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Abstract

Suboptimal breastfeeding practices, early initiation of complementary feeding, and monotonous cereal-based diets have been implicated as contributors to continuing high rates of child undernutrition in sub-Saharan Africa. Nutrition-sensitive interventions, including agricultural programs that increase access to nutrient-rich vegetables, legumes, and animal-source foods, have the potential to achieve sustainable improvements in children's diets. In the quest to evaluate the efficacy of such programs in improving growth and development in the first 2 years of life, there is a role for mixed methods research to better understand existing infant and young child feeding practices. This analysis forms part of a longitudinal study assessing the impact of improvements to poultry health and crop production on diets and growth of 503 randomly selected children from eight rural communities in Manyoni District in central Tanzania. Using an explanatory sequential design, the quantitative phase of data collection was conducted between May 2014 and May 2016, comprising six monthly structured questionnaires, four monthly household-level documentation of chicken and egg consumption, and fortnightly records of children's breastfeeding status. The subsequent qualitative phase involved in-depth interviews with a subset of 39 mothers in October 2016. Breastfeeding was almost universal (96.8%) and of long duration (mean = 21.7 months, *SD* = 3.6), but early initiation of complementary feeding was also common (74.4%; mean = 4.0 months, *SD* = 1.8), overwhelmingly driven by maternal perceptions of insufficient milk supply (95.0%). Chicken and eggs were infrequently eaten, but close associations between maternal and child consumption patterns ($p < .001$) suggest the potential for strategies that increase household-level consumption to bring nutritional benefits to young children.

KEYWORDS

breastfeeding, complementary feeding, cultural context, infant and child nutrition, infant feeding decisions, low income countries animal-source food

1 | INTRODUCTION

With suboptimal breastfeeding estimated to contribute to over 800,000 child deaths annually (Black et al., 2013), exclusive breastfeeding to 6 months of age has been heralded as one of the most effective interventions to prevent child mortality (Jones, Steketee, Black, Bhutta, & Morris, 2003). This is not yet widely practised in many countries, including in Tanzania where the median duration of exclusive breastfeeding at a national level is reported to be 3 months (Ministry of Health, Community Development, Gender, Elderly and

Acronyms: ASF, animal-source foods; HAZ, height-for-age *z*-score; IYCF, infant and young child feeding; WHO, World Health Organization

Children, Ministry of Health, National Bureau of Statistics, Office of the Chief Government Statistician and ICF, 2016). Perceived insufficient milk supply has been identified as the most common reason for the early initiation of complementary feeding, across diverse socio-economic, cultural, and geographic settings (Dettwyler & Fishman, 1992; Gussler & Briesemeister, 1980; Sacco, Caulfield, Gittelsohn, & Martínez, 2006). Factors implicated in this phenomenon include infant crying (Dettwyler & Fishman, 1992; Segura-Millan, Dewey, & Perez-Escamilla, 1994; Tully & Dewey, 1985), low maternal confidence in breastfeeding ability (Buxton et al., 1991), inadequate breastfeeding knowledge and technique (Hill & Aldag, 1991; Segura-Millan et al., 1994), the availability and marketing of infant formula (Greiner, van Esterik, & Latham, 1981) and, in some contexts, insufficient contact between mothers and infants (Gussler & Briesemeister, 1980). The need for public health interventions that provide women with information about lactogenesis, interpretation of infant behaviours such as crying, and strategies to respond to common breastfeeding problems has been noted (Arts et al., 2011; Segura-Millan et al., 1994).

Beyond 6 months, it is recommended that infants receive safe and nutritionally adequate complementary foods, with continued breastfeeding to 2 years of age or above (WHO, 2002). Monotonous cereal-based diets and infrequent consumption of nutrient-rich vegetables, legumes, and animal-source foods (ASF) place many children in low- and middle-income countries at risk of stunting (low height for age) and micronutrient deficiencies. Analysis of national survey data from Tanzania has revealed only 15.9% of breastfed children 6–23 months of age to meet the requirements for minimum dietary diversity, meal frequency, and acceptable diet (Victor, Baines, Agho, & Dibley, 2014). Consumption of ASF has been shown to promote growth, improved cognitive function, physical activity, and health (Black, 2003; Iannotti et al., 2017; Neumann, Murphy, Gewa, Grillenberger, & Bwibo, 2007), yet despite a ratio of one food-producing animal for every human in Africa (Turk, 2013), inclusion of ASF in local diets remains limited. Programs that promote health and reduce mortality among livestock have the potential to generate income and improve human diets; however, it is important to recognise that the effects of such programs may be unevenly felt across a community, where decisions around income allocation and household diets reflect social, cultural, and economic influences.

This mixed methods study of infant and young child feeding (IYCF) practices is nested within a cluster randomised controlled trial assessing whether community-based vaccination programs against Newcastle disease in village chickens and improvements to crop diversity, cultivation, and storage practices improve height-for-age *z*-scores (HAZ) in young children in rural Tanzania and Zambia (Alders et al., 2014). Newcastle disease is a viral disease of poultry, responsible for the loss of economic livelihood and a potential source of nutrition in many low- and middle-income countries (Alders, 2014). Periodic outbreaks result in high mortality among free-ranging chicken flocks and serve as a disincentive for the investment of time or resources in village chickens and a barrier to the consumption of poultry products. In addressing constraints to poultry and crop production, this trial aims to measure the impact of agricultural interventions on the diets and growth of children.

Within the context of this integrated nutrition program, the present study seeks to better understand child feeding practices with the aim of identifying both current barriers and mechanisms for change. Effective behaviour change interventions for nutrition programs in low- and middle-income countries have been identified to have two key determinants: thoughtful formative research to develop and implement interventions and a hypothesis of impact pathways and relevant behaviour outcomes (Fabrizio, van Liere, & Pelto, 2014). Key objectives were to determine the timing of initiation of complementary feeding and weaning, explore reasons for discontinuation of exclusive breastfeeding prior to 6 months, and characterise existing infant and young child diets, with a specific focus on the consumption of poultry products.

Key messages

- Maternal perception of insufficient milk was the predominant driver for initiating complementary feeding before 6 months of age.
- Poultry products were infrequently eaten, but longitudinal analyses indicated a close association between dietary patterns of mothers and their young children, and no evidence of gender-based customs regarding egg consumption by children.
- Participant-completed pictorial dietary records, providing seasonal data on chicken and egg consumption, were effective in this low-literacy setting but relied on support from trained Community Assistants.
- Investing time and multi-disciplinary research skills to conduct mixed methods assessments of diets and child feeding is central to understanding and addressing nutritional challenges.

2 | METHODS

2.1 | Study area and population

This paper presents longitudinal findings from a study of 503 children from eight rural villages in Sanza and Majiri Wards, Manyoni District, Singida Region, in the semi-arid central zone of Tanzania. Project sites were selected in consultation with government partners at national, regional, and district levels, guided by the prevalence of childhood stunting and the absence of existing nutritional interventions. One third (34%) of Tanzanian children under the age of 5 years were reported as stunted in the most recent national survey (i.e., HAZ greater than two standard deviations below the median of the WHO, 2006, reference population), with a regional stunting prevalence of 29% in Singida and 37% in the adjacent Dodoma Region (Ministry of Health, Community Development, Gender, Elderly and Children et al., 2016).

Ninety-seven per cent of rural households in Tanzania cultivate crops, with combined agricultural activities (crop, livestock, and labour) estimated to generate 70% of income (Covarrubias, Nsiima, & Zezza, 2012). Agriculture in Tanzania is predominantly rain fed and consequently is highly susceptible to adverse weather patterns (Kubik & Maurel, 2016). A unimodal pattern of rainfall is seen in the study area, with long-term mean annual rainfall of 624 mm and a mean of 49 rain days reported at a district level (Lema & Majule, 2009). Based on daily records from a centrally located rain gauge in each of the two study sites, rainfall during the first of two wet seasons in the period of data collection was particularly poor, with 447 mm (30 rain days) received in Sanza Ward and 275 mm (21 days) in Majiri Ward.

Following a community-wide census, lists were compiled of households that met the eligibility criteria of including a child under 24 months of age, currently keeping chickens or having expressed an interest in keeping chickens and intending to reside within the area for the duration of the study. Sample size calculation for the cluster randomised controlled trial involving 20 communities (of which this study evaluates findings from eight) was based on an estimated baseline stunting rate of 35% with an aim of reducing this to 25% by the end of the project (i.e., a 10% reduction), giving 80% power to detect this difference as being significant at the two-sided 5% level, assuming an intracluster correlation coefficient of .014.

Two-stage sampling was used to first enrol all eligible households with children under 12 months of age and then enrol additional households with children aged 12–24 months using random selection to give 240 households in Sanza Ward and 280 households in Majiri Ward. Baseline data collection was completed for 229 households in Sanza Ward in May 2014 and 274 households in Majiri Ward in November 2014, as part of the staged implementation within the larger project design, with follow-up data collected at six monthly intervals to May 2016 (Figure 1).

2.2 | Quantitative data sources

Male and female enumerators were recruited from the community and trained to administer a coded structured questionnaire to mothers of children enrolled in the study. This questionnaire was developed from the Demographic and Health Survey, applied in Tanzania most recently in 2015 (Ministry of Health, Community Development, Gender, Elderly and Children et al., 2016). Questions covered the timing of initiation of breastfeeding, prelacteal feeding, the timing and nature of complementary feeding, reasons for introduction of complementary foods before 6 months of age, and total duration of breastfeeding. Information was also collected on mothers' participation in formal education, employment and relationship status, water access, and sanitation facilities. Printed survey questions and training sessions were in Swahili, with enumerators encouraged to make use of local languages where appropriate to aid in communication. This questionnaire formed part of the baseline data collection and was applied in an abridged form at six monthly intervals until May 2016, to collate longitudinal information on child feeding practices (Figure 1).

Child length or height measurements were also taken every 6 months to May 2016. Measurements were performed by trained personnel from the Ministry of Health and recorded to the nearest 1 mm using UNICEF portable baby/child length-height measuring boards. Recumbent length was measured for children up to 24 months of age and standing height for children over 24 months. Where this protocol was not followed, in order to minimise stress to the child and maximise measurement accuracy (6.0% total measurements), a standard adjustment was applied—with standing height approximated to be 7 mm less than recumbent length (WHO, 2006). Child birthdates were verified against health clinic records where possible (80.7%), with some cases where children had not been issued with an official health record, or where records had been misplaced or damaged.

Equal numbers of male and female community representatives (Community Assistants) were employed and trained to visit households on a twice monthly basis for ongoing data collection. Information was recorded on the number of chickens owned and the breastfeeding status of enrolled children within the previous 2 weeks: (a) exclusively breastfed, (b) receiving breast milk and complementary foods, or (c) nonbreastfed. Exclusive

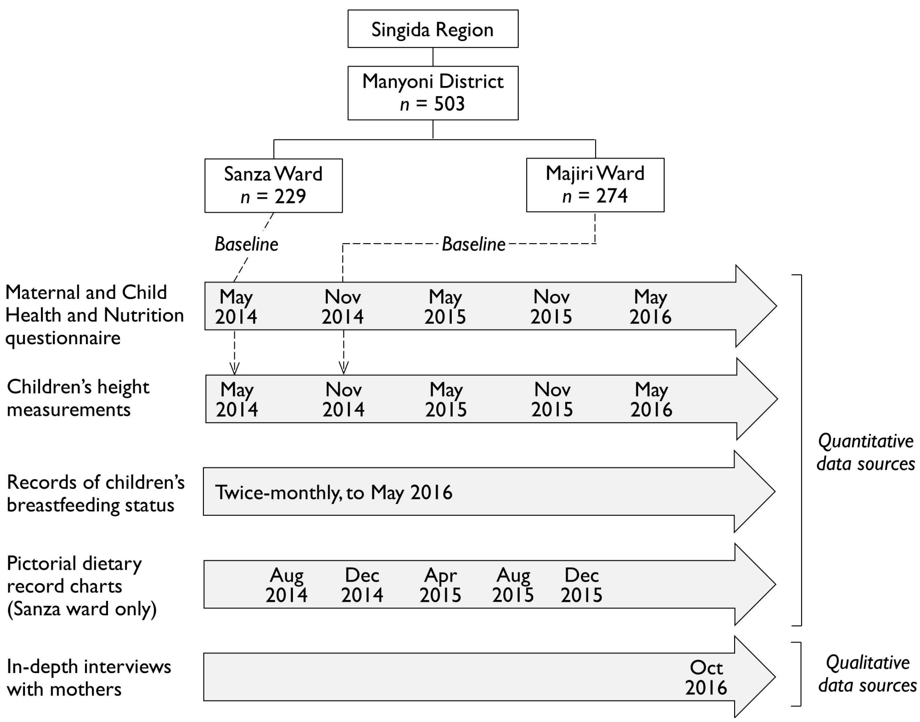

FIGURE 1 Overview of administrative units in the study area, with the number of enrolled households and the timing of quantitative and qualitative data collection (including the 6-month delay between baseline data collection in the two wards)

breastfeeding was defined as receiving no other food or drink (even water) except breast milk but allowing for oral rehydration solutions and drops or syrups, including vitamins, minerals, and medications (WHO, 2002).

In Sanza Ward, pictorial record charts were distributed to all enrolled households at four monthly intervals, in the months of August and December in 2014 and April, August, and December in 2015, to document the consumption of poultry products over a period of four consecutive weeks. This research tool was developed for use in communities with low levels of literacy, adapted from an approach used in reproductive health research in Tanzania and Uganda (Francis et al., 2013; Francis et al., 2012) and intended to be able to be used without an understanding of written language. Simple artwork depicting a chicken, eggs, an infant, a pregnant woman, and a breastfeeding mother was presented in a table layout (Figure 2). Prior to each data collection period, the Community Assistants were trained to instruct a representative from each participating household to use a mark to record any meal containing chicken or egg consumed by the enrolled child or by a pregnant or breastfeeding woman in their household (if present). Community Assistants visited each household at the end of each week to review the pictorial charts and assist participants in recording data in any incomplete charts.

2.3 | Qualitative data sources

The qualitative phase of data collection was conducted in October 2016. Thirty-nine in-depth interviews were carried out with a subset of mothers of children enrolled in the longitudinal study. Stratified purposive sampling was used to identify four to six women in each of the eight villages. Eligibility criteria were that women were available on the intended day of interview and willing to engage in discussions for approximately 1 hr. With the aim of achieving diverse representation of households, selection of mothers for interviews was also guided by children's HAZ (both more than two standard deviations below and above the median), marked changes in HAZ over successive measurements (both improving and failing growth patterns), timing of introduction of complementary foods (prior to 6 months, at 6 months and beyond 6 months), chicken ownership and flock size in the previous 24 months (households with no chickens, intermittent and consistent ownership of chickens, and small and larger flocks), and language group (targeting both Gogo and Sukuma households), as determined by prior analysis of questionnaire and anthropometric data.

The majority of interviews were conducted at women's homes, with a smaller number held in a central location in the village at the time that women and their children attended the local health facility. Distances to be travelled to reach women at their home were not a consideration in selection of interviewees. Discussions were conducted predominantly in Swahili with occasional use of the language of the more common group, *Kigogo*, and were led by an English speaker familiar with the study setting, using a semistructured guide with open-ended questions and facilitated by a translator. For each interview, a Community Assistant was also present to lead introductions and provide additional translation assistance where required. Audio recordings and written notes, predominantly in English, were taken. Questions were based around three main themes: infant and young child feeding, household diets, and poultry keeping. A selection of topics was covered with each interviewee, keeping discussions within the approximate time frame of 1 hr.

2.4 | Data analysis

Analysis of quantitative data was performed using Genstat software (VSN International, version 18). Descriptive analysis was used to characterise IYCF practices, by ward and in the overall study population, including the timing of initiation of breastfeeding, use of prelacteal fluids, timing and nature of complementary feeding, reasons for introduction of complementary foods prior to 6 months of age, and total duration of breastfeeding. Filter questions within the six monthly questionnaire were designed to restrict data collection on the timing of weaning to events within the prior 6 months but led to missing data when mothers erroneously thought this information had been provided

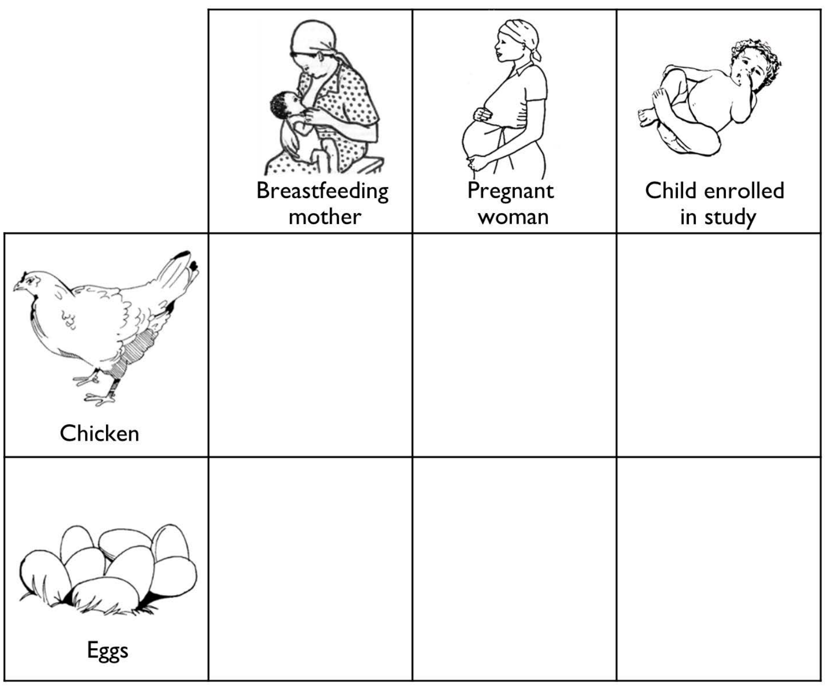

FIGURE 2 Design of pictorial record chart (with English translations of Swahili text) for completion by a representative of each household, to indicate the consumption of poultry products by children enrolled in the study, and a pregnant or breastfeeding woman within the same household

during the previous application of the questionnaire. In these cases and those where mothers were not available to complete the six monthly questionnaire (132 children), children's breastfeeding status was drawn from fortnightly records collected by the Community Assistants.

Demographic characteristics, livestock ownership, and children's height-for-age were compared (a) between the two wards and (b) between the interviewed households and others within the study population. Intergroup comparisons were performed using *t* tests and chi-square tests for continuous and bivariate categorical variables, respectively. Differences were considered significant at $p < .05$.

Descriptive summaries were also compiled using data from pictorial records of chicken and egg consumption to determine the proportion of children and breastfeeding or pregnant women consuming chicken or eggs and mean number of meals containing these food items, over each of the five 4-week data collection periods. Evaluating children's consumption of chicken and eggs separately, univariable analyses using generalised linear mixed models were initially performed to test associations with child gender, child age, and maternal consumption of chicken or eggs. Geographic and temporal variation was accounted for through the inclusion of ward, village and subvillage locations, and data collection period as random effects. Multivariable models were constructed using variables of suggestive significance ($p < .1$) based on univariable models and backward elimination used to manually remove variables not significant at the 5% level to reach the final models.

Retrospective coding of written interview notes by the primary investigator was used to detect common themes surrounding three broad topics: infant and young child feeding, household diets, and poultry keeping. Thematic analysis was conducted manually, to identify points of consensus and difference among interviewees. Quotations are given in English, derived from translations provided in the context of interviews and later review of audio recordings. Interviewees have been de-identified, and responses are identified by women's age and household location.

2.5 | Ethical considerations

Study design, protocols, and research instruments were approved by the National Institute for Medical Research ethics committee (NIMR/HQ/R.8a/Vol.IX/1690) in Tanzania and the University of Sydney Human Research Ethics Committee (2014/209). All participants provided informed consent prior to participating in the study, with assurance of confidentiality, anonymity, voluntary participation, and no adverse effects in case of refusal.

3 | RESULTS

3.1 | Characteristics of the study population

An overview of selected demographic characteristics is given in Table 1, for each of the two wards ($n = 229$ in Sanza and $n = 274$ in Majiri), for the overall sample ($n = 503$), and for the subset who participated in the in-depth interviews ($n = 39$). Significant intergroup differences are indicated. The mean age of children at enrolment was 8.6 months of age. Children within

TABLE 1 Overview of selected demographic characteristics, using baseline questionnaire data: overall, by ward, and in the subset participating in in-depth interviews

	Sanza Ward	Majiri Ward	Overall	In-depth interviews
Number of households (*n*)	229	274	503	39
Date of data collection	May 2014	Nov 2014		Oct 2016
Children				
Age at enrolment (months), mean (*SD*)	9.9 (6.1)[a]	7.6 (4.3)[a]	8.6 (5.3)	8.4 (5.6)
Female (%)	55.5	47.4	51.1	35.9
Stunting at baseline (%)	36.8[a]	28.5[a]	32.2	41.7
HAZ at baseline, mean (*SD*)	−1.5 (1.2)	−1.5 (1.1)	−1.5 (1.2)	−1.7 (1.6)
Mothers				
Age at baseline (years), mean (*SD*)	28.5 (7.5)[a]	26.8 (7.5)[a]	27.7 (7.6)	28.9 (7.7)
No formal education (%)	22.8[a]	40.6[a]	32.5	39.5
Households				
Female headed (%)	30.2[a]	16.4[a]	22.7	15.8
Number of members, mean (*SD*)	5.4 (1.9)	5.5 (2.6)	5.4 (2.3)	5.8 (2.4)
Language group (%)				
Gogo	78.2[a]	74.8[a]	76.3	76.9
Sukuma	6.1[a]	14.6[a]	10.7[b]	23.1[b]
Other	4.4	2.6	3.4	0.0
Not specified	11.4[a]	8.0[a]	9.5[b]	0.0[b]
Livestock ownership at baseline (%)				
Chickens	51.1	46.8	48.8[b]	65.8[b]
Goats and sheep	27.1[a]	47.8[a]	38.3	36.8
Cattle	26.7[a]	36.2[a]	31.8[b]	47.4[b]

Note. *SD* = standard deviation; HAZ = height-for-age *z*-score; Significant differences ($p < .05$) are indicated as follows:

[a]Between the two wards.

[b]Between the overall sample and the subset participating in in-depth interviews.

the study sample were significantly older in Sanza Ward (mean age of 9.9 vs. 7.6 months; $p < .001$), as a result of a lower number of households in this area, necessitating the inclusion of more children from the 12- to 24-month category. Approximately one third of children (32.2%) were classified as stunted at the time of first measurement, with a mean HAZ of −1.5.

Low levels of formal education were seen across the study population, with 32.5% of mothers never having attended school and significant variation between the two wards (22.8% in Sanza vs. 40.6% in Majiri; $p < .001$). Fewer female-headed households (16.4% vs. 30.2%; $p < .001$), higher levels of small ruminant ownership (47.8% vs. 27.1%; $p < .001$), and greater representation of the Sukuma language group (14.6% vs. 6.1%; $p = .003$) were also seen among the Majiri participants compared with those from Sanza. Among those participating in in-depth interviews, there was a significantly higher proportion of women from households identifying as Sukuma and from households keeping chickens, as part of a conscious effort to explore differences in IYCF practices between language groups and potential contributions of chickens to household diets.

3.2 | Timing of breastfeeding and complementary feeding

Approximately two thirds of children were born in a health facility (67.5%), and among those born at home 16.2% were recorded as having been weighed at a health facility within an hour of birth (Table 2). Of 503 children, the vast majority (96.8%) were reported to have been breastfed for any period of time. Breastfeeding was initiated within 1 hr of birth for 77.5% of infants and within 1 day for 93.9%. Mothers of 40.7% of children indicated that fluids other than breast milk had been given to their child in the first 3 days post-partum, before breast milk production had fully commenced. Water with sugar

TABLE 2 Childbirth, breastfeeding, and early complementary feeding practices of enrolled children in the overall study population and by ward, compiled from six monthly questionnaire responses and fortnightly household visits to record children's breastfeeding status

	Sanza Ward	Majiri Ward	Overall
Enrolled children (*n*)	229	274	503
Delivered by caesarean section (%)	3.5	7.4	5.6
Delivered at home (%)	35.7	29.8	32.5
Weighed at health facility within 1 hr of delivery (%)	27.2	5.1	16.2
Ever breastfed (%)	94.7	98.5	96.8
Breastfeeding initiated within 1 hr (%)	67.5	85.2	77.5
Breastfeeding initiated within 24 hr (%)	88.5	98.5	93.9
Prelacteal feeding (%)	46.5	35.8	40.7
Water with sugar (%)	29.4	27.8	28.5
Water with sugar and salt (%)	13.2	3.7	8.0
Tea (%)	1.8	3.3	2.6
Milk other than human breast milk (%)	2.6	2.2	2.4
Plain water (%)	1.3	1.1	1.2
Age in months at initiation of complementary feeding			
Mean (*SD*)	4.2 (1.9)	3.8 (1.7)	4.0 (1.8)
Range	1–11	1–9	1–11
Exclusively breastfed until 6 months (%)	29.8	22.1	25.6
Reasons for early initiation of complementary feeding (%)			
Insufficient breast milk	89.7	98.0	95.0
Child refused breast milk	6.0	0.5	2.5
Maternal illness	3.4	1.0	1.9
Separation of mother and child	0.9	0.5	0.6
Items commonly added to porridge during early complementary feeding			
Sugar	77.8	86.9	83.3
Nuts or beans	30.4	56.3	46.0
Baobab fruit	12.6	17.0	15.2
Cow's milk	8.1	12.6	10.9
Oil	1.5	1.5	1.5
Egg	1.5	1.0	1.2
Meat	0.0	0.5	0.3
Age in months at weaning			
Mean (*SD*)	22.0 (3.5)	21.3 (3.6)	21.7 (3.6)
Range	11–36	11–29	11–36
Breastfeeding continued until 24 months (%)	38.4	30.5	34.5

Note. *SD* = standard deviation.

was the predominant fluid given in these circumstances (28.5% infants), substantially more common than non-human milk (2.4%) or plain water (1.2%).

Questionnaire data indicated the mean age for initiation of complementary feeding to be 4 months (range of 1–11 months) and exclusive breastfeeding to 6 months of age to be practised by 25.6% of mothers. Among interviewed mothers, despite the purposive selection of interviewees introducing bias and resulting in an increased proportion of mothers of stunted children, similar timing of the introduction of complementary foods was reported. Of 28 interviewees with whom the topic was discussed, 18 reported having introduced liquids or foods other than breast milk before 6 months of age (mean age of 3.8 months, range of 2 weeks to 8 months). Two women attested that they did not know of any mothers within their community who had sustained exclusive breastfeeding to 6 months.

In the overall study population, the mean age of weaning was 21.7 months (range of 11–36 months), with 34.5% of mothers meeting WHO recommendations for continued breastfeeding to 24 months of age or above.

3.3 | Reasons for early initiation of complementary feeding

Among the overall study population, reasons for early introduction of complementary foods were sought through a semistructured question. Of the mothers who reported introducing foods or fluids before 6 months of age (n = 374), 95% selected the response of “insufficient breast milk” as the primary reason for their decision from five listed responses read aloud by enumerators (which also included a subsequent pregnancy, child refusal to feed, maternal illness, or separation of mother and child)—with the opportunity for unlisted responses to be recorded. In Sanza Ward, where insufficient breast milk was nominated by a significantly lower proportion of mothers than in Majiri Ward (89.7% cf. 98.0%; p = .007), infants' refusal to breastfeed was the second most common reason given (6.0%). More specific observations motivating a change in feeding practices, such as infant crying or weight loss, were not among listed options and were not nominated by any questionnaire respondents.

In comparison, during interviews, 14 women cited children crying as a reason to introduce other foods, nine identified their milk supply to be insufficient in quantity, and five described the consistency of breast milk as being too watery. Reasons for crying were acknowledged to be many and varied, but a common response to persistent and protracted crying—including after breastfeeding and overnight—was to offer liquids and foods other than breast milk (see Figure 3). Many interviewed mothers indicated their awareness of the recommendation of exclusive breastfeeding to 6 months, with one conveying a firmness in the delivery of this guideline by health personnel: “When you go to the hospital, they tell you that you must breastfeed for six months, in strong voices” (24-year-old woman from Chicheho Village, Sanza Ward).

Two women described an association between their child feeding from a particular breast and vomiting, in the absence of any maternal symptoms in this breast. One of these women reported having consulted a nurse at the local health facility, who advised her to persist with feeding from the other breast but said she had opted to initiate complementary feeding at 5 months because she felt that the child was not receiving enough milk. No other women reported having sought advice from health staff about difficulties associated with breastfeeding, although it was indicated that such an opportunity would exist during monthly weight checks for infants. Interviewees more commonly reported discussing breastfeeding difficulties with their mother, mother-in-law or, in one case, husband.

3.4 | Nature of complementary foods

Of 341 infants reported in the questionnaire to have received solid or semi-solid foods prior to 6 months of age, all were given cereal-based porridges. Among this subset, a majority (83.3%) of mothers reported sugar to have been added to infants' porridge during the early phase of complementary feeding (Table 2). “Nuts or beans” were reported as being added to porridge for 46.0% of infants, baobab fruit powder for 15.2%, and cow's milk for 10.9%. Other ASF were only mentioned by a small number of mothers, with eggs recorded as being added to porridge for 1.2% of infants and meat for 0.3%. A failure to define the regularity of consumption in this section of the questionnaire may have led to an over-reporting of food items added to porridge on an infrequent or occasional basis, for reasons such as economic constraints or seasonal availability.

It is possible that baobab fruit, which was not among the listed food items but was recorded in the “additional items” category, was under-reported in questionnaire responses, depending on enumerators' proficiency in probing for nonlisted food items. Several participants in in-depth interviews described adding baobab fruit and groundnuts to their young child's porridge—in accordance with questionnaire data—however, further questioning revealed the former to depend on seasonal availability (with most fruit being consumed or sold within a short period following harvest) and the latter to be infrequent due to limited groundnut production in the area.

In-depth interview findings confirmed a limited range of foods to be offered to children in the initial phases of complementary feeding. Nine women reported water with sugar added to have been the first item other than breast milk offered to their child, particularly when complementary feeding was initiated before 3 months of age. One mother described preparing a watery porridge for her 1-month-old twins, passing it through a sieve to remove any solid fragments. Fifteen mothers indicated a soft maize or sorghum porridge with sugar to have been the initial complementary food, and four women (all from cattle-owning households) reported giving cow's milk.

Moderate variation was evident in mothers' approaches to continued complementary feeding, with no clear association between the age of initiating complementary feeding and the timing of introduction of specific foods. In some cases, children who received soft porridges at an early age started eating *ugali* (a stiff maize- or sorghum-based porridge, the predominant staple dish of the area) and its common accompaniment of green leafy vegetable (typically from noncultivated plant sources) sooner than those adhering to the recommended 6 months of exclusive breastfeeding, who might continue on sweetened porridges until 1 year of age. In other cases,

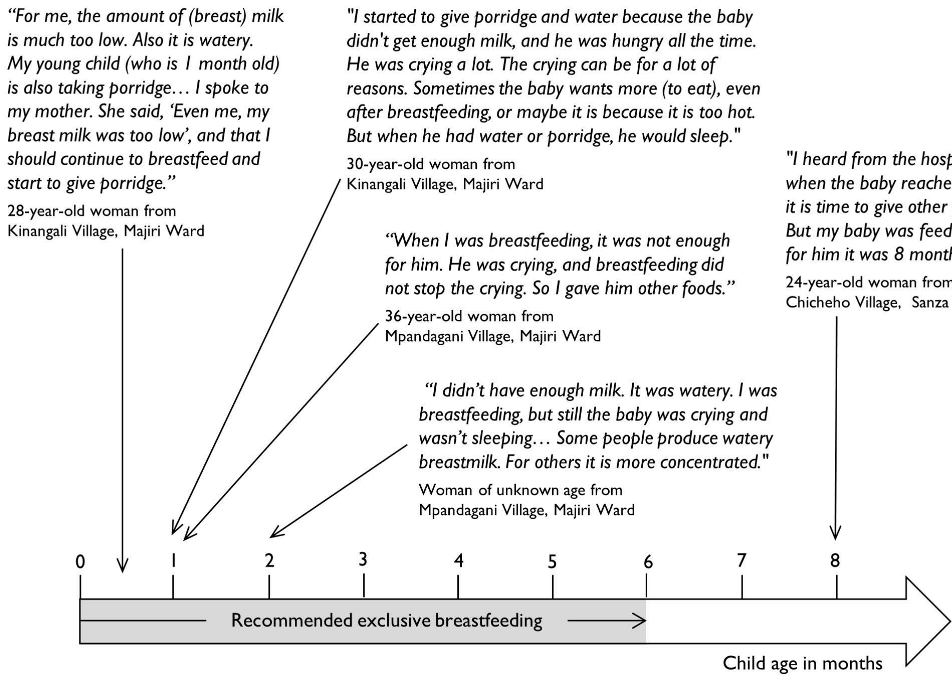

FIGURE 3 Mothers' experiences of breastfeeding, according to the age of their child at initiation of complementary feeding (qualitative data collected through in-depth interviews)

mothers reported introducing both soft porridge and more solid household foods simultaneously, or in quick succession, from 6 months of age.

Three women explained that meat and fish would be introduced later than vegetables and legumes, with one mother mentioning 12 months of age and two suggesting 18 months as an appropriate time. Household consumption of meat and fish among the study population was variable but largely infrequent (see Table 3), suggesting the timing of introduction to be based not only on conscious decisions about a child's readiness for these foods but on their frequency of consumption within the wider household. Although egg consumption was also documented as being very low across the study population (Tables 3 and 4), five women made reference to a specific custom prohibiting their consumption by uncircumcised male children.

3.5 | Household diets

Beyond the initial phase of complementary feeding in which sweetened cereal-based porridges predominate, there was consensus among interviewees that children's diets would increasingly reflect the foods eaten by other members of their household. It was reported that by 24 months of age, there would be no appreciable differences between children's and adults' diets. Table 3 highlights the variation in consumption frequency for selected food items between households, compiled from information provided during in-depth interviews, together with reported reasons for eating certain foods and barriers to their more frequent inclusion in household diets. Consumption of beans and meat from cattle or small ruminants was reported to be reliant on households having disposable income for their purchase. Such items were reported to be eaten several times per week in some households and very occasionally, perhaps even only once per year, in others. Consumption of poultry products was indicated to be closely associated with ownership of chickens and on the number of chickens owned. As discussed further in the next section, for many households, particularly those with small flocks, eating chicken was very rare and often reserved for festive occasions, visiting guests or occasions when birds had died of disease.

Only seven women (17.9%) reported having made any conscious changes in their diet while breastfeeding. Cereal-based porridge was the most common food item reported to promote milk production, sometimes with the addition of sugar or groundnuts: "When you have children, you should drink porridge, and then the milk will come" (24-year-old woman from Chicheho Village, Sanza Ward). Several women said larger portions of their regular diet would be eaten, but it was noted that pain or poor appetite in the early post-partum period might make this difficult. One interviewee expressed exasperation at the notion that a different diet might be achieved in the local setting: "You can see the difficult situation here. How could I eat any special foods?" (woman of unknown age from Mpandagani Village, Majiri Ward). Another described seasonal variation in food availability as being significant: "When there is rainfall, there are a lot of (green leafy) vegetables. You can mix them with tomatoes and other vegetables. It is easier to breastfeed in the wet season" (34-year-old woman from Sanza Village, Sanza Ward).

3.6 | Consumption of poultry products

Qualitative data exploring the contributions of chicken meat and eggs to local diets indicate consumption frequency to vary substantially

TABLE 3 Consumption frequency of selected food items, with associated reasons for and barriers to consumption, compiled from in-depth interviews with mothers. Findings are presented alongside corresponding food group-based recommendations for Tanzania

Food group-based recommendations for adults in Tanzania (TFNC, 2011)	Food item discussed with interviewees	Reported consumption frequency	Reported reasons to consume	Reported barriers to consumption
Animal-source foods and legumes 2–3 servings per day One serving is equal to • A single egg • A palm-sized piece of meat or fish • 250 ml milk • Half a cup of cooked beans	Eggs	Infrequent consumption by majority of interviewed households (from “never” to “occasionally”). Three women reported eggs to be eaten on a regular basis, every 1–2 weeks. One mother said eggs would be given preferentially to children and particularly to young children.	Availability. A common circumstance for consuming eggs would be when a hen has died or abandoned her eggs or has laid more than she might be able to raise as chicks. One woman described having added egg to her child's porridge to improve her growth, and two others mentioned eggs as a beneficial food for children.	Not owning chickens or owning a small number only. No interviewees mentioned buying eggs to eat. Most women emphasised the need to keep eggs for hatching. (“If you eat eggs, where will you get chickens?”). There was one mention of the significance of language group, with the suggestion that it is not customary for Sukuma families to eat eggs.
	Chicken meat	Substantial variation between households. Only four women indicated chickens to be slaughtered with any regularity, ranging from once per month to three times per week. For others, consumption was mostly associated with special occasions.	Large flock size and the ease of slaughtering chickens at home were cited by those consuming chickens on a regular basis. Visiting guests and special occasions (e.g., public holidays or weddings) were common reasons to eat chicken. Two women said chickens would be consumed at times of vegetable scarcity. Two reported chickens would only be eaten if they died of disease.	Decision-making on the consumption or sale of chickens was reported to commonly involve the male household head. An emphasis on the need to retain chickens for sale in times of need was a common barrier to more frequent consumption. One woman from a large household indicated the number of chickens required to feed all household members to be a deterrent.
	Other meat or fish	Marked variation between households. Meat or fish were reported to be eaten three times per week by three interviewees and once per week by two. For the majority, consumption was much less frequent: once per month, once every 3 months, or even once per year.	Three women indicated meat consumption to depend on the availability of income. One interviewee indicated her husband's role as a butcher to facilitate access to meat in their household. Two said small dried fish would be eaten when vegetables were not available.	Lack of money available to purchase meat is the primary constraint to consumption. One Sukuma woman identified the requirement to involve a butcher in the slaughter process as a deterrent, compared to the ease with which chickens could be slaughtered at home.
	Milk	Marked variation according to cattle ownership and seasonal availability. Milk was reported to be consumed infrequently or never by those not owning cattle and commonly but with seasonal variation in the frequency and volume (usually two to three times daily in the wet season) by those owning cattle.	Cow's milk is seen as a suitable alternative or supplement to human breast milk and was commonly reported as an early complementary food (boiled or added to porridge) by those with cattle. Several women indicated cow's milk would be given to young infants left in the care of others during the day while their mother was engaged in agricultural work. One mother reported milk to have been given to help her daughter grow.	Not owning cattle, a lack of funds to buy milk and limited availability for sale were identified as common barriers. For cattle-owning households, the amount of milk was said to vary considerably between seasons, according to feed availability and the reproductive status of cows. One mother indicated the milk from a cow to vary from 200 ml per day towards the end of the dry season to 2 L in the wet season.
	Beans	Marked variation: rarely in some households, three times weekly in others. One mother indicated beans would be given preferentially to children, when available.	Enjoyed by children. One mother described adding beans to her child's porridge to promote growth, as instructed by health staff. Another said eating beans would be more common when green leafy vegetables were not available (e.g., towards the end of the dry season).	Lack of funds to purchase from local markets. Beans were not grown by any of the interviewed households. Decreased consumption was described in the previous year, when poor rainfall adversely impacted agricultural yields and household income.
Cereals and tubers 6–11 servings per day One serving is equal to a fist-sized portion of cooked sweet potatoes.	Sweet potatoes	Marked variation between households, particularly between the two predominant language groups of the study area (Sukuma and Gogo). In Sukuma households, sweet potatoes are commonly eaten as the first meal of the day.	Both white- and orange-fleshed varieties were reported to be enjoyed. One interviewee described children putting on weight at times of year when sweet potatoes are being eaten.	Not commonly grown by members of Gogo households, for the suggested reason (from members of both language groups) that the cultivation techniques are arduous, particularly without access to draught power. One Gogo mother reported sweet potatoes to cause bloating in her children.

(Continues)

TABLE 3 (Continued)

Food group-based recommendations for adults in Tanzania (TFNC, 2011)	Food item discussed with interviewees	Reported consumption frequency	Reported reasons to consume	Reported barriers to consumption
Vegetables 3–5 servings per day One serving is equal to a palm-sized portion of cooked vegetables.	Green leafy vegetables	Universally commonly consumed. All women reported eating green leafy vegetables on a daily or twice-daily basis for most of the year, usually as the main (and sometimes the only) accompaniment to the staple carbohydrate.	Availability. A range of both cultivated and noncultivated green leafy vegetables are eaten. Examples given included amaranth, sweet potato leaves, jute mallow, and *kipari* (a noncultivated plant growing in the study area).	Unavailability. Green leafy vegetables are commonly harvested and dried in April, after the rains. There may be times later in the year, towards the end of the dry season, when the supply of dry leaves has been exhausted and fresh leaves are not yet available.
Fruit 2–4 servings per day One serving is equal to • A single orange or banana • A palm-sized piece of watermelon or papaya	Fruit	Not commonly consumed, except for baobab fruit. Varying frequency according to households' financial capacity to purchase fruit at local markets and the seasonal availability of noncultivated fruits.	Enjoyed by children. Powder from baobab fruit was commonly reported to be added to children's porridge in the early phase of complementary feeding, together with sugar, to enhance the flavour. One mother cited fruit as being beneficial for children's growth.	Lack of disposable income for the purchase of fruit such as bananas from local markets. Wild fruits are only available at certain times of year. Two interviewees reported the sale of baobab fruit to be prioritised over home consumption, to fund the purchase of staple foods.

within the study area, as outlined in Table 3. Of eight interviewees asked about their motivations for keeping chickens, all cited opportunities for income generation—to meet small household expenses, school fees, children's clothing, and medical costs—as a primary reason, two mentioned their use as gifts for visitors, and one spoke of direct contributions to household diets in times of food scarcity. "When you have a problem getting vegetables, you can slaughter a chicken or even eat some eggs" (52-year-old woman, Ikasi Village, Sanza Ward).

A common theme emerging from interviews was the low frequency with which poultry products were consumed in a majority of households: constrained by limited availability and, among chicken-owning households, a sense of the need to retain chickens to sell in times of need, and eggs to hatch to replace bird losses. Household size was identified by one interviewee, living with her husband, nine children, three of her children's spouses and six grandchildren, as an important factor: "If there is a couple and one child, it is easy to eat (chicken). Even if I have a lot of chickens, I still have a big family to feed" (woman of unknown age from Mahaka Village, Majiri Ward).

Analysis of completed dietary record charts from Sanza Ward was undertaken for children enrolled in the longitudinal study and, where present, for a breastfeeding woman within the same household,

TABLE 4 Consumption of poultry products by enrolled children and breastfeeding women in Sanza Ward, by month of data collection (based on pictorial record charts completed by households)

	Aug 2014*	Dec 2014*	Apr 2015	Aug 2015	Dec 2015
Completed dietary records (*n*)					
Enrolled children	200	197	206	177	147
Breastfeeding women	202	192	153	83	64
All participants					
Chicken eaten at least once in month (%)					
Enrolled children	21.5	16.2	14.6	13.0	14.3
Breastfeeding women	22.8	16.7	18.3	12.0	12.5
Eggs eaten at least once in month (%)					
Enrolled children	18.0	7.1	10.7	14.8	14.3
Breastfeeding women	15.3	7.8	9.8	15.0	19.0
Participants consuming poultry products in given month					
No. meals with chicken in month, mean (*SD*)					
Enrolled children	2.3 (1.6)	1.8 (1.1)	2.3 (1.9)	2.5 (2.2)	2.6 (1.5)
Breastfeeding women	2.3 (1.6)	1.8 (1.1)	2.0 (1.8)	2.2 (3.0)	3.5 (2.5)
No. meals with eggs in month, mean (*SD*)					
Enrolled children	3.0 (2.0)	1.5 (0.6)	2.2 (1.0)	3.1 (2.7)	5.1 (5.5)
Breastfeeding women	3.1 (1.9)	1.5 (0.7)	2.3 (0.8)	3.3 (3.6)	7.7 (7.0)

Note. *SD* = standard deviation.

*Exclusively breastfed children excluded from analyses (six children in August 2014 and one child in December 2014).

typically the child's mother. Records for pregnant women were excluded from this analysis, due to low numbers within the study population (in which all households included a child under 24 months of age at the time of enrolment), and confusion in some instances over how to record the absence of a pregnant woman, as distinct from a pregnant woman being present but not consuming any poultry products. Questionnaire data on the timing of the introduction of complementary feeding were used to identify exclusively breastfed children at the time of dietary records being completed, enabling them to be omitted from analyses of chicken and egg consumption. This resulted in exclusion of six children in the first application of the research tool and one child in the second application.

Fluctuation in the number of completed records was seen due to some households travelling at the time of data collection, relocating outside the study area, or choosing not to continue to participate. A substantial decrease in the number of completed records for breastfeeding women can be noted with increasing time, as children enrolled in the study were weaned. Across all months of data collection, very low levels of consumption of chicken meat and eggs were recorded among both young children and breastfeeding women. Table 4 shows the percentage of women and children eating poultry products at least once during each month-long period of data collection—in the case of children consuming meals containing chicken, ranging from 12.5% to 21.8% (in August 2015 and August 2014, respectively). For both chicken and eggs, household-level records indicate that a large majority of women and children do not consume these products even once over the course of a given month.

The probability of consuming chicken meat and eggs differed significantly between data collection periods (both $p < .001$), as assessed using separate binomial generalised linear mixed models allowing for geographic clustering. There is no indication of a seasonal pattern based on this limited period of data collection. In addition to a low proportion of women and children consuming chicken and eggs, the frequency with which these products were consumed was also very low. Among those participants reported to have consumed chicken, a mean of 1.8–2.6 meals per month was recorded for children and 1.8–3.5 for breastfeeding mothers. Egg consumption over a period of 1 month was similarly uncommon (7.1–18.0% of children and 7.8–19.0% breastfeeding women) and infrequent (1.5–5.1 meals per month for children and 1.5–7.7 meals per month for breastfeeding women, among those consuming eggs in a given month).

Poisson generalised linear mixed models were used to test the significance of the number of meals containing poultry products consumed by mothers as a predictor for the number consumed by their children. Chicken meat and eggs were evaluated through separate models. For both chicken meat and eggs, the number of meals consumed by a woman in a given month was significantly positively associated (both $p < .001$) with the number consumed by her child in the same month. The predicted consumption frequency of poultry products by a child rose with increasing consumption frequency by their mother (see Figure 4 and Table 5). Large standard errors were noted to be associated with model-based means for egg consumption within this population, where eggs are very infrequently eaten. Summary output of regression coefficients and variance components from both models is shown in Table 5.

No significant association was identified between child age and the consumption of either chicken or eggs. During focus group discussions conducted within the overarching research project, in which tea and hard-boiled eggs were served to participants, four women were observed on separate occasions to take small pieces of the yolk, mould it to a smooth shape, and feed it to their young children. On questioning, women indicated the softer texture of the yolk to be more suitable and palatable for infants. Five women acknowledged traditional beliefs within the area precluding the consumption of eggs by male children prior to circumcision, at around 2 years of age. Four indicated this to be a practice followed within their own families, justified by fears about interference with wound healing, eggs appearing at the preputial opening following circumcision and family customs. Four other interviewed women denied the existence of any food customs related to children's gender. Univariable analysis was suggestive of female children consuming eggs more frequently than male children ($p = .07$), but this was not significant when combined with mothers' egg consumption within a multivariable model ($p = .20$).

4 | DISCUSSION

Infant and young child feeding is an inherently complex area of research, whereby care-giving behaviours reflect an interplay of social, cultural, economic, and environmental influences. Among women living in affluent countries, including African refugee populations,

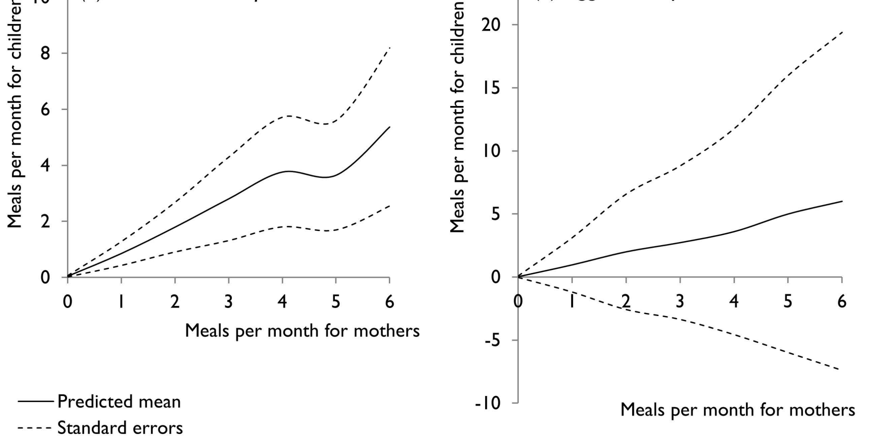

FIGURE 4 Predicted number of meals containing poultry products consumed by children per month, according to maternal consumption frequency (based on pictorial record charts completed by households)

TABLE 5 Regression coefficients and variance components from Poisson generalised linear mixed models indicating the number of meals containing poultry products consumed by a mother to be a significant predictor for the number consumed by her child. Separate models have been used for (a) chicken meat and (b) eggs

(a) Chicken (p < .001)				(b) Eggs (p < .001)			
Fixed effect		**Coeff**	***SE***	**Fixed effect**		**Coeff**	***SE***
Constant		−3.153	0.516	Constant		−3.528	0.469
No. of meals per month consumed by child's mother	0	0	—	No. of meals per month consumed by child's mother	0	0	
	1	2.995	0.250		1	3.494	0.295
	2	3.738	0.237		2	4.221	0.276
	3	4.185	0.307		3	4.531	0.293
	4	4.478	0.292		4	4.809	0.284
	5	4.447	0.318		5	5.137	0.304
	6	4.834	0.298		6	5.32	0.293
	7	5.169	0.473		7	5.474	0.442
	8	—	—		8	5.607	0.339
	9	5.496	0.459		12	5.648	0.304
	10	5.345	0.394		14	6.167	0.352
					25	6.706	0.307
Random effect	**Variance**	***SE***		**Random effect**	**Variance**	***SE***	
Ward	0.218	—		Ward	0.167	—	
Ward and village	0	—		Ward and village	0	—	
Ward, village, and subvillage	0.109	0.089		Ward, village, and subvillage	0	—	
Ward, village, subvillage, and ID	0	—		Ward, village, subvillage, and ID	0	—	
Dispersion	1	—		Dispersion	1	—	

Note. *SE* = standard error; Coeff = coefficient.

breastfeeding difficulties and a departure from intended child feeding practices have been associated with maternal discontent and feelings of culpability (Burns, Schmied, Sheehan, & Fenwick, 2010; Hufton & Raven, 2016; Murphy, 1999). Where child feeding practices deviate from guidelines provided by health personnel, mothers may be unwilling to speak openly and candidly about their experiences. There is potential for added complexity when working with low-literacy and low-income populations, in which a heightened power imbalance often exists between breastfeeding women and those working in the health sector (Bassett, Bijlmakers, & Sanders, 1997; Molyneux, Peshu, & Marsh, 2005).

Against this backdrop, researchers seeking to document IYCF practices may be faced with further challenges of cultural and linguistic differences, perceived hierarchies between investigators and participants, and an unfamiliarity with processes of data collection and informed consent (Molyneux, Wassenaar, Peshu, & Marsh, 2005). Among limitations of this study, the potential for acquiescence bias was recognised, whereby participants tend to respond positively to neutral questions, as well as social desirability bias, where answers that are perceived to be more acceptable than true attitudes or behaviours may be given (Kaminska & Foulsham, 2013; Ross & Mirowsky, 1984). A recent study in Central America has suggested that a physical inability to breastfeed might be considered an acceptable justification for early initiation of complementary feeding but that women may be unwilling to discuss reasons for not wanting to breastfeed (Safon et al., 2017). By identifying herself with her disciplinary background as a veterinarian, the primary investigator in the present study sought to minimise association with medical personnel, with whom nonadherence to IYCF guidelines has been suggested to be less likely to be shared (Mabilia, 2005).

Widespread familiarity with recommendations for exclusive breastfeeding to 6 months was evident among study participants, and "6 months" was a common initial response to interview questions about the timing of initiation of complementary feeding. With further probing, clarification about specific food items and reference to the experiences of other mothers within the community, it was common for interviewees to proceed to disclose specific breastfeeding challenges and to amend their response to indicate a younger age of complementary feeding. Some uncertainty surrounds the level of accuracy that might be achieved by enumerators, documenting similar information through structured questions within the context of a multipage survey.

Motivations for early commencement of complementary feeding provide an example of the value of an explanatory sequential mixed methods approach. Analysis of questionnaire-based data identified inadequate breast milk as the primary factor influencing decision-making for a substantial majority (95.0%) of mothers. This response encompasses the broad and complex phenomenon of perceived insufficient milk supply and served to highlight an area for further exploration through qualitative methods. In-depth interviews revealed persistent crying and fractious behaviour as the predominant triggers for women to deem their breast milk inadequate—in quantity or quality—to meet their child's nutritional needs. The recurring notion of "watery" breast milk aligns with previous reports of Tanzanian women viewing consistency as an important indicator of milk quality (Mabilia, 2005) and warrants closer investigation to understand against which reference this judgement is made.

Insufficient milk supply was noted to have been a recurrent experience for several multiparous women. References to previous lactation experiences and, in one case, those of an interviewee's own mother conveyed a sense of the capacity to breastfeed being intrinsic to an individual—perhaps with familial influences. Beyond an increase in the consumption of cereal-based porridges, dietary changes among breastfeeding women appear infrequent. A marked disparity is evident between existing diets and the diversity of food groups advocated in government-endorsed extension materials (Ministry of Health and Social Welfare, 2012), which depict a marked departure from the monotonous cereal-based diets common among this population and which would necessitate a substantial shift in the allocation of household resources.

Although this paper highlights early initiation of complementary feeding as the common deviation from WHO recommendations in this setting, a small minority (3.2%) of the study sample reported having continued exclusive breastfeeding beyond 6 months of age. During interviews, two of these women conveyed a sense of accomplishment—that for their child, their breast milk was "enough." It is noted that beyond 6 months of age, low levels of iron and zinc in breast milk and depletion of prenatal stores place exclusively breastfed infants at risk of deficiency if an exogenous source of these micronutrients is not provided (Butte, Lopez-Alarcon, & Garza, 2002; Dewey, 2013). It has also been proposed that many mothers are unable to meet the energy requirements of a 6-month-old infant, based on the metabolisable energy content of breast milk and the quantity of milk transfer at this time (Reilly & Wells, 2005).

Cereal-based porridges were identified as the first semi-solid food across the entire study sample, described during interviews as a watery gruel suited to infants' limited swallowing ability. Capturing information about the range and timing of introduction of specific complementary foods proved difficult, both in survey questions and in retrospective discussions with mothers. Although some interviewees were forthcoming with specific information about their child's dietary patterns and food preferences, others elaborated little on the topic. Although questionnaire responses indicate groundnuts, beans, and baobab fruit to be among the foods added to infants' porridge, in-depth interview data suggest limited access to these items for many families.

Household diets varied substantially across the community. Where barriers to the consumption of specific foods were widespread across the study population, such as the seasonal availability of green leafy vegetables, little variation was seen in the consumption frequency reported by women. Where barriers relate to traditions, household size, livestock ownership, or income availability, larger differences in consumption frequency appear to emerge. Milk consumption was one such food item: consumed daily in many cattle-owning households and very rarely in households without cattle. As for complementary feeding practices, it proved difficult to estimate the quantity of cow's milk consumed within the household, and how this might vary with seasonal changes in feed availability for cattle.

Although previous research in Tanzania documented an increase in the number of chickens and eggs sold, bartered, or consumed over a 3-year period following the introduction of Newcastle disease vaccination (Harun et al., 2009), pictorial record charts in this study indicated infrequent consumption of poultry products across all data collection periods. This is not surprising in the early stages of establishment of Newcastle disease control programs in the study area and in the face of increasing weather variability. Community members' long-term experience of seasonal disease outbreaks and high levels of mortality in free-ranging chicken flocks has been linked to infrequent consumption of eggs and chickens, with poultry keepers prioritising the hatching of eggs to provide replacement stock and retention of chickens for sale in times of financial need (Alders & Pym, 2009; Bagnol, 2001; Pym, Guerne Bleich, & Hoffman, 2006)—as attested by interviewed mothers within this area.

These record charts appear to have proved effective as an approach to household-level data collection; however, it should be acknowledged that their use was reliant on the involvement of Community Assistants employed in each village. These representatives have been responsible for training representatives from each household to complete the charts and overseeing their progress through the month-long data collection period. Despite a subjectively simple design, the process of identifying the appropriate location within a table layout to record a particular meal consumed by a particular household member was not intuitive for all participants, in communities where almost one third of women (32.5%) have had no access to formal education.

Despite very low consumption of chicken meat and eggs within this population, the finding of close associations between mothers and their children eating these items is promising. Documentation of these dietary patterns from five 1-month records over a 20-month period provides encouragement that programs that increase the consumption of poultry products at a household level will bring direct nutritional benefits for infants and young children within those households—an outcome that would be expected to be enhanced through targeted awareness-raising activities relating to child nutrition. Within many cultures, traditional beliefs, and taboos surround the eating of eggs by young children and pregnant women (Iannotti & Roy, 2013; Meyer-Rochow, 2009; Trant, 1954). In this study, qualitative data identified customs precluding the consumption of eggs by uncircumcised male children but appeared to be variably practised across the community and dietary records showed no significant gender-based differences in egg consumption frequency.

5 | CONCLUSIONS

In a setting where caring for children is an almost universally held role for women and the intergenerational transfer of care-giving information begins at a young age, questions by outsiders about breastfeeding and complementary feeding practices can appear senseless and may trigger suspicion in many rural African communities. The use of a mixed methods approach in this study sought to facilitate triangulation of findings, reflect on methodological approaches better suited to specific topics, and use targeted discussions with individual informants to more deeply explore findings from sample-wide questionnaires. Low and abnormally timed rainfall during the study period resulted in an unforeseen level of mobility among participating households, with a drastically reduced harvest prompting some to relocate outside the area to pursue alternative livelihood strategies. With increasing weather variability in the future, studies of populations reliant on rain-fed agriculture should consider the potential of increased participant dropout and adjust sample size calculations accordingly.

As shown at a national level in Tanzania (Ministry of Health, Community Development, Gender, Elderly and Children, Ministry of Health, National Bureau of Statistics, Office of the Chief

Government Statistician and ICF, 2016), breastfeeding was confirmed to be widespread and of long duration in these rural communities in Manyoni District. However, with 74.4% of mothers commencing complementary feeding prior to 6 months—primarily motivated by maternal perceptions of insufficient milk supply—it is clear that guidelines intended to maximise the likelihood of infants' nutritional needs being met are falling short of their potential impact. Although women within the study described receiving nutritional information of a general nature during routine perinatal visits to local health facilities, older female family members were identified as the usual source of guidance for specific challenges. Conflict is evident between advice from these sources for early complementary feeding as a response to breastfeeding difficulties and nationally endorsed IYCF recommendations, which advocate exclusive breastfeeding to 6 months but may fail to address specific challenges using culturally sensitive approaches.

Within programs seeking to influence diets through improved access to nutrient-rich foods, an understanding of local beliefs, practices, constraints, and priorities is key to achieving impact. This study highlights the importance of involving both local health staff and broader family networks in addressing maternal perceptions of inadequate breast milk production. Chicken meat and eggs were rarely eaten among study participants, yet children's intake was shown to follow their mothers', and no significant gender-based barriers to consumption by children were found. As poultry health programs reduce mortality and increase chicken ownership and flock size within these communities, families will be faced with decisions about the management and use of poultry. Culturally appropriate messaging should acknowledge the multiple contributions of chickens, as an accessible income source and a means of participating in traditional customs, while promoting their direct nutritional benefits for young children and women of reproductive age.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

JDB developed the primary concept of the paper; BB, IDH, RA, and WM provided input into development of the qualitative component of the study; JDB conducted in-depth interviews and led data analysis; PT provided support for quantitative analyses and BB for qualitative analyses; JDB wrote the initial and subsequent drafts of the paper; and BB, IDH, PT, RA, and WM contributed to critical revision of the manuscript.

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Chapter 7.
Evaluating associations between chicken ownership and diets, height-for-age and diarrhoea in children

Previous elements of this thesis have identified chickens as an accessible and versatile form of livestock (Chapter 3) and demonstrated a positive association between Newcastle disease vaccination and greater chicken numbers (Chapter 4); however, low levels of chicken meat and egg consumption have been documented during the study period (Chapter 6). This final results-based chapter tests associations between village chicken-keeping and diets, height-for-age and diarrhoea in children over a two year period in this setting.

By examining height-for-age, Chapter 7 provides an opportunity to assess the cumulative effect of a range of factors over time, including ownership of chickens and other livestock, the overnight housing location of chickens, measures of household wealth, and sociocultural influences linked to language group. Efforts have been made to address the complexity of livestock-nutrition linkages in rural communities, by using multiple and diverse measures of livestock ownership and by situating predictor variables within suggested impact pathways.

This chapter has not been submitted for publication, but has been formatted as a discrete piece of work (with a review of relevant literature, details of the study design, setting, participant selection, data collection, etc.) in the general style of a journal manuscript.

Image 7. A cluster of houses in the style traditionally built by members of the Sukuma language group. *Kisukuma* is spoken in a minority of households in this setting (10.7% of study participants). Chickens can be seen roaming in this homestead environment, and are commonly kept inside people's houses at night (reported by 64.2% of chicken-keeping households during the study period).

Photo credit: Julia de Bruyn, 2015.

Chapter 7. Evaluating associations between chicken ownership and maternal and child diets and height-for-age and diarrhoea in children

7.1 Introduction

To achieve lasting impact in enhancing food and nutrition security in resource-poor settings, there is a need for strategies which align with local priorities and address context-specific constraints. Mixed crop-livestock farming is widely practised throughout sub-Saharan Africa (Thornton & Herrero, 2015) and has been shown to strengthen the resilience of smallholder farmers to climate change (Altieri, Nicholls, Henao, & Lana, 2015; Seo, 2010); however, despite a ratio of one food-producing animal for every human in this region (Turk, 2013), programs involving livestock remain a relatively small component of food and nutrition security research and development.

A growing body of literature explores the effects of livestock on the health and growth of children in low- and middle-income countries. Positive impacts may occur via direct access to nutrient-rich animal-source foods (ASF) (Murphy & Allen, 2003; Neumann, Harris, & Rogers, 2002) or through income generation, which may contribute to dietary diversification, medical expenses or an improved home environment (Randolph et al., 2007). Research into negative health impacts has historically focussed on transmission of respiratory and vector-borne zoonotic pathogens, but more recent concerns have centred on the risks associated with exposure to livestock faeces in low-income rural settings (Penakalapati et al., 2017).

The potential for adverse outcomes has been linked to both pathogenic bacteria, responsible for infectious diarrhoea (Zambrano, Levy, Menezes, & Freeman, 2014), and non-pathogenic bacteria, implicated as a cause of subclinical environmental enteric dysfunction (previously termed "tropical enteropathy"). In this latter condition, chronic damage to the gastrointestinal tract is postulated to reduce nutrient absorption and cause low-level immune stimulation, restricting children's growth and development (Mbuya & Humphrey, 2016; Ngure et al., 2014). A recent review identified limited evidence to support causal pathways between environmental enteric dysfunction and child stunting, suggesting the condition to be more complex than previously conceived (Harper et al., 2018).

Chickens have come under particular scrutiny as a source of faecal contamination, given their close proximity to children in many resource-poor settings. Small flocks of indigenous-breed chickens roam freely during the day, scavenging for food within the village environment, and are commonly housed within human dwellings overnight, to reduce the risk of losses due to predation or theft (Glatz & Pym, 2013; Guèye, 1998). It is the inherently low requirements for capital, labour and other inputs which is proposed to make the potential contributions of village chickens to household income and diets so significant (Aini, 1990; Guèye, 1998; Sonaiya, 2004). These contributions may be further enhanced by the central role of women as the primary caretakers of village chickens (Bagnol, 2009; Guèye, 2000, 2005), with income and resources controlled by women recognised to have disproportionately strong effects on health and nutrition outcomes (Ruel & Alderman, 2013; World Bank, 2007).

Recent efforts to determine the net impact of chicken ownership, and livestock ownership more broadly, on child growth and health have largely reported on cross-sectional studies, and often on the analysis of existing datasets (Headey & Hirvonen, 2016; Headey et al., 2017; Hetherington, Wiethoelter, Negin, & Mor, 2017; Schmidt et al., 2016). While offering the advantages of large sample sizes and nationally-representative sampling, a potential shortfall of large-scale multi-purpose surveys, such as the Demographic and Health Survey (DHS), is the limited opportunity for understanding specific livestock management practices which may carry significant benefits and risks in relation to human health and nutrition. Information is typically lacking on labour division within livestock-keeping households, seasonal fluctuations in animal ownership, and the use of housing or enclosures which separate animals from household members.

Ethiopia's 2015 *Feed the Future* survey revealed a significant positive association between chicken ownership and child height-for-age Z-scores (HAZ); however, this is suggested to have been counteracted by a negative association with the practice of keeping chickens indoors overnight (Headey & Hirvonen, 2015). Data from the 2011 Uganda DHS demonstrated non-native cattle ownership to be significantly associated with improved HAZ in children, which was not mediated by the consumption of dairy products, and no significant effect of owning native cattle, pigs or poultry was found (Fierstein, Eliasziw, Rogers, & Forrester, 2017). Elsewhere, findings of significant negative associations between the presence of animal faeces in the homestead environment and children's HAZ in Bangladesh and Ethiopia, but not in Vietnam (Headey et al., 2017), highlight the variable and likely context-specific nature of livestock-nutrition linkages.

Appropriate source data and outcome variables are vital to draw meaningful conclusions amidst the complexity of varying livestock production systems, sociocultural influences and seasonal variation in resource-poor settings. In a systematic review examining relationships between domestic animal ownership and child health, a majority of studies focused on respondents' reports of diarrhoea as the primary health outcome (Zambrano et al., 2014). Impaired height-for-age (stunting) has been advocated as a more objective measure which reflects the cumulative effect of multiple influences, such as dietary quality, environmental enteric disorder and recurring diarrhoea, on children's growth over a longer period of time (Fierstein et al., 2017).

Some studies have employed the Tropical Livestock Unit (TLU) as a predictor of nutrition outcomes (Headey et al., 2017; Mosites et al., 2015). This unit represents smallholder livestock holdings, of mixed species, breeds and ages, as a value based on the approximate metabolic weight of each. The TLU was developed to quantify livestock production and relate livestock numbers to human populations or land resources (Chilonda & Otte, 2006; Jahnke, 1982). Limitations include: (a) a reliance on estimations of livestock size and condition based on region-specific guidelines; and (b) the potential for this unit to be applied in situations where the "amount" of livestock does not equate, for example, to their sociocultural value or to the incidence of stunting, wasting or illness in children. Quinlan et al. (2016) identify the use of TLUs to convert livestock assets into a "unidimensional measure of wealth in kilograms of meat" to be inappropriate. Based on work with male and female pastoralists of Maasai communities in Northern Tanzania, the authors identify cattle to be valued as the "gold standard" above smaller ruminants and other livestock, and report metabolic equivalence models to overlook the subjective value of livestock which may differ according to sociocultural and temporal factors, as well as individual estimation.

The concept of a "livestock ladder" has been used to describe livestock ownership as an opportunity for rural households to accumulate assets and rise out of poverty (Dolberg, 2001; Maass et al., 2013; Todd, 1998). Beyond their economic value, however, there are notable distinctions in the purposes served by different forms of livestock in resource-poor settings. Village chickens, viewed as the lowest step on the livestock ladder, offer a readily-accessible source of income, an opportunity to engage in social customs, and access to nutritious food items (Akinola & Essien, 2011; Alders & Pym, 2009; Guèye, 2000). By contrast, larger livestock such as cattle are associated with wealth and social status, and provide longer-term savings, insurance and draught animal power, but are infrequently used to meet immediate household needs (Doran, Low, & Kemp, 1979; Maass et al., 2013; Moll, 2005).

This study is nested within a larger investigation: a five-year cluster randomised controlled trial assessing the impact of community-based vaccination programs against Newcastle disease in village chickens and a range of interventions to improve crop diversity, management and storage on maternal and child health outcomes (Alders et al., 2014). The primary objectives of this study were to evaluate longitudinal associations between village chicken ownership and overnight chicken housing location and (a) dietary patterns of young children and their mothers, (b) HAZ in children, and (c) the occurrence of diarrhoea in children. Potential pathways being tested in this study are outlined in Figure 1. Analyses have used a range of livestock-associated predictor variables, and both short-term (diets and diarrhoea) and longer-term (HAZ) outcome variables, to optimise the understanding of how domestic animal ownership has influenced children over a two year period in these rural communities of central Tanzania.

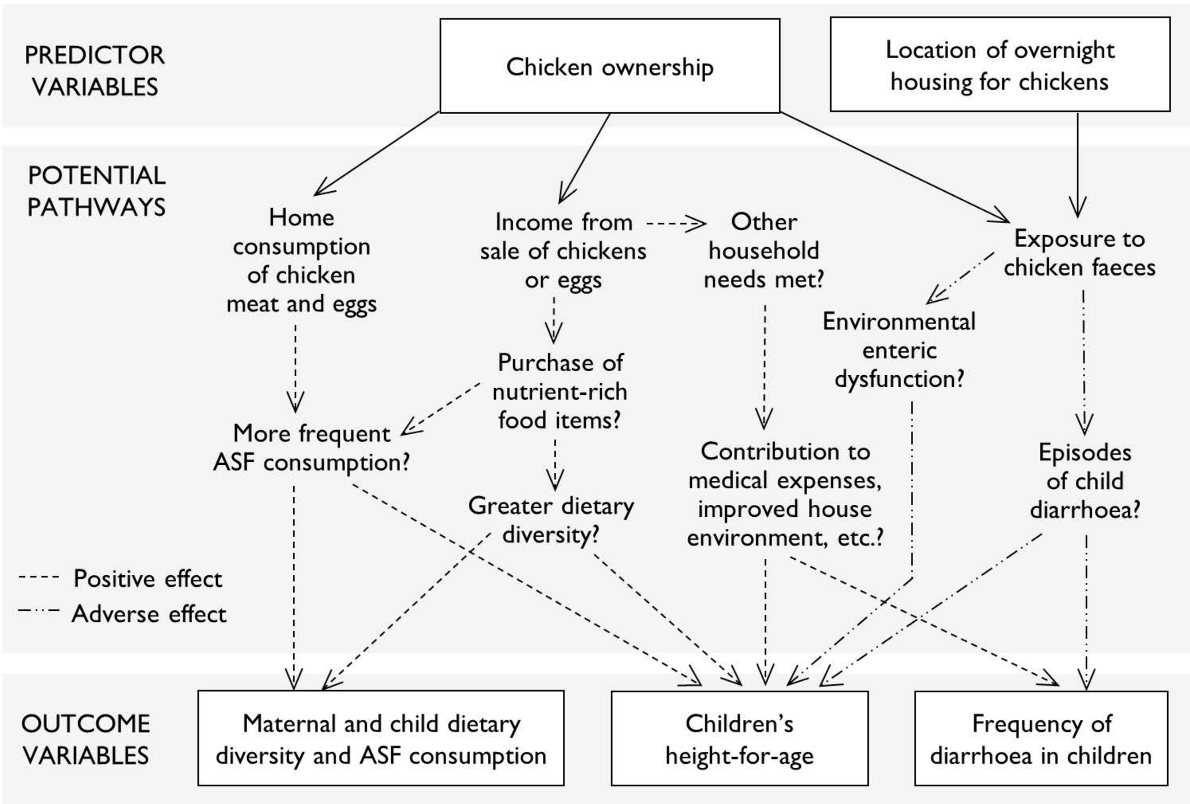

Figure 1. Potential pathways under evaluation in this study, linking village chicken ownership and overnight housing location with maternal and child diets, child anthropometry and diarrhoea.

7.2 Methods

7.2.1 Study area and population

This longitudinal study of 503 households was conducted in eight rural villages from two wards in Manyoni District, Singida Region in the semi-arid Central Zone of Tanzania. Unimodal rainfall typically falls between November and April, with long-term data indicating mean annual rainfall of 624 mm (SD = 179 mm) and a mean number of rain days of 49 (SD = 15) at a district level (Lema & Majule, 2009). Project sites were selected in consultation with government partners at national, regional and district levels, guided by the prevalence of childhood stunting and the absence of existing nutritional interventions.

A ward census was conducted by the project in April 2014 in Sanza Ward and October 2014 in Majiri Ward, with enumerators registering details of all household members, ownership of chickens and interest in chicken-keeping. Eligibility criteria for the study were that households included one or more children under 24 months of age (mo) at the time of the census, either currently kept chickens or expressed an interest in keeping chickens, and intended to reside within the project area for the duration of the study. Two-stage sampling used to enrol a total of 240 households in Sanza Ward and 280 in Majiri Ward, by first enrolling all eligible households with a child under 12 mo, and then using random selection to enrol additional households with a child aged 12-24 mo. For households containing more than one child under 24 mo, the younger child was enrolled in the study, or in the case of twins, one child was randomly selected.

Baseline data collection was completed for 229 households from Sanza Ward in May 2014, and 274 households from Majiri Ward in November 2014, as part of the staged implementation within the larger project design. The total number of households and number of enrolled households having completed baseline data collection are given in Table 1 for each of the eight villages.

Table 1. Total number of households registered during a preliminary census conducted by the project, and number of enrolled households completing baseline data collection, by village and ward.

Ward	Village	Total households (*n*)	Enrolled households (*n*)
Sanza	Ntope	490	60
	Sanza	642	58
	Chicheho	341	54
	Ikasi	257	57
	Ward total	1730	229
Majiri	Mpandagani	764	69
	Kinangali	801	71
	Majiri	951	68
	Mahaka	264	66
	Ward total	2780	274
Overall		4510	503

7.2.2 Data collection

Questionnaires

Male and female enumerators were recruited from the community in consultation with local leaders and trained to administer two coded semi-structured questionnaires to participating households. Printed survey questions and training sessions were in Swahili, but enumerators were encouraged to make use of the languages of the two predominant language groups (*Kigogo* and *Kisukuma*) where appropriate to aid in communication.

One questionnaire (Appendix A), directed to mothers of enrolled children at six-monthly intervals, encompassed maternal education, household water sources, toilet facilities, and maternal and child diets. Six-monthly dietary assessments were based on mothers' recall of foods and beverages consumed during the day prior to the interview, by herself and her child. The "open recall" method of data collection was followed, in which enumerators use probing questions to assist the respondent in recalling items consumed and identifying ingredients of mixed dishes (FAO & FHI 360, 2016). Each item mentioned by the respondent was circled on a predefined list, or recorded as an unlisted item. Training sessions prior to each round of data collection included time spent discussing unlisted food items which might be consumed in the local context, including non-domesticated animals and non-cultivated plants. Unlisted items appearing frequently on completed surveys were added to the food lists for subsequent rounds of data collection. In rare cases where the child's mother was not available for interview or not living with her child, the child's primary caretaker was interviewed.

A second questionnaire (Appendix B), applied annually to an intended equal number of male and female household members (actual sample comprised 60.5% female respondents of 1354 completed questionnaires in total) collected information on household demographic characteristics, house materials and household assets, livestock ownership and chicken-keeping practices, including the location of overnight housing for chickens.

Household visits

Balanced numbers of male and female representatives from each village ("Community Assistants") were selected in consultation with community leaders, employed on a part-time basis and trained to visit participating households on a twice-monthly basis for ongoing data collection. Information was recorded on the number of chickens owned by the household, the vaccination status of chickens, the breastfeeding status of the enrolled child (exclusively breastfed, receiving both breast milk and complementary foods, or non-breastfed), and the occurrence of diarrhoea in the enrolled child within the previous two weeks (Appendix C). Diarrhoea was defined as the passage of three or more loose or liquid stools per day, or more frequent passage than is normal for the individual child (WHO, 2013).

Anthropometry

Child length or height measurements were taken by trained personnel from the Ministry of Health, recorded to the nearest 1 mm using UNICEF portable baby/child length-height measuring boards. Recumbent length was measured for children up to 24 mo, and standing height for children over 24 mo. Where this protocol was not followed, in order to minimise stress to the child and maximise measurement accuracy (6.0% total measurements), a standard adjustment was applied, with standing height approximated to be 7 mm less than recumbent length (WHO Multicentre Growth Reference Study Group, 2006). Child birthdates were verified against health clinic records where possible (80.7%), with some cases where children had not been issued with an official health record, or where records had been misplaced or damaged.

Maternal and child weight was measured to the nearest 0.1 kg using TANITA HD355 digital scales. Footwear, socks, outerwear and *kitenge* (lengths of fabric commonly used for swaddling and as a sling for carrying young children) were removed, and children held by their mothers for a combined weight to be recorded. Maternal weight was recorded separately, and children's weight determined from the difference between these two values.

7.2.3 Data analysis

Defining variables

Descriptions and data sources for predictor and outcome variables are outlined in Table 2. Emergency Nutrition Assessment for SMART software (http://www.nutrisurvey.net/ena/ena.html) was used to calculate height-for-age Z-scores (HAZ) and weight-for-height Z-scores (WHZ) from children's measurements, based on WHO child growth standards (WHO Multicentre Growth Reference Study Group, 2006). Measurements were taken at six-monthly intervals, from May 2014 in Sanza and November 2014 in Majiri until May 2016 in both wards. Z-scores below -6 or above +6 were identified as extreme or potentially incorrect values, and were excluded from analyses (WHO, 2009). Z-scores of less than -2 for height-for-age and weight-for-height were classified as stunting and wasting, respectively.

A "diarrhoea score" was used to reflect each child's incidence of diarrhoea over the six-month period preceding each round of anthropometry. This score was employed to account for variability in the number of data points per child (due to absence during twice-monthly data collection visits), and was calculated using a ratio between the number of positive records of diarrhoea, as reported by the child's primary caretaker, and the total number of records per child.

Dietary diversity (DD) scores and dichotomous indicators of dietary adequacy were calculated for children and their mothers, using information collected at six-monthly intervals from November 2014 to May 2016 in all villages. A comparison of the food groups used in the indicators for women and children are given in Table 3. For mothers, scores were calculated based on the Minimum Dietary Diversity for Women of Reproductive Age (MDD-W) indicator, which uses ten defined food groups and the consumption of items from at least five groups during the previous day or night to achieve minimum dietary diversity (FAO & FHI 360, 2016).

For children, the Infant and Young Child Minimum Dietary Diversity (IYCMDD) indicator, based on seven food groups and a cut-off of four food groups consumed during the previous day or night, was used (WHO, 2008). To achieve consistency in the longitudinal evaluation of diets, this indicator was used beyond its intended age range of 6-23 months, as has been done elsewhere (Bandoh & Kenu, 2017). Since the indicator was developed to reflect the quality of complementary foods and does not include breast milk, results for breastfed and non-breastfed children have been reported separately. Consumption of ASF, overall and in the categories of eggs, chicken meat, other meat and fish, and milk, was also evaluated for children and mothers.

Table 2. Descriptions and data sources for variables evaluated

	Variable	Definition or description of categories	Data source
Child	Age	• In months, based on mother's recall of child's date of birth and verified against clinic health records where available	Baseline Maternal and Child Health and Nutrition (MCHN) questionnaire
	Sex	• Male or female	Baseline MCHN questionnaire
	Height-for-age Z-score	• Calculated based on WHO child growth standards (WHO Multicentre Growth Reference Study Group, 2006)	Six-monthly anthropometry
	Weight-for-height Z-score	• Calculated based on WHO child growth standards (WHO Multicentre Growth Reference Study Group, 2006)	Six-monthly anthropometry
	Diarrhoea score	• Ratio of positive records of diarrhoea to total number of records per child over six-month periods. As a predictor of child HAZ and probability of stunting, diarrhoea scores for the preceding six months have been used.	Two-weekly household visits
Mother and child	Dietary diversity score	• Number of food groups reported as having been consumed in the day or night prior to interview by mother (of 10 defined groups (FAO & FHI 360, 2016)) and child (of 7 groups (WHO, 2008))	Six-monthly MCHN questionnaire
	Dietary adequacy	• Dichotomous variable, based on minimum cut-offs for women (≥5 of 10 food groups (FAO & FHI 360, 2016)) and children (≥4 of 7 food groups (WHO, 2008))	Six-monthly MCHN questionnaires
	ASF consumption	• Dichotomous variable, according to reports of food consumed during the day or night prior to interview, overall and by category: – Eggs – Chicken meat – Other meat and fish – Milk	Six-monthly MCHN questionnaires
Household demographics	Maternal age	• In years, based on mother's recall or calculated from self-reported date of birth if age unknown	Baseline MCHN questionnaire
	Maternal formal education	• Dichotomous variable for no formal education vs. some level of primary or secondary school education	Baseline MCHN questionnaire
	Household size	• Total number of household members, with a household defined as people living together and sharing food at least three days of each week for the previous six months (Alkire et al., 2013)	Annual household questionnaires
	Head of household	• Male or female, as reported by questionnaire respondent (any household member 16 years of age or older, with intended even numbers of male and female respondents)	Annual livelihood questionnaires
	Household language group	• Dichotomous variable distinguishing the Sukuma language group from other groups; determined from the first language of the mother and father of enrolled children, and the gender of the household head	Six-monthly MCHN questionnaires

	Variable	Definition or description of categories	Data source
Water and sanitation	Water source	• Categorised as improved or unimproved (WHO & UNICEF, 2006)	Six-monthly MCHN questionnaires
	Toilet facility	• Categorised as improved or unimproved (WHO & UNICEF, 2006)	Six-monthly MCHN questionnaires
Socioeconomic status	Household Domestic Assets Index (HDAI)	• Weighted sum of livestock and non-livestock assets (Njuki et al., 2011) *For dietary models:* Chickens and cattle excluded from HDAI, to test their association with dietary outcomes separately	Annual livelihood questionnaires
	Non-livestock Asset Index (NLAI)	• Weighted sum of non-livestock assets only (Njuki et al., 2011) *For stunting and diarrhoea models:* NLAI used rather than HDAI, to evaluate livestock variables separately	Annual livelihood questionnaires
Livestock ownership	Livestock ownership	• Dichotomous variable (yes / no) for owning any form of livestock	Annual livelihood questionnaires
	Cattle ownership	• Dichotomous variable (yes / no) for owning cattle • Dichotomous variable for median number of cattle owned (i.e. >7 vs. ≤7) • Number of cattle owned	Annual livelihood questionnaires
	Small ruminant ownership	• Dichotomous variable (yes / no) for owning sheep or goats • Dichotomous variable for median number of sheep or goats owned (i.e. >11 vs. ≤11) • Number of sheep or goats owned	Annual livelihood questionnaires
	Chicken ownership	*For dietary models:* Variables based on chicken ownership during the month of dietary assessment • Dichotomous (yes / no) variable • Dichotomous variable for median number of chickens (i.e. >4 vs. ≤4) • Number of chickens >2 mo *For stunting and diarrhoea models:* Variables based on chicken ownership over six-month periods preceding anthropometry • Dichotomous variable: yes (if mean number ≥1) / no (if <1) • Dichotomous variable for above median number of chickens (i.e. > 4 vs. ≤4) • Mean number of chickens >2 mo	Twice-monthly household visits
	Overnight housing of chickens	• Three-level factor for six-month periods preceding each round of anthropometry: 1. No chickens 2. Chickens kept inside 3. Chickens kept outside	Annual livelihood questionnaires
	"Livestock ladder"	• Four-level factor for six-month periods preceding each round of anthropometry: 1. No livestock 2. Chickens only 3. Small ruminants +/- chickens 4. Cattle +/- small ruminants or chickens	Annual livelihood questionnaires, Twice-monthly household visits

Table 3. Comparison of food groups used in the evaluation of dietary adequacy for mothers (≥5 of 10 groups (FAO & FHI 360, 2016)) and enrolled children (≥4 of 7 groups (WHO, 2008)) in this study.

Mothers	Children
Grains, white roots and tubers, and plantains	Grains, roots and tubers
Pulses (beans, peas and lentils)	Legumes and nuts
Nuts and seeds	
Dairy	Dairy products
Meat, poultry and fish	Flesh foods (meat, poultry, fish, organ meats)
Eggs	Eggs
Dark green leafy vegetables	Vitamin A-rich fruits and vegetables
Other vitamin A-rich fruits and vegetables	
Other vegetables	Other fruits and vegetables
Other fruits	

In this study, a "household" was defined as a group of people living together and sharing food from the same pot, with members having lived in the household at least three days of each week for the previous six months (Alkire et al., 2013). This definition seeks to encompass individuals who share some common resources and make some common budget and expenditure decisions.

Socioeconomic status was represented using several variants of an index developed for use in sub-Saharan Africa, which assigns a weight to livestock and non-livestock assets according to their equivalent value (Njuki et al., 2011). Information on the development and validation of this index is not readily-available, but it is currently recommended for all projects receiving funding from the Bill and Melinda Gates Foundation. The relative value of assets is context-specific; however, based on input from Tanzanian research partners and time spent in project sites, the thesis candidate judged the weighting system to provide an adequate estimation of wealth for use in this analysis. The HDAI was modified to accommodate available data (excluding components relating to land ownership, plot size and the depreciation of assets), and a weighting was applied to eleven material assets (radio, television, refrigerator, mobile phone, mosquito net, table, sewing machine, bicycle, motorcycle, car and ox-cart) and six forms of livestock (cattle, sheep, goats, donkeys, pigs and poultry). Three variants of this index were used, as outlined in Table 4.

Sources of drinking water were classified as improved, for piped water, public taps or protected wells or boreholes, and unimproved for unprotected wells and other open sources such as rivers (WHO & UNICEF, 2006). Households were considered to have an improved toilet if the facility was used only by members of one household and if waste is separated from human contact (WHO & UNICEF, 2006).

Table 4. Indicators to represent household socioeconomic status in this study.

Indicator	Definition	Use
Household Domestic Asset Index (HDAI)	A weighted sum of material and livestock assets	To characterise households' socioeconomic status in descriptive summaries of the study population.
HDAI excluding cattle and chickens	A weighted sum of material and selected livestock assets (sheep, goats, donkeys, pigs)	To control for variation in socioeconomic status in multivariable models for maternal and child diets, where the influence of cattle and chicken ownership was tested separately.
Non-Livestock Asset Index (NLAI)	A weighted sum of material assets only	To control for variation in socioeconomic status in multivariable models for child stunting and diarrhoea, where multiple livestock-associated variables were tested separately.

Two questions were used to determine maternal age: self-reported date of birth, and self-reported age in years at the time of baseline data collection. Where there was a conflict between these two responses, birthdate was considered a more reliable data source and was used to calculate age. Household language group was also considered as a potential determinant of child growth outcomes, based on observed and documented differences in household dynamics, diets and the practice of agropastoralism in this setting (Mabilia, 1996; Selemani et al., 2012). Information on the "first language" of each of the enrolled child's parents was collated with the gender of the household head to determine the dominant language group of each household, as a proxy for a range of cultural and agricultural practices.

To address the complex linkages between livestock, health and nutrition, multiple variables based on livestock ownership were assembled (Table 2). For each major category of animals, variables were constructed to reflect ownership:

- as a bivariate categorical variable (i.e. yes / no),
- relative to the median herd or flock size in the study population (i.e. > / ≤ median), and
- in terms of the number of animals owned.

A "livestock ladder" variable was also calculated, which categorised households into four levels of livestock ownership based on the animal species owned:

- no livestock,
- chickens only,
- small ruminants, with or without chickens, and
- cattle, with or without other livestock.

Each variable was constructed to reflect livestock ownership for the period preceding each six-monthly round of child anthropometry. Information on ruminant ownership was drawn from the annual household questionnaire, while chicken ownership was based on a more detailed dataset from twice-monthly household visits. This decision was made in recognition of the highly variable nature of chicken ownership in village settings, where substantial fluctuations in ownership and flock size may be seen due to short reproductive cycles, frequent sales to meet household needs, and losses due to predation or seasonal disease outbreaks. Records of chicken numbers were separated into those under two months of age (i.e. chicks) and those over two months of age. To evaluate contributions to diets, income and household environments, chicks were excluded from measures of chicken flock size. A summary of the construction of chicken-associated variables, including the time periods relevant to various outcome variables, is shown in Figure 2.

To test associations between chicken ownership and maternal and child diets, the number of chickens owned during the month of dietary assessment was used. In analyses for longer-term outcomes, a broader assessment of chicken ownership was considered to be more relevant, rather than a single point-in-time count of chicken numbers. To test associations with children's HAZ, therefore, the mean number of chickens owned by a household during the six-month period *preceding* each measurement was calculated. This same variable was used as a predictor of the diarrhoea score, reflecting the number of episodes of child diarrhoea over a six-month period. To form a dichotomous variable for chicken ownership in these analyses, households were categorised as "chicken-keeping" if their mean number of chickens was one or greater for a six-month period, and "non-chicken-keeping" if less than one. Information on the location of overnight chicken housing was drawn from the annual questionnaires.

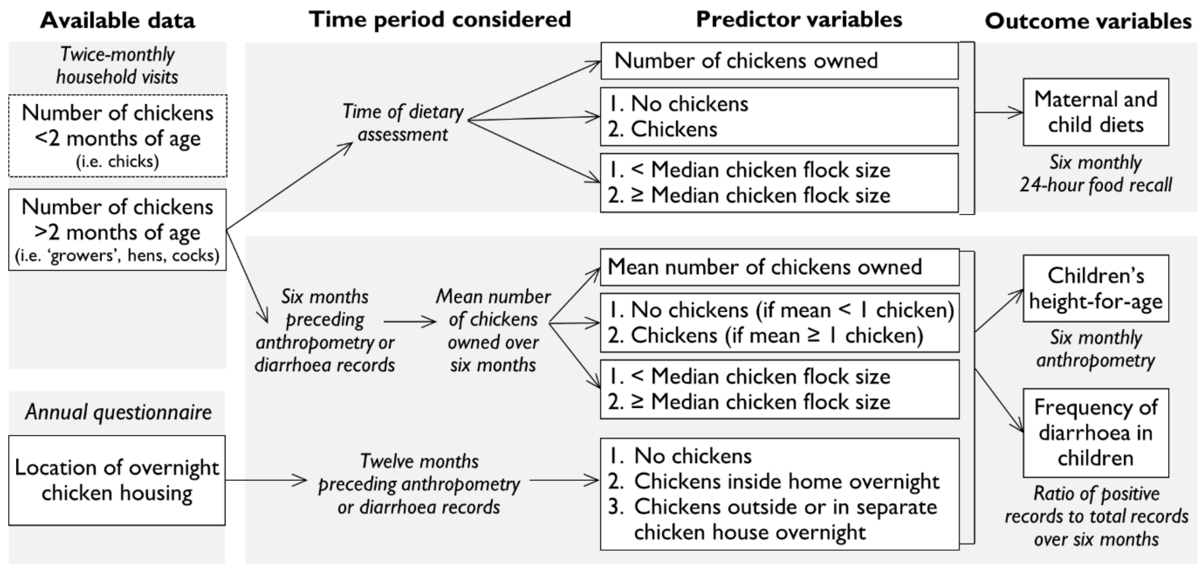

Figure 2. Use of available data on chicken ownership and overnight housing location to assemble predictors of maternal and child dietary outcomes, height-for-age and diarrhoea in children. Consideration has been given to the age of chickens and the time period over which chicken ownership is measured.

Descriptive statistics

Descriptive analyses were used to characterise the study population, explore variation between the two wards, and evaluate intended predictor and outcome variables. Percentages were determined for categorical variables, and means and standard deviations or medians and interquartile ranges calculated, for normally and non-normally distributed continuous variables, respectively. Inter-group comparisons for the two wards were performed using *t*-tests and chi-square tests for continuous and bivariate categorical variables, respectively. Differences were considered significant at $p < 0.05$. Graphical summaries were used to depict a range of categorical variables relating to livestock ownership. Dietary outcomes, including dietary diversity (DD) scores and the percentage of participants consuming adequately diverse diets and those consuming ASFs, were also represented graphically: for mothers, breastfed and non-breastfed children at six-monthly intervals.

Univariable and multivariable models

All analyses were conducted in the form of linear mixed models or generalised linear mixed models, using Genstat Release 18 software (https://www.vsni.co.uk/). Consideration was given to the potential for spatial clustering by including ward, village and sub-village locations as random effects, along with household identifiers to account for repeat-measure data. Three broad components of the study included:

1. maternal and child dietary diversity, dietary adequacy and the consumption of ASF;
2. child HAZ and probability of the stunting; and,
3. children's "diarrhoea score" (the ratio of positive records of diarrhoea to the total number of records per child over a defined time period).

In each case, predictor variables of interest (demographic, socioeconomic and livestock-associated) were collated for six-month periods corresponding to each outcome variable. For livestock numbers and asset scores, log-transformations were used to minimise the excessive influence of very large numbers. Univariable models were first used to test unconditional associations between predictor and outcome variables. Multivariable models were constructed using variables of suggestive significance ($p < 0.1$) based on univariable models, and stepwise backward elimination was used to manually remove variables with *p*-values greater than 0.1 to reach the final models. Both significant ($p < 0.05$) and suggestive ($0.05 \leq p < 0.1$) associations have been reported.

7.3 Results

7.3.1 Characterising the study population

Of a total of 513 children randomly selected to participate in the study, adequate baseline data were available to allow 503 children to be included in this analysis. An attrition rate of 16.9% was seen at the time of final data collection in May 2016, due to periods of travel, relocation outside the study area (n = 39), parents' choice to discontinue their child's involvement in the study (n = 5), and child deaths (n = 6). Table 5 presents an overview of individual- and household-level characteristics at the time of baseline data collection, by ward and in the overall sample.

The mean age of children at enrolment was 8.6 mo (SD 5.3, range of 0.6-28.1 mo). Variation in child age was seen across the two wards, with a greater number of eligible households in Majiri Ward enabling more children to be enrolled in the first stage of the two-stage selection process (i.e. <12 mo). The mean age of mothers at baseline data collection was 27.7 years (range of 13-54 years). There was a low level of school attendance amongst women, with almost one-third of mothers (32.5%) reporting having had no formal education. Given the small number of women with education beyond a primary school level (3.4%), a dichotomous variable for maternal education was used as a predictor variable in later analyses, distinguishing those mothers with some school attendance from those with none.

Twenty-two language groups were represented within the study population, with *Kigogo* as the primary language for 75.7% of households and *Kisukuma* the primary language for 9.1%. The Sukuma language group (those speaking *Kisukuma*) constituted a significantly larger percentage of enrolled households in Majiri Ward compared to Sanza Ward (14.6% vs. 6.1%, p = 0.02). For a large majority of enrolled children, both parents were reported to share their first language (94.1%). Households included a mean number of 5.5 members (range of 2-21), and 22.7% reported a female head of household (30.2% in Sanza Ward, 16.4% in Majiri Ward).

At the time of baseline data collection, only 4.9% of households reported accessing an improved water source. Variation was observed across data collection periods, according to season and the state of operation of public water distribution facilities. Less than 2% of respondents reported using improved toilet facilities, and almost three-quarters (72.7%) shared toilet facilities with one or more other households.

Table 5. Overview of study population according to baseline questionnaire responses, by ward and overall.

Location	Sanza Ward	Majiri Ward	Overall
Baseline data collection	May 2014	Nov 2014	
Enrolled households (*n*)	229	274	503
Sex of child, female (%)	55.5	47.4	51.1
Child age in months			
Mean (SD)	9.9 (6.1)[a]	7.6 (4.3)[a]	8.6 (5.3)
Range	1.2 – 28.1	0.6 – 22.5	0.6 – 28.1
Maternal age in years			
Mean (SD)	28.5 (7.5)[a]	26.8 (7.5)[a]	27.7 (7.6)
Range	15 – 50	13 – 54	13 – 54
Age unknown (%)	9.2[b]	23.7[b]	17.1
Maternal education (%)			
No formal education	22.7[b]	40.5[b]	32.4
Some primary school	68.6[b]	56.6[b]	62.0
Some secondary school	5.7[b]	1.5[b]	3.4
Unspecified level	3.1	1.5	2.2
Primary language of household (%)			
Kigogo	78.2[b]	74.8[b]	76.3
Kisukuma	6.1[b]	14.6[b]	10.7
Other	4.4	2.6	3.4
Unspecified	11.4[b]	8.0[b]	9.5
Parents of same language group (%)	92.1	95.6	94.1
Number of household members			
Mean (SD)	5.6 (2.0)	5.5 (2.3)	5.5 (2.2)
Range	2 – 16	2 – 21	2 – 21
Female-headed households (%)	30.2[b]	16.4[b]	22.7
Socioeconomic status, median (IQR)			
Non-livestock and livestock assets, HDAI	12 (5-51)	26 (7-115)	19 (7-76)
Non-livestock assets only, NLAI	7 (3-11)	9 (3-13)	9 (3-12)
Livestock ownership (%)			
Cattle	26.7[b]	36.2[b]	31.8
Sheep or goats	27.1[b]	47.8[b]	38.3
Chickens	51.1[b]	42.1[b]	46.3
Number of livestock, median (IQR)[c]			
Cattle	4 (2-17)[a]	10 (4-20)[b]	7 (4-20)
Sheep or goats	14 (7-20)	12 (5-25)	12 (6-24)
Chickens	7 (2-13)	8 (5-13)	8 (4-13)
Improved water source (%)	2.6	2.2	4.9
Improved toilet facilities (%)	3.1[b]	0.4[b]	1.6

Significant differences between wards ($p < 0.05$), as determined by [a]*t*-tests and [b]chi-square tests.
[c]Amongst households owning livestock, by category.

7.3.2 Socioeconomic status and livestock ownership

Given the close linkages between socioeconomic status and livestock ownership in rural households, multiple variables and indices were employed to appropriately quantify the contributions of chicken-keeping, as well as other livestock and non-livestock assets to nutrition outcomes. The HDAI, based on the weighted sum of livestock and non-livestock assets, varied widely across the study sample, at baseline ranging from 0 (for ten households) to 1007, with a median score of 19 and a markedly positively-skewed distribution. The median HDAI in Majiri

Ward was more than twice that in Sanza Ward (26 vs. 12), however less prominent variation was seen in household wealth based on non-livestock assets (median NLAI of 9 in Majiri Ward, vs. 7 in Sanza Ward).

The percentage of participating households owning ruminants was higher in Majiri Ward compared to Sanza Ward (36.2% vs. 26.7%, $p = 0.024$ for cattle; 47.8% vs. 27.1%, $p < 0.001$ for sheep and goats), and numbers of cattle owned were significantly greater (median herd size of 10 in Majiri vs. 4 in Sanza, $p = 0.012$). Baseline data suggested levels of chicken ownership to be higher in Sanza Ward compared to Majiri Ward (51.1% vs. 42.1%, $p = 0.047$), however the seasonal variation in chicken numbers and differing months of baseline assessments in the two wards prevents conclusions being drawn using these data.

Questionnaire data from all data collection periods were collated to produce descriptive summaries of livestock ownership (May 2014 – May 2016 in Sanza Ward, Nov 2014 – May 2016 in Majiri Ward; Figure 3). More than seventy per cent of households (70.8%) reported owning some form of livestock, with chickens kept by 55.0%, sheep and goats by 38.4% and cattle by 31.5%. Over one third of all participating households (35.3%), or almost two-thirds of chicken-keeping households (64.2%), reported chickens to be housed in a room inside their home overnight, rather than in a chicken-house or roosting in trees.

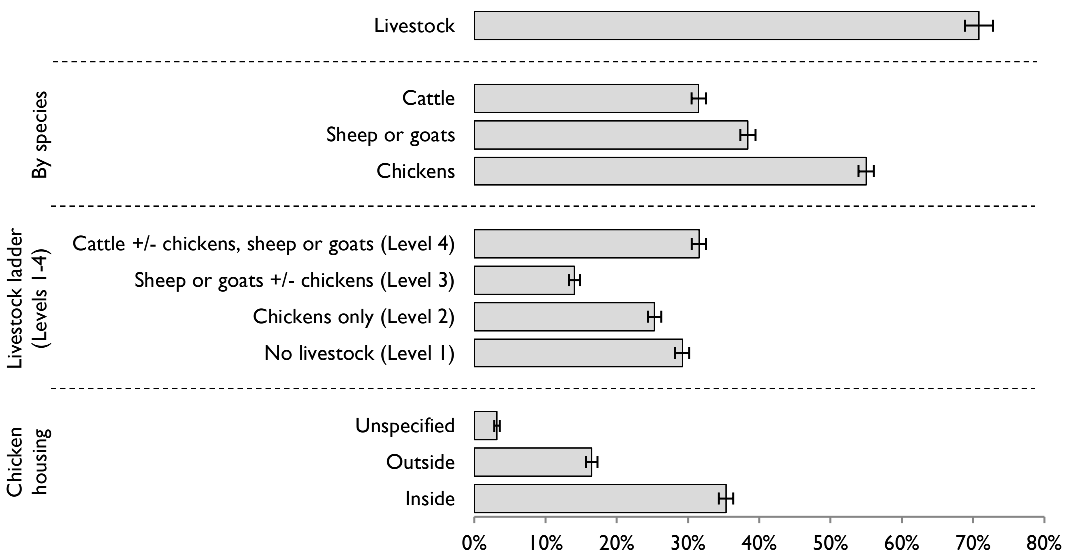

Figure 3. Percentage of households owning livestock, as recorded across all data collection periods: overall, by species, according to the livestock ladder and, for chickens, by the location of overnight housing. 95% confidence intervals are shown.

Generalised linear mixed models which accounted for geographic clustering and longitudinal data were used to test associations between households' socioeconomic status measured through non-livestock assets (i.e. quintiles of the NLAI) and their likelihood of owning livestock. The NLAI was shown to be positively associated ($p < 0.001$) with the probability of ownership for all categories of animals, however the extent of the association varied between species (Figure 4). Households in the lowest NLAI quintile were identified to have a 0.44 probability of owning chickens, compared with a 0.12 probability of owning sheep or goats and a 0.07 probability of owning cattle. The comparative increase in the likelihood of animal ownership with increasing NLAI quintiles also varied between livestock categories. A household in the highest quintile had 21.2 times greater odds of owning cattle (0.61 probability vs. 0.07), 9.6 times greater odds of owning sheep or goats (0.56 vs. 0.12), and 4.1 times greater odds of owning chickens (0.77 vs. 0.44), compared to a household in the lowest quintile.

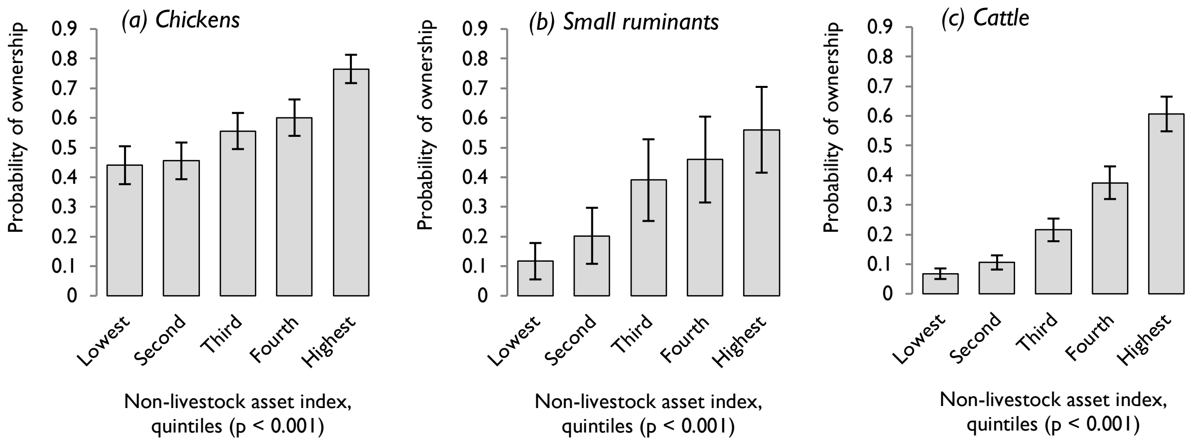

Figure 4. Probability of owning livestock, according to quintiles of the non-livestock asset index (NLAI).
For all categories of animals, the NLAI was positively associated with the probability of ownership ($p < 0.001$). Standard errors are shown.

An image-based representation of the livestock ladder is given in Figure 5. Using this hierarchical approach to categorise livestock ownership, around one-quarter of participating households (25.3%) were identified to keep only chickens, 14.0% kept sheep or goats, with or without chickens but without cattle, and 31.5% kept cattle, with or without other livestock. Accounting for geographic variation and individual household effects, positive associations ($p < 0.001$) were also identified between the livestock ladder and the NLAI. Model-based means show a markedly greater asset score based on material assets amongst households in the highest "rung" on the livestock ladder (Figure 6a). Substantially greater mean NLAI scores were also identified with owning chickens, small ruminants and cattle, compared to not owning each form of livestock (Figure 6b).

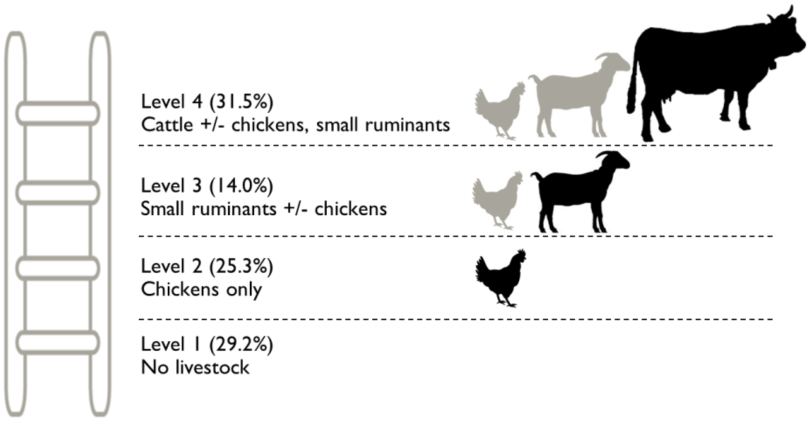

Figure 5. Graphical representation of levels on the "livestock ladder", and the percentage of participating households allocated to each category, based on survey data across all data collection periods.

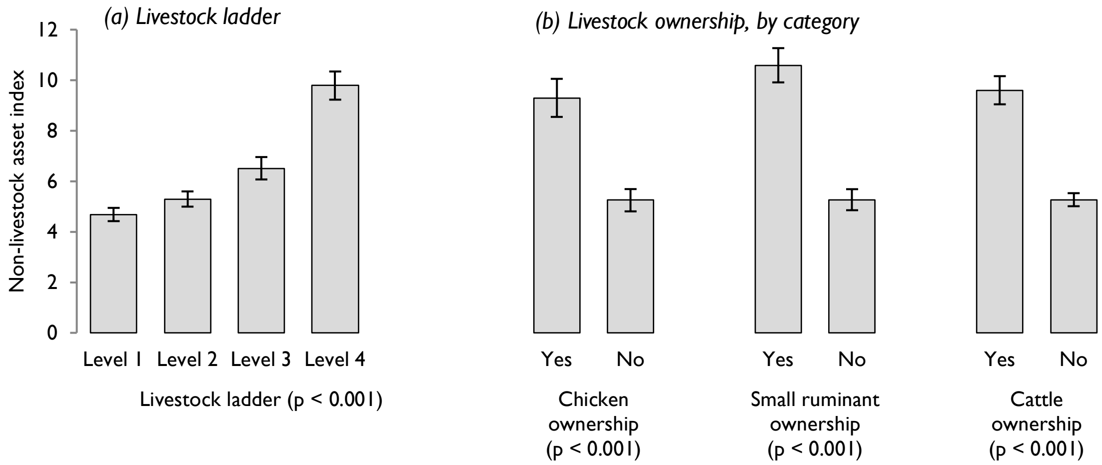

Figure 6. Mean non-livestock asset index (NLAI) scores according to (a) levels on the livestock ladder, and (b) ownership of chickens, small ruminants and cattle. Standard errors are shown.

7.3.3 Maternal and child diets

Dietary diversity and animal-source food consumption

Dietary adequacy and the consumption of ASF by enrolled children and their mothers is shown in Figure 7, by data collection period and overall. Of a total of 1790 completed records for women, only 27.1% had an adequately diverse diet (≥5 of 10 food groups) with 41.8% consuming one or more ASF in the recall period. Consumption of eggs and chicken meat were very low (2.1% mothers for each item, across all records), and markedly less common than other forms of meat or fish (25.4%) and milk (19.7%). Diets of breastfed and non-breastfed children were evaluated separately. Due to the age of children at enrolment in the study (<24 mo), small numbers of non-breastfed children during early data collection periods and small numbers of breastfed children during later periods resulted in wide confidence intervals for some percentages reported. Approximately one third of breastfed children (32.6%, of 873 records) and over half of non-breastfed children (55.6%, of 882 records) met the cut-off for adequate dietary diversity (≥4 of 7 food groups).

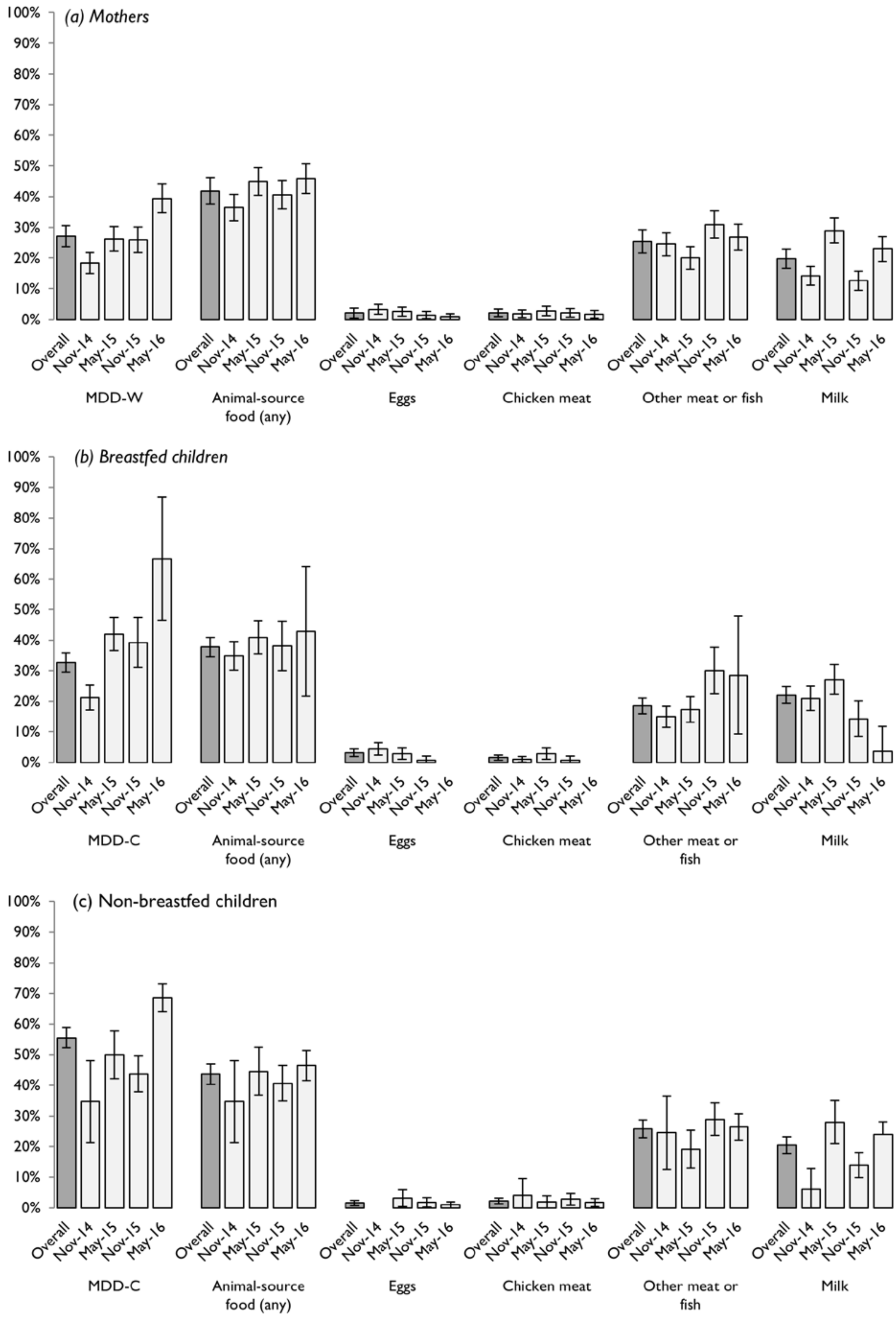

Figure 7. Percentage of mothers and children achieving adequate diets (according to MDD-W and IYCMDD, respectively) and consuming animal-source foods, based on six-monthly 24-hour food recall, overall and by data collection period. 95% confidence intervals are shown.

An increase in the percentage of women consuming an adequate diet was seen across successive data collection periods, from 18.4% in November 2014 to 39.4% in May 2016. Similar increases for both breastfed (21.3% to 66.7%) and non-breastfed children (34.7% to 68.6%) were also noted. Of specific ASF, there was prominent variation in the consumption of milk between data collection periods. With the exception of the small number of breastfed children in May 2016 ($n = 21$), records indicate more common consumption during May compared to November.

The mean DD score recorded over all data collection periods was 3.8 (SD 1.4) for mothers, 3.0 (SD 1.3) for breastfed children and 3.7 (SD 1.1) for non-breastfed children (Figure 8). As for the minimum cut-offs for dietary adequacy, graphical summaries suggest a mild increase in mean scores over time. Although the percentage of non-breastfed children receiving an "adequately diverse" diet was double that of their mothers (55.6% vs. 27.1%), the DD scores or number of distinct food groups eaten were similar for both groups.

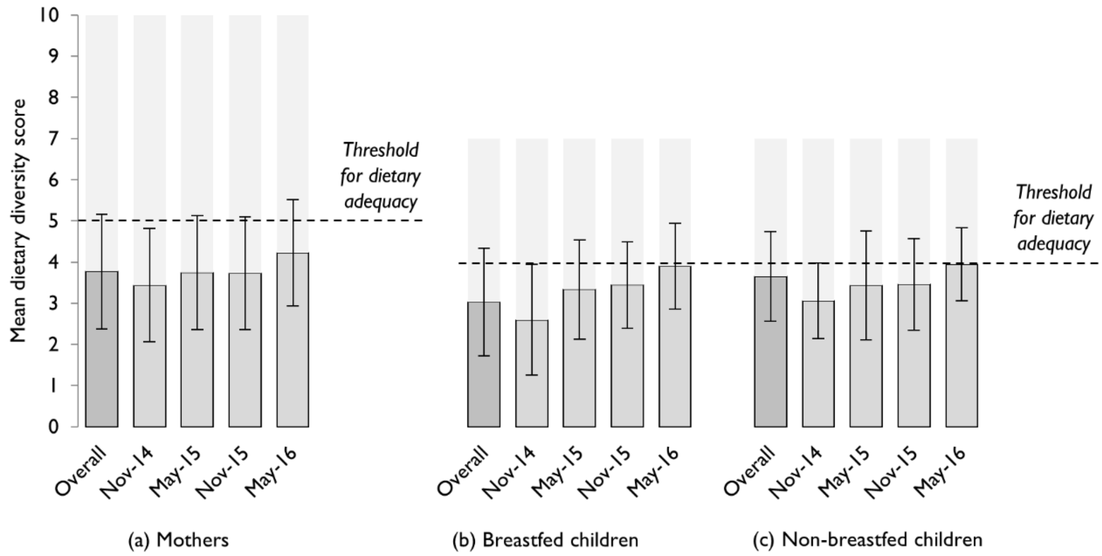

Figure 8. Mean dietary diversity scores of mothers (relative to 10 food groups) and children (relative to 7 food groups), overall and by data collection period. Light grey shading indicates the number of food groups. Standard errors are shown.

Univariable and multivariable models

Several measures of chicken ownership were identified as being significantly associated with positive dietary outcomes in univariable models (Table 6), however in a majority of cases these associations were not significant within multivariable models (Table 7). For example, despite positive unconditional associations ($p < 0.001$) between the number of chickens owned by a household and DD scores for mothers and breastfed children, no significant associations were identified when the adjusted HDAI (i.e. a measure of socioeconomic status, excluding chickens and cattle) was also included in models. One notable exception to this pattern was the consumption of ASF by women, which was positively associated with both the number of chickens (p = 0.009) and cattle (p = 0.005) owned by a household, but not with estimates of household wealth based on other assets (p = 0.190).

In final multivariable models (Table 7), across all dietary outcomes and participant groups, no significant differences were detected between the categories of chicken-keeping and non-chicken-keeping households. In two models, one assessing the probability of mothers achieving an adequately diverse diet and one evaluating DD scores amongst breastfed children, positive associations were identified with ownership of greater than the median number of chickens (i.e. more than four birds >2 mo). The number of chickens owned by a household, tested as a continuous variable, was also positively associated with DD scores for non-breastfed children (p = 0.038), and chicken consumption by breastfed children (p = 0.016), and suggested to be positively associated with chicken consumption by mothers (p = 0.053).

In all three participant groups, egg consumption was not associated with chicken ownership, but rather with the adjusted HDAI. Although eggs were infrequently eaten across the study population, mothers in the highest wealth quintile were suggested to have 16.5 times greater odds of consuming eggs than those in the lowest quintile (0.038 probability vs 0.002), and breastfed children in the highest quintile to have 17.9 times greater odds than those in the lowest quintile (0.053 vs. 0.003). In contrast to the lack of association between chicken ownership and egg consumption, cattle numbers were a strong predictor of milk consumption for all groups ($p < 0.001$), allowing for the influence of season and language group (with households identifying as Sukuma significantly more likely to consume milk ($p < 0.001$ for mothers and non-breastfed children, p = 0.002 for breastfed children)).

For all groups, significant variation in DD scores, dietary adequacy and milk consumption were seen between months of dietary assessments. In all cases, diets were significantly more diverse, more likely to meet thresholds for nutritional adequacy, and milk more likely to be consumed in May, compared to November. Suggestive associations were detected between maternal age and two dietary outcomes, with older mothers recording slightly lower DD scores (p = 0.067, β = -0.004) and lower probability of egg consumption (p = 0.092, β = -0.044). No associations were detected between maternal formal education and diets for women or children.

Table 6. Univariable models[a] evaluating the significance of predictor variables for maternal and child dietary adequacy, dietary diversity and ASF consumption, showing *p*-values and the direction of associations (+/-). Grey shading indicates all suggestive associations ($p < 0.1$).

	Dietary adequacy	DD score[b]	ASF consumption			
			Any	Chicken	Egg	Milk
(a) Mothers						
Month of dietary assessment, May	<0.001 (+)	<0.001 (+)	<0.001(+)	0.694	0.343	<0.001 (+)
Maternal age	0.393	0.299	0.043 (-)	0.976	0.423	0.157
Maternal formal education, yes	0.090 (+)	0.095 (+)	0.939	0.465	0.959	0.239
Breastfeeding, yes	<0.001 (-)	<0.001 (-)	0.022 (-)	0.887	0.018 (+)	0.377
Sex of household head, female	0.502	0.725	0.284	0.428	0.015 (+)	0.004 (-)
Number of household members	0.815	0.944	0.864	0.213	0.689	0.016 (+)
Language group, Sukuma	0.484	0.118	0.001 (+)	0.120	0.486	<0.001 (+)
Household domestic asset index[c,d]	<0.001 (+)	<0.001 (+)	<0.001 (+)	0.024 (+)	0.005 (+)	<0.001 (+)
Chickens owned, yes	0.004 (+)	0.003 (+)	0.003 (+)	0.036 (+)	0.685	0.011 (+)
Chickens, above median number	<0.001 (+)	0.009 (+)	0.011 (+)	0.463	0.148	0.003 (+)
Chickens, number owned[c]	<0.001 (+)	<0.001 (+)	<0.001 (+)	0.013 (+)	0.159	<0.001 (+)
Cattle owned, yes	0.003 (+)	0.002 (+)	<0.001 (+)	0.251	0.146	<0.001 (+)
Cattle, above median number	0.167	0.053 (+)	0.003 (+)	0.418	0.305	<0.001 (+)
Cattle, number owned[c]	0.003 (+)	0.001 (+)	<0.001 (+)	0.137	0.070 (+)	<0.001 (+)
(b) Breastfed children						
Month of dietary assessment, May	<0.001 (+)	<0.001 (+)	0.655	0.149	0.458	0.021
Child age	<0.001 (+)	<0.001 (+)	0.043 (+)	0.224	0.158	0.152
Sex of child, female	0.196	0.998	0.425	0.929	0.865	0.304
Child height-for-age Z-score	0.518	0.192	0.623	0.256	0.588	0.372
Maternal formal education, yes	0.673	0.517	0.460	0.134	0.326	0.680
Sex of household head, female	0.656	0.518	0.559	0.513	0.106	0.113
Number of household members	0.075 (+)	0.142	0.361	0.591	0.391	0.018 (+)
Language group, Sukuma	0.015 (+)	0.103	0.002 (+)	0.260	0.127	<0.001 (+)
Household domestic asset index[c,d]	<0.001 (+)	0.002 (+)	<0.001 (+)	0.162	0.214	<0.001 (+)
Chickens owned, yes	0.012 (+)	0.004 (+)	0.008 (+)	0.104	0.242	0.013 (+)
Chickens, above median number	0.005 (+)	<0.001 (+)	0.004 (+)	0.162	0.178	0.003 (+)
Chickens, number owned[c]	0.003 (+)	<0.001 (+)	<0.001 (+)	0.016 (+)	0.104	0.008 (+)
Cattle owned, yes	0.004 (+)	0.025 (+)	<0.001 (+)	0.181	N/A	<0.001 (+)
Cattle, above median number	<0.001 (+)	0.020 (+)	<0.001 (+)	0.289	0.704	<0.001 (+)
Cattle, number owned[c]	<0.001 (+)	0.004 (+)	<0.001 (+)	0.182	0.048 (+)	<0.001 (+)
(c) Non-breastfed children						
Month of dietary assessment, May	<0.001 (+)	<0.001 (+)	0.003 (+)	0.849	0.834	<0.001 (+)
Child age	0.138	0.023 (+)	0.884	0.163	0.045 (-)	0.950
Sex of child, female	0.123	0.180	0.015 (-)	0.799	0.328	0.288
Child height-for-age Z-score	0.044 (+)	0.060 (+)	0.568	0.434	0.976	0.323
Maternal formal education, yes	0.165	0.237	0.332	0.536	0.968	0.212
Sex of household head, female	0.307	0.892	0.565	0.482	0.266	0.082 (-)
Number of household members	0.789	0.709	0.924	0.080 (+)	0.185	0.116
Language group, Sukuma	0.289	0.063 (+)	0.003 (+)	0.231	0.751	<0.001 (+)
Household domestic asset index[c,d]	0.667	0.098 (+)	0.287	0.365	0.075 (+)	0.004 (+)
Chickens owned, yes	0.215	0.119	0.375	0.402	0.654	0.145
Chickens, above median number	0.725	0.097 (+)	0.169	0.998	0.432	0.021 (+)
Chickens, number owned[c]	0.361	0.025 (+)	0.056 (+)	0.521	0.103	0.007 (+)
Cattle owned, yes	0.491	0.111	0.090 (+)	0.600	0.629	<0.001 (+)
Cattle, above median number	0.768	0.531	0.051 (+)	N/A	0.554	<0.001 (+)
Cattle, number owned[c]	0.780	0.124	0.024 (+)	0.846	0.517	<0.001 (+)

[a] Generalised linear mixed models using binomial distribution, allowing for geographic clustering and longitudinal data

[b] Binomial totals of 10 for women (MDD-W) and 7 for children (IYCMDD)

[c] log-transformed variables used to minimise excessive influence of large numbers

[d] Cattle and chickens excluded from HDAI, evaluated as separate predictor variables

Table 7. Final multivariable models[a] for maternal and child dietary diversity and ASF consumption, showing *p*-values and the direction of significant ($p < 0.05$) and suggestive ($0.05 \le p < 0.1$) associations. Grey shading has been retained to show variables of suggestive significance in prior univariable models (Table 6).

	Dietary adequacy	DD score[b]	ASF consumption			
			Any	Chicken	Egg	Milk
(a) Mothers						
Month of dietary assessment, May	<0.001 (+)	<0.001 (+)	0.006 (+)	*NS*	*NS*	<0.001 (+)
Maternal age	*NS*	0.067 (-)	*NS*	*NS*	0.092 (-)	*NS*
Maternal formal education, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Breastfeeding, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Sex of household head, female	*NS*	0.068 (+)	*NS*	*NS*	<0.001 (+)	0.014 (-)
Number of household members	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Language group, Sukuma	*NS*	*NS*	0.032 (+)	*NS*	*NS*	<0.001 (+)
Household domestic asset index[c,d]	0.002 (+)	<0.001 (+)	*NS*	0.058 (+)	0.005 (+)	*NS*
Chickens owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Chickens, above median number	0.023 (+)[e]	*NS*	*NS*	*NS*	*NS*	*NS*
Chickens, number owned[c]	0.032 (+)[e]	*NS*	0.009 (+)	0.053 (+)	*NS*	*NS*
Cattle owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Cattle, above median number	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Cattle, number owned[c]	*NS*	*NS*	0.005 (+)	*NS*	*NS*	<0.001 (+)
(b) Breastfed children						
Month of dietary assessment, May	0.002 (+)	0.057 (+)	*NS*	*NS*	*NS*	0.028 (+)
Child age	<0.001 (+)	<0.001 (+)	*NS*	*NS*	*NS*	*NS*
Sex of child, female	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Child height-for-age Z-score	*NS*	0.075 (+)	*NS*	*NS*	*NS*	*NS*
Maternal formal education, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Sex of household head, female	*NS*	*NS*	*NS*	*NS*	0.032 (+)	*NS*
Number of household members	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Language group, Sukuma	0.046 (+)	*NS*	0.014 (+)	*NS*	*NS*	0.002 (+)
Household domestic asset index[c,d]	*NS*	0.002 (+)	<0.001 (+)	*NS*	<0.001 (+)	*NS*
Chickens owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Chickens, above median number	*NS*	0.039 (+)	*NS*	*NS*	*NS*	*NS*
Chickens, number owned[c]	*NS*	*NS*	0.083 (+)	0.016 (+)	*NS*	*NS*
Cattle owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	0.010 (+)[f]
Cattle, above median number	*NS*	*NS*	*NS*	*NS*	*NS*	<0.001 (+)[f]
Cattle, number owned[c]	<0.001 (+)	*NS*	*NS*	*NS*	*NS*	<0.001 (+)[f]
(c) Non-breastfed children						
Month of dietary assessment, May	<0.001 (+)	<0.001 (+)	0.003 (+)	*NS*	*NS*	<0.001
Child age	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Sex of child, female	0.045 (-)	0.066 (-)	0.014 (-)	*NS*	*NS*	*NS*
Child height-for-age Z-score	0.029 (+)	0.061 (+)	*NS*	*NS*	*NS*	*NS*
Maternal formal education, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Sex of household head, female	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Number of household members	*NS*	*NS*	*NS*	0.080 (+)	0.059 (-)	*NS*
Language group, Sukuma	*NS*	*NS*	0.002 (+)	*NS*	*NS*	<0.001 (+)
Household domestic asset index[c,d]	*NS*	*NS*	*NS*	*NS*	0.023 (+)	*NS*
Chickens owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Chickens, above median number	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Chickens, number owned[c]	*NS*	0.038 (+)	*NS*	*NS*	*NS*	*NS*
Cattle owned, yes	*NS*	*NS*	*NS*	*NS*	*NS*	0.003 (+)
Cattle, above median number	*NS*	*NS*	*NS*	*NS*	*NS*	0.050 (+)
Cattle, number owned[c]	*NS*	*NS*	*NS*	*NS*	*NS*	<0.001 (+)

[a] Generalised linear mixed models using binomial distribution, allowing for geographic clustering and longitudinal data
[b] Binomial totals of 10 for women (MDD-W) and 7 for children (IYCMDD)
[c] log-transformed variables used to minimise excessive influence of large numbers
[d] Cattle and chickens excluded from HDAI, evaluated as separate predictor variables
[e] Two alternative models were constructed, one using the number of chickens owned and one using above- / below-median flock size, each together with the month of dietary assessment and HDAI (*p*-values for these latter variables remained unchanged).
[f] Three alternative models were constructed, one using cattle ownership as a dichotomous variable, one using above- / below-median cattle herd size and one using the number of cattle owned, each with the month of dietary assessment and language group (*p*-values for these latter variables remained unchanged). *NS* – non-significant within multivariable model

Both women and breastfed children were more likely to consume eggs in a female-headed household compared with a male-headed one ($p < 0.001$ and $p = 0.032$, respectively). While model-based predictions were low across all groups, breastfed children in female-headed households were determined to have 2.6 times greater odds of consuming eggs, compared to those in male-headed households (0.041 probability of consuming egg, vs. 0.016). Being part of a female-headed household was also suggested to be associated with higher DD scores for mothers (mean of 3.90 vs. 3.74 for male-headed households, $p = 0.068$), although women were less likely to consume milk ($p = 0.011$), controlling for variation in cattle ownership and language group. No significant associations were evident between household size and dietary patterns of children and their mothers.

Increasing child age was significantly associated with higher DD scores ($p < 0.001$; Figure 9a) and a higher probability of an adequately diverse diet ($p < 0.001$) for breastfed children, but not for non-breastfed children. Across the range of dietary outcomes evaluated, gender-based differences were only evident amongst the non-breastfed group. There was a significantly greater likelihood of male children meeting the cut-off for dietary adequacy ($p = 0.045$; Figure 9b) and a suggestive association with higher DD scores ($p = 0.066$). Boys were also significantly more likely to consume ASF than girls ($p = 0.014$; Figure 9b), controlling for differences in language group and data collection period.

Increasing HAZ amongst non-breastfed children was positively associated with the probability of consuming an adequately diverse diet ($p = 0.029$). Suggestive positive associations between HAZ and DD scores were also identified for children in both categories ($p = 0.075$ for breastfed children; $p = 0.061$ for non-breastfed children).

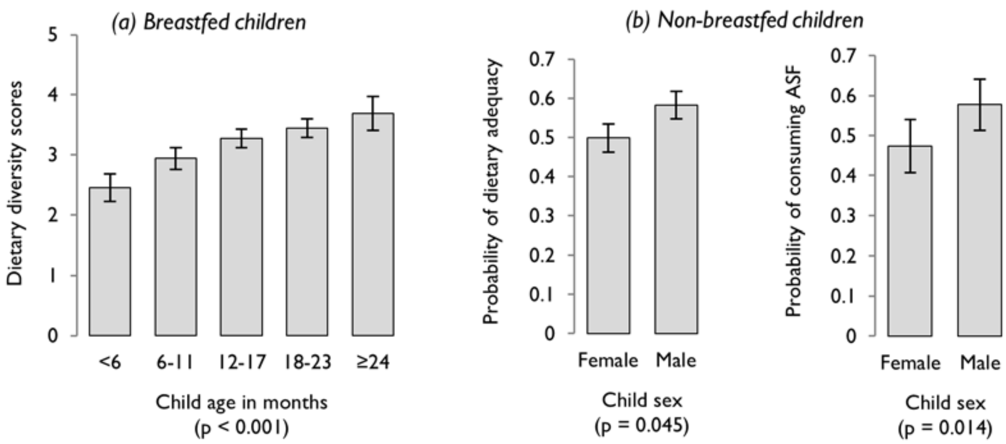

Figure 9. Multivariable models using longitudinal data show: (a) increasing dietary diversity scores with increasing child age, amongst breastfed children; and (b) a higher probability of both dietary adequacy and ASF consumption for boys compared to girls, amongst non-breastfed children. Standard errors are shown.

7.3.4 Child anthropometry and diarrhoea

Prevalence of stunting and wasting

Summaries of anthropometric data were disaggregated by ward and by time period (Table 8). The prevalence of stunting increased from 36.8% to 49.5% over the first three data collection periods in Sanza Ward, reducing to 39.8% at the time of the final data collection. In Majiri Ward, where the mean age of children was lower at enrolment (7.6 mo vs. 9.9 mo; $p < 0.001$), a continuing increase in the prevalence of stunting was seen over successive data periods, from 28.3% to 53.0%. Mean WHZ deviated less from international growth standards, with wasting levels ranging from 2.0-3.2% in Sanza Ward and 2.2-5.2% in Majiri Ward.

Table 8. Overview of height-for-age Z-scores (HAZ), weight-for-height Z-scores (WHZ) and the percentage of stunting and wasting amongst enrolled children, by ward and by data collection period.

	Mean HAZ (SD)	% Stunting	Mean WHZ (SD)	% Wasting	*n*
(a) Sanza Ward					
May 2014	-1.52 (1.13)	36.8	-0.01 (1.21)	3.2	220
Nov 2014	-1.63 (1.18)	34.5	-0.10 (1.08)	2.0	200
May 2015	-2.02 (1.14)	49.5	-0.07 (0.99)	2.0	202
Nov 2015	-1.98 (1.05)	48.2	0.00 (0.98)	2.6	191
May 2016	-1.77 (1.05)	39.8	-0.05 (0.91)	2.0	201
(b) Majiri Ward					
Nov 2014	-1.45 (1.21)	28.3	0.36 (1.20)	2.2	272
May 2015	-1.86 (1.05)	41.4	-0.16 (1.07)	2.3	261
Nov 2015	-1.99 (0.98)	49.6	-0.48 (0.96)	5.2	234
May 2016	-2.16 (1.00)	53.0	-0.30 (0.96)	4.2	217

Univariable and multivariable models

As for dietary outcomes, univariable models were first used to test unconditional associations between demographic, socioeconomic and livestock-associated variables and (a) HAZ, (b) probability of stunting, and (c) diarrhoea in children. Variables relating to the consumption of ASF by children during the day prior to anthropometry, overall and by category were also included. These short-term dietary indicators may be unlikely to be associated with long-term outcomes such as height-for-age; however, the potential for patterns to be identified at a population level was considered adequate to warrant their consideration.

Children's age, gender, diarrhoea frequency, household language group and wealth quintiles based on non-livestock assets were significantly associated with HAZ within univariable linear mixed models (Table 9), and remained significant at the 5% level in a multivariable model (Table 10). Height-for-age Z-scores were negatively associated with increasing child age, the male gender, higher numbers of positive records of diarrhoea, language groups other than Sukuma, and lower NLAI scores. Of the livestock and dietary variables identified as being significantly or suggestively associated with HAZ in univariable models, none were significant in multivariable models. These included the number of chickens owned by a household (p = 0.960 in multivariable model), livestock ownership as a bivariate categorical variable (p = 0.409), and children's consumption of milk (p = 0.802) or meat or fish (p = 0.236) during the previous day.

Similar associations were identified when considering stunting as a binary outcome, with a higher probability of stunting linked to increasing age, male children, language groups other than Sukuma and lower asset scores. No significant relationships between any livestock or dietary variables and the probability of stunting were found. Univariable analysis indicated a suggestive association with the HDAI (livestock and non-livestock assets), but it was the NLAI (non-livestock assets only) which was highly significantly associated (p < 0.001) with the probability of stunting in both uni- and multivariable models (Tables 9 and 10). Using NLAI quintiles, the most marked variation was associated with households in the lowest asset quintile, where children were predicted to have 2.1 times greater odds of stunting compared to children in the middle quintile, and 3.1 times greater odds than those in the highest quintile (Figure 10a). Significantly lower mean HAZ was also identified amongst the lowest NLAI quintile (Figure 10b).

Multivariable models revealed a significantly lower likelihood of diarrhoea with increasing child age (p < 0.001). Ownership of cattle was associated with a small but significant reduction in the probability of child diarrhoea (p = 0.021), with children in cattle-owning households identified to have a 0.036 probability of diarrhoea in a given fortnight, compared to a 0.045 probability in a household without cattle (Figure 11a). Controlling for child age and cattle ownership, however, milk consumption was linked to an increased probability of diarrhoea (p = 0.007), based on a single 24-hour dietary assessment conducted in each six-month period of diarrhoea records (Figure 11b).

There was also a suggestive association (p = 0.059) between consumption of chicken meat and a lower probability of child diarrhoea (Figure 11c). When variables related to chicken-keeping were tested in the same model, no significant difference in the number of positive diarrhoea records was evident according to chicken ownership (p = 0.305), the number of chickens owned (p = 0.498), or the practice of keeping chickens within the home overnight (p = 0.550).

Table 9. Univariable models evaluating the significance of predictor variables for height-for-age Z-scores (HAZ)[a], probability of stunting (HAZ<-2)[b] and diarrhoea frequency[b] in children, showing *p*-values and the direction of associations (+/-). Grey shading indicates all suggestive associations ($p < 0.1$).

	HAZ	Stunting	Diarrhoea
Child age	<0.001 (-)	<0.001 (+)	<0.001 (-)
Sex of child, female	0.006 (+)	0.003 (-)	0.681
Diarrhoea frequency	0.004 (-)	0.558	N/A
Height-for-age Z-score	N/A	N/A	0.641
Month of data collection, May[c]	<0.001 (-)	0.011 (+)	0.031 (-)
Sex of household head, female	0.126	0.495	0.995
Number of household members	0.761	0.504	0.808
Maternal formal education, yes	0.794	0.305	0.351
Household language group, Sukuma	<0.001 (+)	0.001 (-)	0.512
Improved water source	0.312	0.627	0.298
Improved toilet facility	0.555	0.945	0.618
Household domestic asset index			
Livestock and non-livestock assets[d]	0.205	0.061 (-)	0.072 (-)
Non-livestock assets only[d]	0.076 (+)	<0.001 (-)	0.828
Non-livestock assets only, quintiles	<0.001 (+)	<0.001 (-)	0.558
Livestock			
Livestock owned, yes	0.086 (-)	0.368	0.327
"Livestock ladder"[e]	0.134	0.467	0.259
Chickens owned, yes	0.214	0.925	0.128
Chickens, above median	0.002 (-)	0.109	0.479
Chickens, number owned[d]	0.007 (-)	0.424	0.252
Chickens, location of overnight housing	0.651	0.692	0.101
Sheep or goats owned, yes	0.618	0.919	0.302
Sheep or goats, above median	0.121	0.035 (-)	0.398
Sheep or goats, number owned[d]	0.100 (+)	0.260	0.513
Cattle owned, yes	0.392	0.541	0.046 (-)
Cattle, above median	0.340	0.060 (-)	0.385
Cattle, number owned[d]	0.125	0.223	0.151
Children's diet, previous 24 hours			
ASF consumption, yes	0.075 (-)	0.405	0.367
Chicken meat consumption, yes	0.181	0.324	0.050 (-)
Other meat or fish consumption, yes	0.001 (-)	0.531	0.473
Egg consumption, yes	0.587	0.814	0.584
Milk consumption, yes	0.084 (+)	0.554	0.042 (+)

[a] Linear mixed models, allowing for geographic clustering and longitudinal data
[b] Generalised linear mixed models using binomial distribution, allowing for geographic clustering and longitudinal data
[c] Two data collection months: May and November. Rainfall typically occurs between November and April in this area.
[d] log-transformed variables used to minimise excessive influence of large numbers
[e] Levels of livestock ownership (the "livestock ladder"): (1) none, (2) chickens only, (3) small ruminants +/- chickens, no cattle, (4) cattle +/- chickens and small ruminants.

Table 10. Final multivariable models for height-for-age Z-scores (HAZ)[a], probability of stunting (HAZ<-2)[b] and diarrhoea frequency[b] in children, showing *p*-values and the direction of significant ($p < 0.05$) and suggestive ($0.05 \leq p < 0.1$) associations. Grey shading has been retained to show variables of suggestive significance in prior univariable models (Table 9).

	HAZ	Stunting	Diarrhoea
Child age	<0.001 (-)	<0.001 (+)	<0.001 (-)
Sex of child, female	0.022 (+)	0.002 (-)	*NS*
Diarrhoea frequency	<0.001 (-)	*NS*	N/A
Height-for-age Z-score	N/A	N/A	*NS*
Month of data collection, May[c]	*NS*	*NS*	*NS*
Sex of household head, female	*NS*	*NS*	*NS*
Number of household members	*NS*	*NS*	*NS*
Maternal formal education, yes	*NS*	*NS*	*NS*
Household language group, Sukuma	<0.001 (+)	0.002 (-)	*NS*
Improved water source	*NS*	*NS*	*NS*
Improved toilet facility	*NS*	*NS*	*NS*
Household domestic asset index			
Livestock and non-livestock assets[d]	*NS*	*NS*	*NS*
Non-livestock assets only[d]	*NS*	<0.001 (-)[f]	*NS*
Non-livestock assets only, quintiles	0.009 (+)	<0.001 (-)[f]	*NS*
Livestock			
Livestock owned, yes	*NS*	*NS*	*NS*
"Livestock ladder"[e]	*NS*	*NS*	*NS*
Chickens owned, yes	*NS*	*NS*	*NS*
Chickens, above median	*NS*	*NS*	*NS*
Chickens, number owned[d]	*NS*	*NS*	*NS*
Chickens, location of overnight housing	*NS*	*NS*	*NS*
Sheep or goats owned, yes	*NS*	*NS*	*NS*
Sheep or goats, above median	*NS*	*NS*	*NS*
Sheep or goats, number owned[d]	*NS*	*NS*	*NS*
Cattle owned, yes	*NS*	*NS*	0.014 (-)
Cattle, above median	*NS*	*NS*	*NS*
Cattle, number owned[d]	*NS*	*NS*	*NS*
Children's diet, previous 24 hours			
ASF consumption, yes	*NS*	*NS*	*NS*
Chicken meat consumption, yes	*NS*	*NS*	0.059 (-)
Other meat or fish consumption, yes	*NS*	*NS*	*NS*
Egg consumption, yes	*NS*	*NS*	*NS*
Milk consumption, yes	*NS*	*NS*	0.007 (+)

[a] Linear mixed models, allowing for geographic clustering and longitudinal data

[a] Generalised linear mixed models using binomial distribution, allowing for geographic clustering and longitudinal data

[c] log-transformed variables used to minimise excessive influence of large numbers

[d] Two data collection months: May and November. Rainfall typically occurs between November and April in this area.

[e] Levels of livestock ownership (the "livestock ladder"): (1) none, (2) chickens only, (3) small ruminants +/- chickens, no cattle, (4) cattle +/- chickens and small ruminants.

[f] Two alternative models were constructed, one using the NLAI as a continuous variable and one using the NLAI as quintiles, each together with the age and sex of child and household language group (*p*-values for these latter variables remained unchanged).

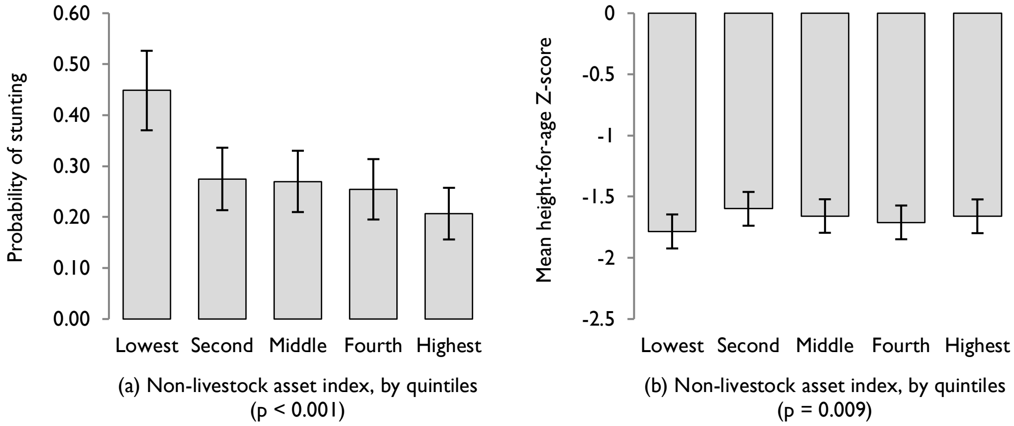

Figure 10. Socioeconomic status, as assessed by a weighted sum of non-livestock assets (NLAI), was significantly associated with (a) the probability of child stunting, and (b) child height-for-age Z-scores. Poorer growth was identified amongst the lowest wealth quintile.

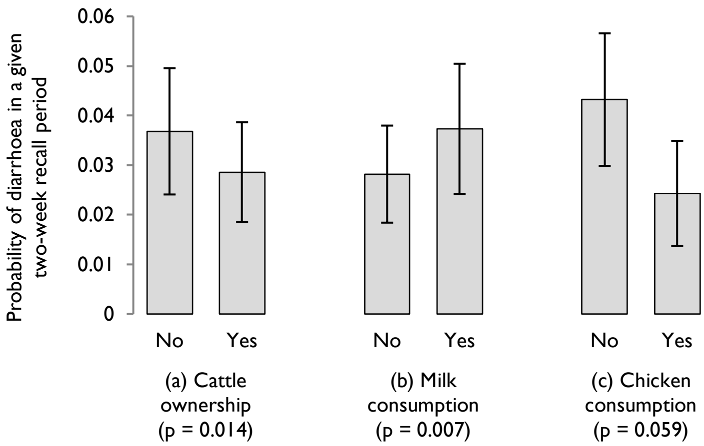

Figure 11. Probability of child diarrhoea being reported in a given two-week period, according to household cattle ownership, and children's consumption of milk or chicken meat in the previous day.

7.4 Discussion

With around two-thirds of breastfed children (67.4%) and almost three-quarters of their mothers (72.6%) failing to achieve an adequately diverse diet during the study period, and with stunting affecting close to half of all children (46.7%) at the time of final data collection, it is clear that substantial improvements in dietary quality are needed within this population. The aim of this chapter has been to combine detailed records of chicken ownership over a 24-month period with information on overnight chicken housing practices, demographic characteristics, sociocultural influences and ownership of other livestock and non-livestock assets, in order to test associations with dietary, growth and health outcomes for young children in this setting.

7.4.1 Seasonal and temporal variation

The opportunity to detect seasonal influences in diets has been limited by the two-year span of data. Seasonality is a key determinant of food availability in many low- to middle-income countries, particularly amongst rural populations, yet it is sometimes overlooked as a consideration in dietary assessments (Savy, Martin-Prevel, Traissac, Eymard-Duvernay, & Delpeuch, 2006). In this setting, where rain-fed agriculture is the predominant source of income and food for many households, there is a risk of food shortage between the depletion of one year's cereal stocks and the following year's harvest. Poultry mortality due to disease outbreaks, with signs consistent with Newcastle disease, are most common between July and November in this area (Buza & Mwamuhehe, 2000) and may also contribute to seasonal fluctuations in the availability of food resources and assets. While a seasonal influence on children's height-for-age is challenging to identify, there was no consistent pattern in levels of wasting between the anthropometric assessments conducted in May and November.

Of the two months of year when dietary assessments were conducted, May would typically be expected to be a time of relative food availability (due to recently-harvested crops and associated income, and a lower risk of chicken mortality) and November a time of food scarcity for less resilient households (when crop supplies have been depleted, income-earning opportunities are scarce, and losses due to Newcastle disease likely amongst unvaccinated chicken flocks). However, daily rainfall records indicate the 2014-2015 rain season to have been particularly poor, with a total rainfall of 447 mm (over 30 days) in Sanza Ward and 275 mm (21 days) in Majiri Ward, substantially lower than the long-term mean annual rainfall of 624 mm (49 days) for Manyoni District (Lema & Majule, 2009). The resultant poor harvest is likely to have resulted in less diverse diets being consumed in May 2015 than would be usual at this time of year.

When reviewing graphical summaries of diets (Figure 7), an increasing proportion of study participants appear to have consumed adequately diverse diets over successive six-monthly assessments, rather than a distinct pattern between the two seasons as might be expected. For breastfeeding children, diversification of diets with increasing age ($p < 0.001$) is likely to have contributed to an upward trend in diet quality measured longitudinally. Multivariable models, which control for children's age, confirm the month of data collection to be highly significantly associated with dietary diversity scores, dietary adequacy and milk consumption for children and their mothers (Table 7), with improved dietary outcomes in May compared to November.

7.4.2 Chicken ownership and maternal and child diets

The most recent national dietary assessment in Tanzania reported eggs to have been consumed by 5.2% of breastfed children under two years of age on the day preceding the interview (MoHCDGEC [Tanzania Mainland] et al, 2016). Egg consumption in this study was even lower, documented in only 3.2% of all records for breastfed children, 2.1% for women and 1.6% for non-breastfed children. Significant associations between egg consumption by all three groups and the HDAI, but not chicken ownership, suggests it to be the financial capacity for households to purchase eggs through local markets – rather than access to eggs laid by a household's own hens – which determines consumption frequency. This supports findings elsewhere in communities accustomed to seasonal disease outbreaks and high levels of mortality in scavenging chicken flocks, where poultry-keepers prioritise the hatching of eggs to provide replacement stock and the retention of chickens for sale in times of need over home consumption (Alders & Pym, 2009; Bagnol, 2001; Guèye, 2002; Pym, Guerne Bleich, & Hoffman, 2006). Previous qualitative work in this study setting has not revealed cultural constraints or currently-held beliefs to suggest other reasons for infrequent egg consumption (de Bruyn et al., 2017).

A significant increase in the probability of breastfed children consuming chicken meat with increasing numbers of chickens owned by their household, and a suggestive increase in the probability of chicken consumption by women, is encouraging. Positive associations between larger chicken flocks and improved diets (i.e. higher dietary diversity scores and increased likelihood of dietary adequacy) were identified in several univariable models, but these associations were not shown to be significant in multivariable models. It is suggested that initial unconditional associations were the result of chicken flock size acting as a proxy for households' socioeconomic status. The lack of significance in a majority of the multivariable models is likely to have been mediated by the inclusion of alternative measures of household wealth, through the HDAI.

In contrast, a greater likelihood of women consuming ASF was found to be significantly associated with increasing numbers of chickens and cattle, but not with wealth estimation based on other assets. In the case of cattle, this effect is likely to reflect access to milk (as shown in the specific model for milk consumption). Based on low levels of chicken meat and egg consumption throughout the study period, however, alternative mechanisms through which women's ASF consumption might benefit from village chicken ownership should be considered. Motivations for chicken-keeping in resource-poor settings include opportunities to store wealth in a form which is readily-accessible to meet immediate household needs, including education and medical expenses, and items such as cooking oil, soap or clothing for children (Guèye, 2002). It may also be the case that, even if poultry products are rarely eaten at home, the sale of chickens may facilitate access to other forms of ASFs – fresh or dried fish, other forms of meat, or milk – through local markets.

7.4.3 "Household headship" and gender

Amongst gender-sensitive approaches employed within this study, efforts were made to recruit balanced numbers of male and female enumerators, interview an even number of male and female household members, and consider the gender of children and the head of their household as potential determinants of health and nutrition outcomes. Use of the concept of "household headship" in surveys and censuses has attracted some criticism, because of the ambiguity of its definition, the implication of a hierarchical relationship, and the common explicit gender bias, whereby the oldest male household member is taken as the "head" (Budlender, 2003; Department of International Economic and Social Affairs, 1988; Rosenhouse Persson, 1989). Assumptions about vulnerability based on this concept have also been questioned, with findings from Kenya suggesting that some female-headed households at very low levels of income were able to adopt successful coping strategies and achieve higher weight-for-age of preschool-aged children than wealthier male- and female-headed households (Kennedy & Haddad, 1994).

Interventions which promote ASF consumption and focus on agricultural income controlled by women are suggested to have the potential to contribute to improved nutrition, but this has not been convincingly demonstrated (Webb & Kennedy, 2014). Despite limitations in using a dichotomous variable to denote a male or female head of household, this study found that, controlling for wealth status, both women and their breastfed children were significantly more likely to consume eggs in households identifying as female-headed. It is likely that a higher degree of autonomy allowed mothers in these households to use income or resources to provide eggs to their young children more commonly than those in male-headed households. Greater autonomy of women may also increase the amount of income allocated to children's food and health care, and time allocated to care-giving practices (Kennedy & Haddad, 1994). In this study, however, beyond egg consumption, no other significant associations were found between the documented gender of the household head and children's dietary quality, ASF consumption, height-for-age, or frequency of diarrhoea.

7.4.4 Child age and gender

Dietary data from national DHS reports are limited to children 6-23 mo, for whom the IYCMDD indicator has been developed, with data disaggregated according to children's breastfeeding status. In this study, rather than exclude those children for whom complementary feeding was initiated prior to the recommended six months of age or those who were continuing breastfeeding beyond 23 mo, all children reported to be receiving both breast milk and complementary foods were included in this category. This resulted in an age range substantially beyond the usual 6-23 mo, with a mean age amongst breastfed children of 13.6 mo and a range from 1.3 to 33.0 mo. Increasing child age was significantly associated with higher dietary diversity scores and an increased probability of dietary adequacy for breastfed children, but this did not continue beyond the point of weaning.

There were no significant gender-based differences in breastfed children's diets; however, amongst non-breastfed children, boys were more likely than girls to receive an adequately diverse diet and to consume ASF. The preferential treatment of sons over daughters has been commonly reported in ethnographic and demographic research (Cronk, 1991). In South Asia, studies indicate that biased food allocation which favours male children is more apparent amongst those of higher wealth groups, and least evident amongst the very poor (Miller, 1997). A puzzling situation exists in this study where, despite evidence of some dietary outcomes favouring male children, improved HAZ and a lower probability of stunting was associated with female children. Gender-based differences in stunting, with poorer growth amongst boys, have been reported in several studies in sub-Saharan Africa (Espo et al., 2002; Ngare & Muttunga, 1999; Wamani, Åstrøm, Peterson, Tumwine, & Tylleskär, 2007).

Although consistently documented, the cause of this disparity is not well understood, particularly given that cases of female-biased parental investment have been rarely documented (Cronk, 1991). Reasons for improved growth amongst girls have been speculated to relate to preferential treatment due to the value of female participation in agricultural labour (Svedberg, 1990), or parental preference for children of the same gender, with mothers' role as primary caretakers of children resulting in greater allocation of resources to girls over boys (Rovin, 2015; Sahn & Stifel, 2002). A meta-analysis of 60 national surveys from sub-Saharan Africa, however, found no evidence of gender-based differences in breastfeeding duration or maternal health-seeking behaviours, based on rates of vaccination and the use of oral rehydration therapy, and contended that biological differences may account for gender-based inequalities in the prevalence of stunting (Garenne, 2003). The current study's finding of improved growth outcomes for girls, despite evidence of dietary practices which favour male children, appears to support this theory.

7.4.5 Livestock, height-for-age and diarrhoea in children

Challenges arise when seeking to measure the impact of livestock on health and nutrition outcomes, while also acknowledging the close association between animal ownership and socioeconomic status in rural communities, particularly amongst pastoralists of East Africa (Quinlan et al., 2016). For 39.6% of households enrolled in the current study, livestock constituted more than three-quarters of their estimated wealth, yet the ownership of livestock (by species, as categories, using a threshold approach, or in numbers), evaluated separately to non-livestock assets was not significantly associated with height-for-age in children.

One notable finding in this study was that, despite close associations between livestock and non-livestock assets (Figures 3 and 5), a lower likelihood of child stunting was associated not with the combined measure of livestock and non-livestock assets, but with the non-livestock asset index. Given that no significant negative associations between animal ownership and stunting were found, the observed dilution effect of including livestock in estimations of wealth suggests varying importance of these two asset categories. The concept of the "livestock ladder" emphasises the value of livestock as a means of "climbing" from poverty (Maass et al., 2013), and posits that the smallest economic benefits are derived from keeping village chickens and that returns increase for keeping small ruminants and cattle (Udo et al., 2011). This study suggests that these economic benefits may not correspond to improved growth outcomes for children.

In resource-poor settings where livestock-keeping is commonly not oriented towards production for market (Randolph et al., 2007), animals often represent financial savings and, particularly in the case of cattle, social status. It is possible to increase animal numbers through the retention of offspring, adding to household wealth, but such assets may contribute little to children's diets, health and growth. In contrast, items such as mobile phones, radios and bicycles demonstrate past expenditure and may serve as a better proxy for households' purchasing behaviour. A demonstrated association between higher non-livestock asset scores and lower levels of stunting may reflect the utilisation of economic resources to address underlying determinants of nutritional status, such as nutritious food purchases, medical expenses or an improved home environment.

This argument is countered by the finding of increased milk consumption by children with increasing numbers of cattle, signifying greater access to a food item which has been shown to improve linear growth amongst stunted children (Neumann, Murphy, Gewa, Grillenberger, & Bwibo, 2007). Although quantitative dietary assessments were not conducted, the volume of milk consumed by children is likely to be relatively low in this setting, particularly in times of limited feed and water availability for cattle, and perhaps insufficient to influence growth. It is also possible that the lack of significance of cattle ownership for child height-for-age may also signify the net effect of nutritional benefits of increased milk consumption being counteracted by undocumented adverse impacts.

While cattle ownership was associated with a small but significantly *lower* probability of diarrhoea, milk consumption was linked to an increased incidence of child diarrhoea. The potential for milk contamination with zoonotic pathogens or aflatoxins (Darwish, Ikenaka, Nakayama, & Ishizuka, 2014; Gizachew, Szonyi, Tegegne, Hanson, & Grace, 2016; Knight-Jones, Hang'ombe, Songe, Sinkala, & Grace, 2016), or for contact with ruminant faecal material within the homestead environment to have subclinical effects on the gastrointestinal tract, negatively affecting linear growth (Headey et al., 2017), cannot be excluded and, although highly speculative within this study, deserves closer investigation.

To address the key research question of whether village chickens have an impact on the growth of young children in this setting, the use of height-for-age as an outcome measure sought to encompass influences on multiple dimensions of children's health, development and environment. Pathways of interest included the potential positive contributions to children's diets and household socioeconomic status, and the potential detrimental effects of diarrhoea and environmental enteric disorder (Figure 1). Direct contributions to diets through the consumption of chicken meat and eggs were found to be very limited amongst this population, at the time of this study. On balance, there were no significant associations between child HAZ and chicken ownership, when the latter was defined (a) as a dichotomous variable, (b) using a threshold of the median chicken flock size, (c) in terms of the number of chickens owned, and (d) accounting for overnight housing location. Separate analysis of longitudinal records of child diarrhoea was used to test associations with village chicken ownership through this particular pathway, which were again found not to be significant.

Keeping chickens inside human dwellings overnight is a common practice in this setting, reported by over two-thirds (64.2%) of chicken-keeping households and more than a third (35.3%) of all those with a child enrolled in the study. Chicken houses may be damaged or destroyed by heavy rainfall during the wet season, and there is often little incentive to construct or repair these facilities when rates of chicken mortality are high and poultry-keeping is not a priority livelihood activity.

In a setting where infants and young children commonly accompany their mother to agricultural plots, and may be left in the care of older siblings, neighbours or relatives, opportunities for exposure to poultry faeces within the homestead or broader village environment are widespread, and not restricted to those households keeping chickens. In contrast, opportunities for children to be in contact with cattle manure are likely to be more closely linked to cattle ownership. Cattle, sheep and goats are typically kept within corrals close to their owners' homes, and taken out to graze and find water – often at quite distant locations – during the day. While chickens may roam between households and within the village environment, cattle are inherently less independent in their movements and therefore present less of a "community-wide" opportunity for adverse child health impacts.

7.4.6 Limitations of this study

Amongst constraints of this study are the limited sample size and the higher-than-anticipated attrition rate (16.9% of households) across the study period, making opportunities to demonstrate significance at the 5% level more difficult. Low and abnormally-timed rainfall over two consecutive rain seasons resulted in an unforeseen level of mobility amongst participating households, with a drastically reduced harvest prompting some to relocate outside the area to pursue alternative livelihood strategies. The potential for attrition-related bias, in which the characteristics of those lost to follow-up is associated with the outcome of interest, has been suggested as a consideration for losses of between 5-20% of participants (Dumville, Torgerson, & Hewitt, 2006). With increasing weather variability in the future, studies of populations reliant on rain-fed agriculture should adjust sample size calculations in recognition of the potential for increased participant drop-out, and consider the implications of more vulnerable, resource-poor segments of a population being lost from the study.

A further limitation of this study was the reliance on self-report of diarrhoea. Findings from Guatemala indicate recall periods of longer than two days to be associated with under-reporting of diarrhoea, particularly milder episodes and amongst older children (Zafar, Luby, & Mendoza, 2009). Despite subjectively simple data being collected during twice-monthly visits to participating households (i.e. the number of chickens owned and the occurrence of child diarrhoea), the potential for respondent or enumerator fatigue must also be considered, given the regularity of data collection over an extended period of time. These potential sources of bias, through inaccurate recall and recording, are considered to be systemic and unlikely to influence associations between diarrhoea frequency and livestock ownership. The use of well-regarded community members for ongoing data collection and monthly visits to the study communities by members of the Tanzanian research team are hoped to have contributed to maintaining positive relationships with study participants, and avoiding the pitfalls of "parachute research" (Tomlinson, Swartz, & Landman, 2006).

7.5 Conclusions

In African village settings, where children commonly live in close proximity to extensively-managed livestock, there is a need for further research into the effects of exposure to faecal material from domestic animals on child health and growth. It has been posited that this pathway may offset the benefits to be gained through consumption of nutrient-rich ASF and contributions of livestock to household income. In the case of village poultry, risks of diarrhoea and environmental enteric disorder in children are suggested by some researchers to be heightened by the practice of housing chickens within people's homes overnight.

In this study, longitudinal analyses were based on twice-monthly records of child diarrhoea and chicken numbers, six-monthly anthropometry and dietary assessments, and accompanying information on chicken management practices, ownership of other livestock, and household demographic, sociocultural and economic characteristics. While the potential for community-wide effects related to free-roaming poultry cannot entirely be ruled out, this study importantly (and of substantial practical significance if confirmed) found *no* association between chicken ownership or chicken housing location and height-for-age, prevalence of stunting or frequency of diarrhoea in young children.

It is possible for recall or recording bias to have affected analysis of child diarrhoea, whereas use of height-for-age as an outcome variable has enabled evaluation of a wide range of factors which may influence child growth, from low birthweight and inadequate nutrition, to recurrent infections or environmental enteric disorder. It is clear that livestock ownership is closely linked to socioeconomic status amongst this study population. However, controlling for non-livestock-associated wealth, analyses presented in this paper have detected no influence (either positive or negative) of animals on children's height-for-age or risk of stunting. This finding raises questions about the pathways through which different forms of livestock currently contribute to children's diets and household livelihoods in this setting. It also casts doubt onto whether the economic benefits of climbing the livestock ladder translate into nutritional benefits for children.

Improved water, sanitation and hygiene practices should be central to efforts to reduce childhood stunting; however, there is a need for careful consideration before warning against livestock ownership by resource-poor households or proposing substantial changes in livestock management practices. For example, confining chickens to enclosures and excluding them from human dwellings will increase production costs and labour inputs, particularly for women, and will reduce their accessibility to poor families. While consumption of chicken meat and eggs was infrequent across the 24-month period of this study, chicken ownership was demonstrated to be significantly associated with more frequent ASF consumption by women and more frequent chicken consumption by young children. Additionally, although chicken ownership was not a significant determinant of additional dietary outcomes alongside the asset index in multivariable models, the contributions of chicken-keeping to socioeconomic status should not be overlooked.

As efforts continue to support rural households to enhance dietary quality through increased access to nutrient-rich food items, such as ASF, questions about the complex and multiple linkages between livestock and human health will arise. Such linkages are likely to vary between animal species, management systems, and geographic and cultural settings. In this study, findings of no net benefit of cattle ownership on child growth despite a strong positive association with maternal and child milk consumption warrant further investigation using mixed-methods approaches. While it is encouraging that no adverse impacts of village poultry were found, it is clear that the current direct contributions of chickens to human diets are limited. In the broader project of which this study forms a subset, it is hoped that the combination of village poultry vaccination programs which support an increase in chicken flock size, and a targeted nutrition education strategy which promotes home consumption of chicken meat and eggs, will facilitate sustainable improvements in the nutritional adequacy of local diets.

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Chapter 8.
General discussion and conclusions

Chapter 8 draws together the various elements of this thesis through a discussion of key findings and recommendations arising from this work. The four main analytical chapters of the thesis (Chapters 4-7) have been positioned along the intended impact pathway linking Newcastle disease vaccination in village chickens with improved height-for-age in children within the *Nkuku4U* study.

Significant benefits of village chicken-keeping for the growth of children have not been identified over the two year period of this study; however, importantly, no negative health or growth impacts have been found. This thesis concludes by calling for integrated approaches to support Newcastle disease vaccination in vulnerable households, build resilience in the face of increasing weather variability and develop nutritional messaging which involves all household members, to harness the elusive potential of chicken-keeping in support of children's growth and development.

Image 8. An older woman from the Sukuma language group with two of her granddaughters, pictured in front of a house in Mahaka Village, Majiri Ward. Access to health services in Mahaka is particularly limited. A mobile clinic visits each month for routine antenatal and "under-five" check-ups, but other services involve travelling substantial distances (on foot or, if the road conditions allow, by bicycle or motorcycle) to the dispensary in Majiri Village.

Photo credit: Julia de Bruyn, 2015.

Chapter 8. General discussion and conclusions

8.1 Overall research objectives

The title of this thesis questions whether the health and nutritional status of children stands to benefit from programs which improve the health and productivity of chickens in rural communities of Tanzania. The potential for the ownership of village chickens to influence children's health encompasses direct and indirect contributions to dietary adequacy and growth, as well as suggested risks of zoonotic disease and environmental enteric dysfunction. Two key aims for this body of work were outlined in Chapter 1: (1) to evaluate the contributions of chicken-keeping to children's diets and height-for-age in eight villages of Manyoni District over a two year period; and (2) to explore opportunities to address barriers and knowledge gaps to support greater contributions.

8.2 Key findings

Village chickens are an accessible and versatile asset for households in resource-poor settings. Key traits of being commonly managed by women and providing nutrient-rich food items make chickens a suitable focus for nutrition-sensitive programs, with potential benefits for women and children.

Chapter 3 reviewed the multiple roles of village chickens in resource-poor settings. Despite their low production levels compared to intensively-raised commercial poultry, village chickens are often incorporated into livelihood strategies to maintain, regain or strengthen food and nutrition security at a household level. Their value has been identified to lie in:

(1) their accessibility, as a low-cost form of livestock able to be maintained with minimal land, labour and capital inputs and therefore kept by even the poorest segments of a population;

(2) their versatility, in providing a form of currency which can be mobilised more readily than larger livestock assets to meet common household needs;

(3) the potential provision of high-quality protein and multiple micronutrients through meat and eggs;

(4) their frequent ownership by women, who are more likely to exert autonomy in decisions about the utilisation of village chickens compared to other livestock assets.

Uptake of a fee-for-service vaccination program against Newcastle disease has varied between communities and campaigns during the study period, with households with larger chicken flocks identified as being more likely to vaccinate.

Village chickens were widely owned in Sanza and Majiri Wards, but flock sizes were generally small and participation in vaccination campaigns has been uneven between communities and campaigns. Chapter 4 shared some of the difficulties encountered in the implementation of the vaccination intervention, including commencing vaccination on the cusp of a high-risk period for ND outbreaks in the first two clusters in Sanza Ward. Amongst the challenges of field-based research is the potential for conflict between the seasonality of disease patterns, weather events or agricultural activities and the need to move forward with planned research activities to meet academic and funding timelines.

Proceeding with vaccination in May 2014 meant accepting the possibility that community members may have interpreted chicken deaths following this first campaign to be the outcome of vaccination, and so taken this as a disincentive to participate in future campaigns. Deaths may have occurred due to causes other than ND, or in birds whose immunity had waned, those which had not responded effectively to the vaccine, or perhaps had not been vaccinated at all. Effective herd immunity against ND has been reported to rely on a minimum of 85% of a chicken flock receiving and mounting an effective immune response to a vaccine (van Boven et al., 2008). This has not been validated in village settings, where the emphasis has principally been on protecting vaccinated birds. Amongst enrolled households, from whom twice-monthly records of chicken ownership were collected, Chapter 4 identified participation in vaccination campaigns during the study period to have ranged from 42-71% in Sanza Ward and 43-58% in Majiri Ward. While an upward trend in vaccination levels has not been seen, as has been reported following the introduction of programs using the I-2 ND vaccine elsewhere in Tanzania and in Mozambique (Harun et al., 2009), the fact that chicken-keepers have continued to pay for the vaccination service during two years of poor and abnormally-timed rainfall is encouraging.

Chapter 4 proposed two potential explanations for the finding that chicken flock size was a determinant of a household's likelihood of vaccinating:

(1) a preference amongst vaccinators to focus their service on those with larger chicken flocks, where the financial incentive for travelling to reach households was greater;
(2) a greater inclination amongst households with more chickens, and therefore perhaps a greater interest or capacity to invest financially in the health of their birds.

Vaccinating in a given ND vaccination campaign was associated with larger chicken flock size in the period following vaccination. Vaccinating in all three campaigns over twelve months was associated with greater chicken numbers at the end of this time, compared to vaccinating once, twice or not at all.

Controlling for socioeconomic and cultural influences, separate analyses in Chapter 4 identified participation in a given vaccination campaign to be positively associated with the mean number of chickens owned during the four month period following vaccination (leading up to the next campaign). Households vaccinating consistently over a twelve-month period were found to have larger chicken flocks at the end of this time, compared to those vaccinating intermittently or not at all. Identifying the direction of associations presented a challenge, and relied on a considered approach to the time frames over which variables based on chicken numbers were constructed: at the time of vaccination, in the period following vaccination, or at the end of twelve months.

Various modelling approaches have been used elsewhere to explore the influence of interventions such as ND vaccination on village chicken flock dynamics (Udo, Asgedom & Viets, 2006; Tomo et al, 2012). Models rely on an understanding of chicken keepers' priorities for sale, consumption and flock expansion. These have been documented to include building to and maintaining a target flock size and ratio of male to female birds (Roberts, 1997; Okitoi et al, 1999), and selling or consuming eggs or additional birds – with varying frequency between seasons (Ondwasy et al, 1999). One limitation of the analyses in Chapter 4 has been the focus on chicken flock size, without accounting for the increased sale and consumption which might have followed the introduction of vaccination programs. Additional qualitative and quantitative information would provide a valuable insight into chicken flock dynamics in this particular setting, and is intended to be explored by others associated with the *Nkuku4U* project.

Accurate food composition data are needed to guide food-based recommendations. Using "recycled" food composition data in African databases, from analyses conducted decades previously or in high-income settings, is often inappropriate, particularly for animal-source foods.

As momentum for vaccination builds and a reduction in mortality due to ND is seen, chicken-keepers will be faced with decisions about the use of chickens and eggs for sale, consumption, or retention to expand their flock size. To develop strong nutritional messaging and valid food-based recommendations for dietary improvement requires an understanding of the food resources accessible within a given setting, the nutritional requirements of target groups, and the nutrient content of food items.

Chapter 5 sought to tackle the last of these areas, by exploring limitations of current food composition databases in sub-Saharan Africa. This element of the thesis was devised when the Tanzanian Food Composition Tables (Lukmanji et al., 2008) were consulted and data sources for individual food items were found to be lacking. General information indicated a majority of data to have been drawn from the Kenyan reference, based on data from the 1960s (FAO & US Department of Health, 1968; Platt, 1962), with additional data supplemented from US and UK sources. This prompted an exploration of food composition data within the African region, to better understand the scope, sources and comparability of available references.

With the growing attention on food-based approaches which use local resources to increase dietary quality, there is a need to identify and respond to knowledge gaps within agriculture-nutrition pathways – not least to demonstrate the impact of interventions. The limitations of food composition tables have been identified not to be sufficiently appreciated by their users (Greenfield & Southgate, 2003). As biological materials, it is inevitable that foods will vary in composition, and expectations for context-specific data should be realistic. The publication which constitutes Chapter 5, however, makes an important contribution by drawing attention to the variation in the nutrient content of ASF likely to be associated with differences in livestock breeds, management systems, diets, seasons and environments, as well as changes over time accompanying selective breeding for rapid growth and high yields.

Given that ASF consumption is known to contribute positively to the nutrient adequacy of diets in resource-poor settings, it might be argued that any increase in the consumption of chicken meat and eggs, beyond the very low levels documented in Chapters 6 and 7, would be beneficial. As global efforts to standardise references and improve data quality continue, however, including through the FAO-led International Network on Food Data Systems and its regional data centres, this thesis has highlighted one important area in need of attention.

Maternal perception of insufficient milk supply was the predominant driver for early initiation of complementary feeding in the study setting. Women were most likely to seek breastfeeding advice from female relatives, rather than local health staff.

Building an understanding of current infant and young child feeding practices in this setting was fundamental in identifying priority areas for improvement and to inform nutrition education strategies. Breastfeeding was widespread and of long duration amongst enrolled households; however, almost three-quarters of mothers reported having introduced foods or liquids other than breast milk prior to the WHO-recommended six months of age. Based on questionnaire responses, a substantial majority of mothers identified insufficient breast milk as the primary motivation for early introduction of complementary feeding. Subsequent interview findings revealed persistent crying and fractious behaviour as common triggers for women to deem their breast milk to be inadequate, in quantity or quality, to meet the nutritional needs of their child.

Although women acknowledged receiving general information during routine perinatal visits to local health facilities, older female family members were identified as the primary source of guidance for specific problems relating to infant and young child feeding. Advice received often encouraged the early introduction of complementary feeding, contrary to nationally-endorsed recommendations, which advocate exclusive breastfeeding to six months of age but may fail to provide culturally-sensitive strategies to achieve this within resource-poor settings.

Although chicken meat and eggs were infrequently eaten over two years in the study setting, consumption by mothers and their young children was closely linked. No gender-based barriers to egg consumption by children were demonstrated.

Amongst many development practitioners, the direct nutritional contributions of village chickens in resource-poor communities appear to be often overestimated. Providing meat and eggs for home consumption is one of the multiple and diverse roles of village chickens (as outlined in Chapter 3), which also include providing a small source of regular income, a liquid asset in times of need, and a means of honouring guests, as a gift or through a shared meal. Triangulation of findings from participant-completed dietary records (Chapter 6) and 24-hour food recall data collected through six-monthly questionnaires (Chapter 7) confirmed very low levels of chicken meat and egg consumption by enrolled children and their mothers throughout the study period.

This is probably not surprising in the early stages of ND vaccination programs in the study area, particularly in the face of increasing weather variability. In Chapter 6, interviewed women reported prioritising the hatching of eggs to provide replacement stock (*"If you eat eggs, where will you get chickens?"*) and retention of chickens for sale in times of need. A value chain analysis in the study sites reported the sale of chickens to be twice as common as consumption, with the latter often limited to periods of chicken disease outbreaks, when sick or deceased chickens might be eaten (Queenan et al., 2016). A strong nutrition education component is likely to be required to overcome communities' long-term experience of seasonal disease outbreaks and associated mortality in chickens.

Several interviewed women described customs which were said to prevent uncircumcised male children from eating eggs; however, these were not supported by analysis of dietary records which found no association between child gender and the probability of egg consumption. Importantly, although poultry products were infrequently eaten, longitudinal analyses revealed a close association between dietary patterns of mothers and their young children, which suggests the potential for strategies which increase household-level consumption to bring nutritional benefits to children.

Assessing the contributions of livestock to nutrition is challenging in settings where livestock ownership and socioeconomic status are closely linked. Climbing the "ladder" of livestock ownership may increase wealth, income-earning opportunities and resilience, but benefits for children's nutrition and growth have not been demonstrated in this study.

Amongst the two most common language groups represented in the study population, and in many rural communities in sub-Saharan Africa, livestock are highly valued and often constitute a signficant proportion of a household's asset base. In Chapter 7, numerous measures of livestock ownership were evaluated as predictors of dietary and growth outcomes, alongside alternative measures of wealth based on material assets. Despite close associations between livestock and non-livestock assets, it was the non-livestock asset index which was identified as being significantly associated with a reduced probability of stunting in children in this study. Wealth measures based on material assets were suggested to serve as a better proxy for households' purchasing behaviour than the number of livestock owned, and therefore to reflect the utilisation of economic resources to address determinants of nutrition.

As a relatively affordable form of livestock, chickens are often seen as the lowest step on the livestock ladder and *"the seeds you sow to get the fruits, cattle"* (Aklilu, Udo, & Almekinders, 2008). The sale or exchange of chickens for sequentially larger livestock species, of greater economic and sociocultural value, has been presented as a means of rising from poverty and reaping greater economic returns from livestock-keeping. This study confirmed the livestock ladder to be positively associated with households' wealth status based on material assets, but found no signficant associations with improved height-for-age in children. In this setting, livestock-keeping is commonly not oriented towards production for market. Rather, an emphasis is placed on animals as a form of financial savings and social status, particularly in the case of larger livestock. Findings presented in this thesis suggest that this may undermine their contributions to children's diets and growth.

Chicken ownership was associated with some positive dietary outcomes, but not with height-for-age or the probability of child stunting. Neither chicken ownership nor the location of overnight chicken housing were associated with the frequency of diarrhoea in children.

Chapters 6 and 7 identified limited direct contributions of chicken-keeping to maternal and child diets during the study period; however, the likelihood of breastfed children and their mothers eating chicken meat was shown to increase with greater numbers of chicken owned. Positive associations between increasing chicken flock size and womens' consumption of ASF may also reflect contributions of poultry-keeping to regular household expenses, including food purchases such as fresh or dried fish, meat and milk through local markets.

In order to address the core research aim of testing associations between village chickens and the growth of young children, height-for-age was used as an outcome indicator which would reflect the cumulative result of multiple influences over an extended period. On balance, neither chicken ownership nor the practice of keeping chickens within people's homes overnight were significantly associated with height-for-age in children. Additionally, based on twice-monthly records over a two year period, no associations were evident with the frequency of diarrhoea in children.

Elements of this thesis have documented small chicken flock sizes (Chapter 4), poor rainfall (Chapters 4, 6, and 7), infrequent consumption of chicken meat and eggs (Chapters 6 and 7), and a long-held inclination amongst study participants to hatch eggs to increase chicken numbers and retain chickens for use in times of need (Chapter 6). Against this backdrop, a failure to detect any significant positive influence of chicken ownership on children's growth might be expected. A more significant finding, however, is that this research has found no adverse effects of chickens on children's height-for-age or diarrhoea frequency.

8.3 Key recommendations

Food composition databases in low- and middle-income countries should be improved by conducting nutrient analysis on animal-source foods from indigenous livestock in low-input production systems, establishing methods to integrate local data into existing databases, and increasing transparency around data sources.

Based on findings from Chapter 5, this thesis proposes three recommendations to improve food composition references. First, primary analyses of ASF from indigenous breed livestock raised under extensive management conditions in resource-poor settings should be prioritised in national databases for low- and middle-income countries. Products from "local chickens" are not only eaten in rural households in sub-Saharan Africa, but also by urban consumers who pay a premium for the older, firmer and more flavoursome meat (Alders & Pym, 2009; Guèye, 1998). Poultry provide a prominent example of the need to generate new data, with a scavenging chicken in an African village bearing little resemblance to a broiler chicken in the United States, raised in an intensive production system to reach the point of slaughter at around 35 days of age.

Secondly, as progress is made in standardising databases and establishing protocols to improve data quality, there is a need to pursue opportunities to enable existing or new data to be integrated into national or regional databases. In Tanzania, capacity for testing certain nutrients exists at Sokoine University of Agriculture, the Tanzania Food and Nutrition Centre, Tanzania Veterinary Laboratory Agency and Tanzania Food and Drug Authority. There would be great value in establishing processes for the gradual expansion of databases, and in encouraging research and development programs which involve food-based approaches to undertake analysis of local food items. Finally, the source of nutrient data, as well as details on food preparation methods, should accompany individual entries in food composition databases, to enable users to make informed decisions about the appropriateness of information for their purposes.

The need to select appropriate outcome indicators in agriculture-nutrition research has been emphasised, but this thesis also highlights the importance of carefully considering predictor variables in order to effectively understand complex linkages.

Earlier sections of this thesis emphasised the need for careful selection of outcome variables in agriculture-nutrition research, to ensure their suitability for the intervention, sample size and duration of the program in question. Analyses in Chapter 7 have also paid close attention to predictor variables. In the case of livestock, this included ensuring the time frame for information on animal ownership was appropriate for the nutrition outcomes being considered. Ownership and numbers of chickens were recognised to fluctuate to a far greater extent than ruminants in village settings. Analysis of dietary outcomes were therefore based on chicken ownership at the time of dietary assessment, while analysis of children's height-for-age (a longer-term outcome) considered chicken ownership over a six month period preceding anthropometry.

In testing livestock-nutrition linkages, the thesis has also explored:

(1) whether an effect depends on ownership of an animal species *per se*;
(2) whether a threshold level of animal numbers exists, beyond which an effect is seen; or,
(3) whether an increase in animal numbers is correlated with a proportionate change in the outcome of interest.

Alongside the many benefits of international and interdisciplinary research, there is a risk that investigators removed from field settings or working beyond their disciplinary area may lack the context- or subject-specific knowledge required to translate research findings into valid and meaningful conclusions. This challenge exists both within project teams (for example, where those with expertise in data analysis may not have opportunities for exposure to study sites), as well as in studies which use open access data, where details of the strengths and limitations of data collection and project implementation may not be adequately shared.

Experiences in the implementation of the current study suggest the likelihood that research findings will reflect the reality of field settings may be increased by:

(1) harnessing the relevant skills and knowledge within or beyond the research team, particularly through in-country partners and social scientists with experience in cross-cultural settings, to validate research methods and findings;
(2) giving due consideration to the construction of both predictor and outcome variables during data analysis, to ensure the complexity of agriculture-nutrition linkages is adequately addressed; and,
(3) increasing access to contextual information, through effective data management and communication, to support investigators removed from the field setting.

Investing time and multi-disciplinary research skills to conduct mixed methods assessments of food systems, dietary practices and agriculture-nutrition pathways is important to addressing nutritional challenges in resource-poor settings.

Although a large proportion of the data contributing to this thesis has been quantitative in nature, it has been drawn from multiple research tools and different modes of data collection to allow "within methods" triangulation. Chapter 6 demonstrated the application of "between methods" triangulation to explore care-giving and child feeding practices in the study setting. Circumstances surrounding breastfeeding difficulties and a departure from intended or recommended feeding practices were acknowledged as likely sensitive topics and to require a considered methodological approach. Quantitative methodology was employed to document infant and young child feeding for the wider population under study, while subsequent qualitative methodology served to explore the perspectives of a smaller number of respondents to understand causality and behavioural drivers for these practices.

Combining and seeking convergence between qualitative and quantitative techniques allows opportunities for a far greater understanding of data, particularly in cross-cultural and interdisciplinary research (Jick, 1979). In this study, associations identified in Chapter 4, between chicken flock size and vaccination uptake, and in Chapter 7, surrounding the relative use of livestock and non-livestock assets to support household food and nutrition security, would benefit from further investigation through qualitative methods.

The influence of research activities on research findings should be recognised, and caution demonstrated in forecasting the impacts which agricultural program inputs may achieve on outcomes relating to livestock, crops or nutrition.

The need for effective control groups, well-defined selection criteria and rigorous study design has been highlighted by recent reviews of agriculture-nutrition research (as summarised in Chapter 1, Table 1). The central aim of the *Nkuku4U* study has been to assess the child growth outcomes which might be achieved through sustainable improvements to chicken and crop systems, and which do not rely on finite donor funding. Although participants were randomly selected following a census within the study area and interventions were randomly allocated across clusters, the potential for research activities to influence community dynamics and expectations needs to be recognised. This is suggested to be particularly so in remote rural areas, such as the villages of Sanza and Majiri Wards, which have historically received little attention from research or development programs. The frequent presence of livestock, crop, health and social science representatives from national and international partner institutions within these communities in recent years has presumably affected behaviours and outcomes. This should be considered when proposing how positive changes associated with the *Nkuku4U* study may be "scaled up" through similar livestock and crop programs administered under the auspices of district councils in other communities.

Analyses in Chapter 4 revealed a significant positive association between enrolment in the *Nkuku4U* study and uptake of the vaccination service. One explanation posited for the higher levels of vaccination amongst enrolled households was that regular questioning about chicken ownership, management, consumption and vaccination resulted in a heightened awareness of chicken-keeping as a livelihood activity and a greater inclination to invest in the vaccination service. There is also potential for this effect to have resonated more widely in the community, not only in enrolled households but amongst their family and neighbours who have observed the regular presence of project personnel within the community over several years. One woman, an owner of a restaurant in Sanza Village who reported her chicken flock to have expanded from around 20 chickens in May 2015 to 200 in May 2016, articulated this clearly: *"I understood the importance of chickens when the project arrived in the ward. I thought, those people are coming from so far away to speak about chickens. It must be important."*

8.4 Conclusions

Working to tackle "wicked problems" involves embracing complexity and, as forecast in Chapter 1, an acceptance that research findings are "not true or false or good or bad, but the best that can be done at the time" (Brown, 2010, p. 4). The beneficial effect of ASF consumption on children's growth has been documented (Neumann, Harris, & Rogers, 2002), but evidence to support the nutritional impact of programs which improve animal health and production and increase access to nutritious food items is currently lacking. A recent study in Ecuador involving the free daily distribution of eggs to infants over twelve months reported a significant reduction in the prevalence of stunting and underweight, compared to a control group (Iannotti et al., 2017), yet this thesis has reported eggs to have been eaten by only around one in fifty children on a given day during the study period. To make it possible for children in Sanza and Majiri Wards, and in other resource-poor communities across the globe, to consume eggs on a daily basis, given the recognised nutritional benefits of doing so, will require substantial progress in identifying and addressing barriers to consumption. It is likely that these will vary in degree both between and within communities.

Research teams comprising members of diverse disciplinary backgrounds and methodological strengths are essential to sustainably strengthen food and nutrition security. This thesis has demonstrated both the benefits to be gained from crossing disciplinary boundaries, and the importance of knowledge and training within a given discipline. In identifying the limitations of current food composition data in sub-Saharan Africa, Chapter 5 highlighted the expertise beyond that of nutritionists, dietitians and food scientists to be relevant to this area. In Chapter 7, the compilation of predictor variables which reflected the dynamics of chicken flocks in village settings and linked livestock ownership with nutritional outcomes in a meaningful way drew on an understanding of animal reproduction, health and management in the study setting.

So, do healthy chickens lead to more healthy children? Does the ownership of village chickens by rural households translate to improved growth for children, without adverse effects associated with zoonotic disease or subclinical effects on children's digestive function? The answer is mixed. Village chickens are an accessible and versatile household asset, and regular ND vaccination has been linked to a signficant increase in chicken numbers. There are also likely to be wider benefits associated with community-based vaccination programs which have not been assessed in this study, including income-earning opportunities for chicken vaccinators and for the various actors within village chicken value chains.

This thesis did not identify any significant benefits of chicken-keeping for the growth of children over a two year period; however, importantly, it found no negative health or growth impacts which would undermine a continued focus on this intervention. As chicken vaccination programs continue within these communities, integrated approaches will be needed to support vaccination in vulnerable households, build resilience in the face of increasing weather variability, and develop nutritional messaging which involves all household members, to harness the elusive nutritional potential of chicken-keeping in support of children's growth and development.

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Appendices.

This section includes English versions of the research tools (questionnaires, data recording sheets and a question guide for in-depth interviews), informed consent forms and a participant information statement. Printed copies of these documents were in Swahili, certified by the National Swahili Council in Tanzania (*Baraza la Kiswahili la Taifa,* BAKITA). To accommodate linguistic diversity and varying levels of literacy, documents were read aloud to study participants by trained enumerators, using local languages where appropriate.

Letters of approval by the National Medical Research Institute in Tanzania, and the Human Research Ethics Committee and Animal Ethics Committee at The University of Sydney, are also included.

Image 9. Village chickens in a semi-scavenging system managed by a woman in Sanza Village, Sanza Ward. As vaccination programs in the study sites have reduced losses due to Newcastle disease, a small number of chicken-keepers have chosen to increase inputs and move towards more intensive production systems.

Photo credit: Julia de Bruyn, 2017.

Appendix A. Maternal and Child Health and Nutrition Questionnaire [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

MATERNAL AND CHILD HEALTH AND NUTRITION QUESTIONNAIRE

Baseline survey

CONFIDENTIAL

HOUSEHOLD CODES:

District

Ward

Village

Subvillage

Household

PARTICIPANTCODES:

Mother (interviewee)

Enrolled child

INTERVIEWER NAME:

GPS COORDINATES

Record location reading at start of interview.

		Degrees	Minutes	Seconds
Latitude	S			
Longitude	E			

SECTION 1. HOUSEHOLD CHARACTERISTICS			
No.	**QUESTIONS**	**CODING CATEGORIES**	**SKIP TO**
101	What is the main source of drinking water for members of your household? *Circle the most appropriate answer (one option only).*	Piped water into house .... 1 Piped water into yard / plot .... 2 Public tap .... 3 Open well in yard / plot .... 4 Open public well .... 5 Neighbouring public well .... 6 Protected well / borehole in yard / plot .... 7 Spring / river / stream / pond / lake / dam .... 8 Other (specify) 96	
102	How long does it take you to go there, get water and come back? *Record number in minutes, including waiting time.*	Minutes taken Don't know 98	
103	What kind of toilet facility do members of your household usually use? *Circle the most appropriate answer (one option only).*	Own ventilated pit latrine .... 1 Ventilated pit latrine shared with other households.... 2 Own traditional pit latrine .... 3 Traditional pit latrine shared with other households . 4 Own flush toilet .... 5 Flush toilet shared with one or more households........ 6 No facilities, bush or field .... 7 Other (specify) 96	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
104	How many households use this toilet facility? *If less than ten, record number. If more than ten or unknown number, circle code.*	Number (if less than 10) [ ] 10 or more households .... 95 Don't know 98	
105	What type of fuel does your household mainly use for cooking? *Circle the most appropriate answer (one option only).*	Firewood........ 1 Paraffin / kerosene........ 2 Crop residuals, straw, grass, animal dung........ 3 Charcoal .... 4 Bottled gas .... 5 Electricity........ 6 No food cooked in household .... 95 Other (specify) .... 96 [ ]	
106	If you were to go to (NAME OF NEAREST HOSPITAL, HEALTH CENTRE OR DISPENSARY), how would you get there? *Circle the most appropriate answer (one option only).*	Car / motorcycle .... 1 Public transport (bus, taxi) .... 2 Animal / animal cart .... 3 Walking .... 4 Bicycle .... 5 Other (specify) .... 96 [ ] Don't know........ 98	
107	How far is it to the nearest health facility? *Record distance in kilometres (km).* *If less than 1km, write "00".* *If more than 95km, write "99".*	Distance in kilometres [ ] Don't know........ 98	
108	Does your household have any mosquito nets that can be used while sleeping?	Yes .... 1 No 2	
109	At the present time, how many meals does your household usually have per day? *Record number of meals.*	Number of meals [ ]	
	SECTION 2. CHARACTERISTICS AND HEALTH OF MOTHER		
	BACKGROUND		
201	In what month and year were you born? *Record month (MM) and year (YYYY) in numbers. Circle the appropriate code if unknown.*	Month [ ][ ] Year [ ][ ][ ][ ] Don't know month ....98 Don't know year........99	
202	How old were you at your last birthday? *Compare 201 and 202 and clarify date with interviewee if inconsistent.*	Age in completed years [ ][ ] Don't know month 98	
203	Have you ever attended school?	Yes ....1 No 2	 →205

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
204	What is the highest level of school you attended? *Circle the most appropriate answer (one option only).*	Pre-primary .... 0 Primary school .... 1 Post-primary school training .... 2 Secondary school .... 3 Post-secondary school training .... 4 University 5	
	EMPLOYMENT, INCOME & DECISION MAKING		
205	In the last seven days, have you been involved in any activity for which you are paid in cash or in kind?	Yes .... 1 No 2	→207
206	Do you usually take up extra work, but did not (in the last seven days) because of illness or other reasons?	Yes .... 1 No 2	 →208
207	What kind of work do you mainly do? *Circle as many responses as apply.*	Crop production / sale .... 1 Cattle or goat production / sale .... 2 Chicken production / sale .... 3 Skilled trade / artisan .... 4 Casual labour .... 5 Mining / mineral sales .... 6 Beer brewing .... 7 Gathering natural products for sale .... 8 Collecting scrap / waste materials for re-sale ....9 Other (specify) 96	
208	Are you currently married or living together with a man as if married?	Yes, currently married .... 1 Yes, living with a man .... 2 No, not in union 3	
209	Who usually decides how the money you earn will be used? *Circle the most appropriate answer (one option only).*	Myself .... 1 My husband / partner .... 2 Both of us together .... 3 Other (specify) 96	
210	Who usually makes decisions about health care for yourself and your child(ren)? *Circle the most appropriate answer (one option only).*	Myself .... 1 My husband / partner .... 2 Both of us together .... 3 Other (specify) 96	
211	Who usually makes decisions about making major household purchases? *Circle the most appropriate answer (one option only).*	Myself .... 1 My husband / partner .... 2 Both of us together .... 3 Other (specify) 96	
	ANTENATAL CARE AND CHILDBIRTH		
212	Are you pregnant now?	Yes .... 1 No .... 2 Unsure 3	 →214 →214
213	How many months pregnant are you? *Record number of completed months.*	Months Don't know month 98	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
214	Have you ever been pregnant?	Yes .... 1 No 2	 →301
216	Did you see anyone for antenatal care for your most recent pregnancy?	Yes .... 1 No .... 2 Don't know 98	 →218 →218
217	How many times did you receive antenatal care during this pregnancy? *Record number, or circle code if unknown.*	Number of times [ ][ ] Don't know month 98	
218	During this pregnancy, were you given or did you buy any iron tablets or syrup? *Show tablets and syrup.*	Yes .... 1 No .... 2 Don't know 98	 →220 →220
219	During the whole pregnancy, for how many days did you take the tablets or syrup? *Record number of days. If the answer is not numeric, probe for an approximate number.*	Number of days [ ][ ] Don't know month 98	
220	During this pregnancy, did you have difficulty with your vision during the daylight?	Yes .... 1 No .... 2 Don't know 98	
221	During this pregnancy, did you suffer from night blindness?	Yes .... 1 No .... 2 Don't know 98	
222	During this pregnancy, did you take any drugs to prevent you from getting malaria?	Yes .... 1 No .... 2 Don't know 98	 →224 →224
223	What drugs did you take? *Record all drugs mentioned. If type of drug is not determined, show typical antimalarial drugs to respondent.*	Fansidar (SP) .... 1 Chloroquine .... 2 Other (specify) .... 96 [ ] Don't know 98	
224	Did you sleep under a mosquito net last night?	Yes .... 1 No .... 2 Don't know 98	
225	Now I would like to ask some questions about your last birth. Is (NAME) still alive? *The next questions are asking about the child enrolled in the study. Circle the appropriate code.*	Alive .... 1 Deceased 2	
226	What is (NAME)'s birth date? *Ask to see the child's clinic card.* *Copy the date of birth from this record.* *Circle code 1 if the clinic card is not available.* *Circle code 98 if there is no clinic card and the mother cannot recall the child's date of birth.*	Day Month Year [ ][ ] [ ][ ] [ ][ ][ ][ ] Clinic card not available .... 1 Don't know birth date 98	
227	Where did you give birth to (NAME)? *Probe to identify the place and circle the appropriate code (one only). List name of health facility, if appropriate.*	**Home** Your home .... 11 Other home .... 12 **Health facility** *NAME OF PLACE:* [ ]	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
		Regional hospital .... 22 District hospital .... 23 Health centre .... 24 Dispensary .... 25 Village health post .... 26 Other (specify) .... 96 [ ]	
228	Was (NAME) delivered by caesarean, that is, did they cut your belly open to take the baby out?	Yes .... 1 No 2	
229	In the first month after delivery, did you receive a vitamin A dose like this? *Show sample of vitamin A capsules.*	Yes .... 1 No .... 2 Don't know 98	
SECTION 3. HEALTH AND NUTRITION OF CHILDREN 0-2 YEARS OF AGE			
301	I would like to ask some more questions about your child who is participating in our research. Is your child male or female? *Record gender of child enrolled in study.*	Male .... 1 Female 2	
302	What is (NAME)'s birth date? *Record DD / MM / YYYY.* *Check against 226.*	Day Month Year [ ][ ] [ ][ ] [ ][ ][ ][ ] Don't know birth date 98	
300 a	What is your "mother tongue", that is, your first language? *Record the first language of the child's **mother** (ie. the respondent). More than one response may be circled.*	Kigogo .... 1 Kisukuma .... 2 Kiswahili .... 3 Other (specify) .... 96 [ ]	
300 b	What is the "mother tongue" or first language of your child's father? *Record the first language of the child's **father**. More than one response may be circled.*	Kigogo .... 1 Kisukuma .... 2 Kiswahili .... 3 Other (specify) .... 96 [ ]	
303	When (NAME) was born, was he or she: • very large? • larger than average? • average? • smaller than average? • very small? *Circle response (one option only).*	Very large .... 1 Larger than average .... 2 Average .... 3 Smaller than average .... 4 Very small .... 5 Don't know 98	
304	Was (NAME) weighed at birth, that is within one hour of being born?	Yes .... 1 No .... 2 Don't know 98	 →306
305	How much did (NAME) weigh at birth? *Record the weight in kilograms from clinic card. If records are not available, circle code 98.*	Weight from card [ ] . [ ][ ] kg Records not available 98	
BREASTFEEDING AND COMPLEMENTARY FEEDING			
306	I would like to ask a few questions about breastfeeding. Did you ever breastfeed (NAME)?	Yes .... 1 No 2	 →312

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
307	How long after birth did you first put (NAME) to the breast? *If less than 1 hour, circle code "000".* *If less than 24 hours, record in hours.* *if more than 24 hours, record in days.*	Immediately .... 000 Number of hours **OR** Number of days [ ][ ] [ ][ ]	
308	In the first 3 days after delivery, before you were producing enough milk, was (NAME) given anything else to drink?	Yes .... 1 No 2	 →310
309	What was (NAME) given to drink? *Record all liquids mentioned. Circle as many answers as appropriate.*	Milk (other than breast milk) .... 1 Plain water .... 2 Sugar or glucose water .... 3 Sugar-salt-water .... 4 Fruit juice .... 5 Infant formula .... 6 Tea / infusions .... 7 Honey .... 8 Other (specify) .... 96 [ ]	
310	Are you still breastfeeding (NAME)?	Yes .... 1 No 2	→312
311	For how many months did you breastfeed (NAME)? *Record the number of months* *(if less than one month, enter "00").* *If unknown, circle code "98".*	Months [ ][ ] Don't know 98	
312	How old was (NAME) when he / she was first fed something other than breast milk to drink? *Probe with common drinks, including juice, cow's milk, water, sugar water, infant formula, or anything else. Record age in months, or circle the appropriate code.*	Months [ ][ ] Don't know .... 98 Have not started giving anything 99	 →318
313	Did (NAME) drink anything from a bottle with a nipple yesterday or last night?	Yes .... 1 No .... 2 Don't know 98	
314	How old was (NAME) when he / she was first fed semi-solid or solid foods to eat? *Record age in months, or circle the appropriate code.*	Months [ ][ ] Don't know .... 98 Have not started giving anything 99	 →318
315	If (NAME) was fed semi-solid or solid foods before the age of 6 months, what was the most common food given? *Circle the most appropriate response (one option only).*	Cereal-based porridge .... 1 Root / tuber-based porridge .... 2 Plantain-based porridge .... 3 Other (specify) .... 96 [ ] Nothing given before the age of 6 months 99	
316	If (NAME) was fed semi-solid or solid foods before the age of 6 months, what was <u>added</u> to the common food given? *Select all options which apply.*	Chicken .... 1 Other meat product .... 2 Egg .... 3 Cow or goat's milk .... 4 Vegetables / leaves 5	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
		Groundnuts / beans .... 6 Fats or oil .... 7 Sugar .... 8 Other (specify) .... 96 [ ] Nothing given before the age of 6 months 99	
317	If (NAME) was fed something other than breast milk before the age of 6 months, what was the reason? *Circle the most appropriate response (one option only).*	Another pregnancy .... 1 Child refused .... 2 Mother fell sick .... 3 Mother had insufficient milk .... 4 Mother and child separated .... 5 Other (specify) .... 96 [ ] Nothing given before the age of 6 months 99	
318	Has (NAME) received vitamin A like this during the last 6 months? *Show a sample of vitamin A capsule.*	Yes .... 1 No .... 2 Don't know 98	
319	In the last seven days, did (NAME) take iron pills, sprinkles with iron, or iron syrup, like any of these? *Show samples of each.*	Yes .... 1 No .... 2 Don't know 98	
320	Has (NAME) taken any de-worming treatment in the last six months, perhaps during a vaccination campaign or a routine visit to the health facility?	Yes .... 1 No .... 2 Don't know 98	
321	Has (NAME) had diarrhoea in the last 2 weeks?	Yes .... 1 No .... 2 Don't know 98	
322	Has (NAME) been ill with a fever at any time in the last 2 weeks?	Yes .... 1 No .... 2 Don't know 98	
323	Has (NAME) been ill with a cough at any time in the last 2 weeks?	Yes .... 1 No .... 2 Don't know 98	
324	Did (NAME) sleep under a mosquito net last night?	Yes .... 1 No .... 2 Don't know 98	

SECTION 4. NUTRITION FOR MOTHERS & CHILDREN			
Now I would like to ask about all food or liquids consumed by you and your child enrolled in the study YESTERDAY, during the day or at night.			
		MOTHER	**ENROLLED CHILD**
401	**Grains and cereals**	Maize (/porridge) ... 1 Millet (/porridge) ... 2 Sorghum (/porridge) ... 3 Rice ... 4 Bread ... 5 Other (specify) ... 96 [ ] None ... 99	Maize (/porridge) ... 1 Millet (/porridge) ... 2 Sorghum (/porridge) ... 3 Rice ... 4 Bread ... 5 Other (specify) ... 96 [ ] None ... 99
402	**Green leafy vegetables**	Cassava leaves ... 1 Bean leaves ... 2 Amaranthus ... 3 Pumpkin leaves ... 4 Spinach ... 5 Cucumber leaves ... 6 *Kipari* ... 7 *Mlende* ... 8 *Mgagani* ... 9 *Mchunga* ... 10 Sweet potato leaves ... 11 Other (specify) ... 96 [ ] None ... 99	Cassava leaves ... 1 Bean leaves ... 2 Amaranthus ... 3 Pumpkin leaves ... 4 Spinach ... 5 Cucumber leaves ... 6 *Kipari* ... 7 *Mlende* ... 8 *Mgagani* ... 9 *Mchunga* ... 10 Sweet potato leaves ... 11 Other (specify) ... 96 [ ] None ... 99
403	**Root vegetables or tubers**	Cassava ... 1 Potatoes ... 2 Sweet potato ... 3 Other (specify) ... 96 [ ] None... 99	Cassava ... 1 Potatoes ... 2 Sweet potato ... 3 Other (specify) ... 96 [ ] None... 99
404	**Other vegetables**	Pumpkin ... 1 Okra ... 2 Eggplant ... 3 Carrots ... 4 Mushrooms ... 5 Other (specify) ... 96 [ ] None ... 99	Pumpkin ... 1 Okra ... 2 Eggplant ... 3 Carrots ... 4 Mushrooms ... 5 Other (specify) ... 96 [ ] None ... 99
405	**Legumes and nuts**	Beans ... 1 Mung beans ... 2 Groundnuts ... 3 Cashew nuts ... 4 Bambara nuts ... 5 Cowpeas ... 6 Other (specify) ... 96 [ ] None ... 99	Beans ... 1 Mung beans ... 2 Groundnuts ... 3 Cashew nuts ... 4 Bambara nuts ... 5 Cowpeas ... 6 Other (specify) ... 96 [ ] None ... 99

		MOTHER	ENROLLED CHILD
406	**Fruits**	Banana .... 1 Mango .... 2 Pawpaw .... 3 Citrus fruit .... 4 Passionfruit .... 5 Pineapple .... 6 Avocado .... 7 Tomato .... 8 Soursop .... 9 Watermelon .... 10 Guava .... 14 Baobab fruit .... 15 Other (specify) .... 96 [ ] None........99	Banana .... 1 Mango .... 2 Pawpaw .... 3 Citrus fruit .... 4 Passionfruit .... 5 Pineapple .... 6 Avocado .... 7 Tomato .... 8 Soursop .... 9 Watermelon .... 10 Guava .... 14 Baobab fruit .... 15 Other (specify) .... 96 [ ] None........99
407	**Meat, fish and offal**	Cow .... 1 Goat .... 2 Pig .... 3 Chicken .... 4 Duck .... 5 Guinea fowl .... 6 Liver .... 7 Fish .... 8 Sheep .... 9 Other (specify) .... 96 [ ] None........ 99	Cow .... 1 Goat .... 2 Pig .... 3 Chicken .... 4 Duck .... 5 Guinea fowl .... 6 Liver .... 7 Fish .... 8 Sheep .... 9 Other (specify) .... 96 [ ] None........ 99
408	**Eggs, dairy and other**	Eggs .... 1 Milk .... 2 Oils, fats, butter .... 3 Tea or coffee .... 4 Sugar or honey .... 5 Iodised salt .... 6 Non-commercial salt .... 7 Other (specify) .... 96 [ ] None 99	Eggs .... 1 Milk .... 2 Oils, fats, butter .... 3 Tea or coffee .... 4 Sugar or honey .... 5 Iodised salt .... 6 Non-commercial salt .... 7 Other (specify) .... 96 [ ] None 99

Appendix B. Annual Livelihood Questionnaire [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

ANNUAL HOUSEHOLD QUESTIONNAIRE

CONFIDENTIAL

HOUSEHOLD CODES:

District

Ward

Village

Subvillage

Household

PARTICIPANTCODES:

Mother (NB. may not be interviewee)

Enrolled child

INTERVIEWER NAME:

GPS COORDINATES

Record location reading at start of interview.

		Degrees	Minutes	Seconds
Latitude	S			
Longitude	E			

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
SECTION 1. IDENTITY			
100	*Is the interviewee the selected mother?*	Yes .... 1 No 2	
101	*Record sex of respondent*	Female .... 1 Male 2	
102	How old are you? *Record age in completed years. Respondents must be 16 years of age or older.*	Age in completed years [ ] Don't know 98	
103	What is your relationship to the head of the household? *Circle the most appropriate answer (one option only).*	I am the head of the household .... 1 Wife / husband of head .... 2 Daughter / son of head .... 3 Daughter-in-law / son-in-law .... 4 Granddaughter / grandson .... 5 Parent .... 6 Sister / brother .... 7 Sister-in-law / brother-in-law .... 8 Other relative .... 9 Adopted / foster / stepdaughter / son.......... 10 Domestic servant .... 11 Friend .... 12 Other not relative (specify) .... 96 [ ]	
104	What is the sex of the head of the household?	Female .... 1 Male 2	
105	How many people live in your household including yourself? *Record number of household members.*	Number of household members [ ]	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
106	How many males and females between 7 and 20 years of age are part of your household? *Record number of male and female household members 7-20 years of age separately. Include parent(s) of enrolled child, if within this age range.*	Number of males 7-20 yrs [ ] Number of females 7-20 yrs [ ]	
107	How many of these males and females attend school on a regular basis? *Record the number of male and female household members attending primary and secondary school separately.*	**Primary school:** Number of males [ ] Number of females [ ] **Secondary school:** Number of males [ ] Number of females [ ]	
SECTION 2. HOUSEHOLD CHARACTERISTICS			
201	What are the materials used in the roof of the house in which the head of the household is living? *Circle the most appropriate answer (one option only). Record observation.*	Grass / thatch / leaves / mud .... 1 Iron sheets .... 2 Tiles .... 3 Concrete .... 4 Asbestos .... 5 Other (specify) .... 96 [ ]	
202	What are the materials used in the walls of the house? *Circle the most appropriate answer (one option only). If more than one type of material is given, select the predominant material type. Record observation.*	Grass .... 1 Wooden poles and mud .... 2 Earth bricks, sun dried .... 3 Baked bricks .... 4 Wood, timber .... 5 Cement bricks .... 6 Stones .... 7 Other (specify) .... 96 [ ]	
203	What are the construction materials used in the floor of the house? *Circle the most appropriate answer (one option only). Record observation.*	Earth / sand / animal dung .... 1 Wood planks / palm / bamboo .... 2 Vinyl / asphalt strips / concrete .... 3 Ceramic tiles .... 4 Cement and concrete .... 5 Other (specify) .... 96 [ ]	
204	What is the main source of water for drinking and everyday use for your household? *Circle the most appropriate answer (one option only).*	Piped water into house .... 1 Piped water into yard / plot .... 2 Public tap .... 3 Open well in yard / plot .... 4 Open public well .... 5 Neighbouring public well .... 6 Protected well / borehole in yard / plot .... 7 Spring / river / stream / pond / lake / dam .... 8 Other (specify) .... 96 [ ]	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
205	What is the main source of energy? *Circle the most appropriate answer (one option only).*	Firewood ..... 1 Paraffin / kerosene ..... 2 Crop residuals, straw, grass, animal dung ..... 3 Charcoal ..... 4 Bottled gas ..... 5 Electricity ..... 6 No food cooked in household ..... 7 Other (specify) ..... 96 [ ]	
206	Does your house have the following goods? *Each item should be read aloud, one by one, and the response for each item recorded.*	Radio or other music device ..... 1 Bicycle ..... 2 Motorcycle ..... 3 Car/tractor/other vehicle ..... 4 Television ..... 5 Refrigeration ..... 6 Mobile phone ..... 7 Shop / kiosk / bar ..... 8 Sewing machine ..... 9 Sofa set ..... 10 Dining table ..... 11 Generator ..... 12 Solar panel ..... 13 Ox cart ..... 14 Non-mobile phone 15	

SECTION 3. HOUSEHOLD LIVELIHOOD

301 During the past 12 months, what were your household's most important sources of cash income?

List up to 4 activities by writing the number corresponding to the answers below in the space next to the correct answer: (1) most important, (2) second most important, (3) third most important, and (4) fFourth most important.

1.	Remittance	[ ]
2.	Food crop production / sale	[ ]
3.	Cash crop production / sale	[ ]
4.	Vegetable production / sale	[ ]
5.	Casual labour	[ ]
6.	Livestock production / sales (cattle and goats)	[ ]
7.	Livestock production / sales (chickens)	[ ]
8.	Sale of livestock products (eg. milk and eggs)	[ ]
9.	Draught power hiring	[ ]
10.	Skilled trade / artisan	[ ]
11.	Own business	[ ]
12.	Petty trade	[ ]
13.	Pension	[ ]
14.	Formal salary / wages	[ ]
15.	Informal salary / wages	[ ]
16.	Fishing / gathering natural products for sale	[ ]
17.	Beer brewing	[ ]
18.	Bee-keeping, honey production	[ ]
19.	Small-scale mining / mineral sales	[ ]
20.	Government social transfers	[ ]
21.	Non-state social transfers	[ ]
22.	Cross border trade	[ ]

	23. Rentals	
	24. Begging	
	25. Gifts	
	26. Food assistance	
	27. Currency trade	
	28. Collecting scrap / waste materials for re-sale	
	96. Other (specify) ______	
	99. No other source of income	

No.	QUESTIONS		
302	Which of the following animal species do you have in the household? How many animals of each species do you have? *Read the options and record the number of breeding females and total number of animals for each category. List any others as appropriate.*		Total number of animals
	1. Cattle		
	2. Goats		
	3. Sheep		
	4. Donkeys		
	5. Pigs		
	6. Ducks		
	7. Dogs		
	8. Cats		
	96. a. Other (specify)		
	96. b. Other (specify)		

SECTION 4. CHICKEN HEALTH, NUTRITION AND MANAGEMENT

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
401	Do you currently keep chickens? *Circle the appropriate code.*	Yes ..... 1 No 2	→404
402	Why do you not currently keep chickens? *Circle as many responses as appropriate (may be more than one option).*	Died from disease ..... 1 Sold ..... 2 Predation ..... 3 Transferred to another flock ..... 4 Other (specify) ..... 96 ______	
403	Has your family kept chickens in the last twelve months?	Yes ..... 1 No 2	→408 →501
404	How many chickens does your family currently have? *Read the list and record the number of each category. Even day old chicks should be recorded.*	1. Total number of chickens ______ 2. Adults (over 5 months) ______ 3. Growers (2 – 5 months) ______ 4. Chicks (under 2 months) ______	
405	How many people in the household currently own chickens?	Number of people ______	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
406	Do you personally own chickens?	Yes .... 1 No 2	
407	How many chickens does each member of your household own? *Record the number of chickens owned by each of the listed household members. Check that the total number of chickens matches the number recorded in questions 404.*	Number owned 1. Adult male(s) [ ] 2. Adult female(s) [ ] 3. Male child(ren) [ ] 4. Female child(ren) [ ] 5. Whole family [ ] Total [ ]	
408	In the last twelve months, did you ever provide additional / supplementary feed to your chickens?	Yes .... 1 No 2	 →412
409	In the last twelve months, how often did you provide additional feed to your chickens? *Select response (one option only).*	Twice daily .... 1 Once daily .... 2 Occasionally .... 3 Never 4	 →412
410	In the last twelve months, during which months of the year did you provide additional feed to your chickens? *Tick boxes for the appropriate month(s). More than one box can be ticked.*	1. January .... [ ] 2. February .... [ ] 3. March .... [ ] 4. April .... [ ] 5. May .... [ ] 6. June .... [ ] 7. July .... [ ] 8. August .... [ ] 9. September .... [ ] 10. October .... [ ] 11. November .... [ ] 12. December .... [ ]	
411	In the last twelve months, what type of feed did you provide? *Circle as many answers as appropriate.*	Leftovers or table scraps .... 1 Take chickens to fields after harvest .... 2 Maize or maize bran .... 3 Vegetable scraps .... 4 Cakes – sunflower, cotton seed, etc .... 5 Millet .... 6 Sorghum .... 7 Cassava .... 8 Sweet potato .... 9 Papaya or leaves .... 10 *Moringa oleifera (mlonge)* .... 11 Maggots .... 12 Insects (eg. termites / cockroaches) .... 13 Eggshells .... 14 Limestone .... 15 Other (specify) .... 96 [ ]	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
412	In the last twelve months, where did you keep your chickens overnight? *Select response (one option only).*	In the kitchen .... 1 In the bedroom .... 2 In a chicken house .... 3 Outside, no special place .... 4 In another room in the house .... 5 Other (specify) .... 96 [ ]	
413	How many chickens and eggs from your own family production did your household utilise in the last month? *Read list and enter numbers in each box.*	Chickens / Eggs 1. Family eating [ ] [ ] 2. Guests/ceremonies [ ] [ ] 3. Sold [ ] [ ] 4. Exchanged [ ] [ ] 5. Gifts [ ] [ ] 6. Other ____________ [ ] [ ] 7. Other ____________ [ ] [ ]	
414	In which months of the last year did you more commonly sell or exchange chickens from your flock? *Tick boxes for the appropriate month(s). More than one box can be ticked.*	1. January .... [ ] 2. February .... [ ] 3. March .... [ ] 4. April .... [ ] 5. May .... [ ] 6. June .... [ ] 7. July .... [ ] 8. August .... [ ] 9. September .... [ ] 10. October .... [ ] 11. November .... [ ] 12. December .... [ ] 99. No birds sold or exchanged........ [ ]	
415	In which months of the last year did you more commonly eat chickens from your flock? *Tick boxes for the appropriate month(s). More than one box can be ticked.*	1. January .... [ ] 2. February .... [ ] 3. March .... [ ] 4. April .... [ ] 5. May .... [ ] 6. June .... [ ] 7. July .... [ ] 8. August .... [ ] 9. September .... [ ] 10. October .... [ ] 11. November .... [ ] 12. December .... [ ] 99. No birds eaten .... [ ]	

No.	QUESTIONS	CODING CATEGORIES	SKIP TO
416	In which months of the year do you commonly experience chickens in your flock dying of Newcastle disease? *Tick boxes for the appropriate month(s). More than one box can be ticked.*	1. January .... 2. February .... 3. March .... 4. April .... 5. May .... 6. June .... 7. July .... 8. August .... 9. September .... 10. October .... 11. November .... 12. December .... 98. Don't know	
417	Have you ever vaccinated your chickens against Newcastle disease?	Yes .... 1 No 2	→ 501
418	When was the first time you vaccinated your chickens? *Record month and year.*	First time vaccinated	
419	When was the last time they were vaccinated? *Record month and year.*	Last time vaccinated	
420	In which vaccination campaigns in the last year did you vaccinate your chickens?	January 2016 Yes .... 1 No .... 2 May 2016 Yes .... 1 No .... 2 September 2016 Yes .... 1 No 2	
421	Who made the decision to vaccinate the chickens? *Circle the appropriate code.* *More than one response may be given*	Family decision .... 1 Adult male (owner) .... 2 Adult female (owner) .... 3 Adult male (not owner) .... 4 Adult female (not owner) 5	
422	What was the result of the last vaccination? *Circle the appropriate code (one response only).*	No difference .... 1 Less deaths .... 2 More deaths .... 3 No deaths .... 4 Don't know 98	

SECTION 5. KNOWLEDGE, COMMUNICATION AND EDUCATION			
No.	**QUESTIONS**	**CODING CATEGORIES**	**SKIP TO**
501	On which of the following topics have you received information? *The list of item should be read.* *Circle as many answers as appropriate.*	None .... 1 Crops Improved agriculture practices .... 2 Improved livestock practices .... 3 Agricultural tools .... 4 Improved seeds .... 5 Inputs (fertilizer, pesticide, etc) .... 6 Crop conservation .... 7 Chickens Veterinary services .... 8 Chicken health .... 9 Chicken nutrition .... 10 Marketing of chickens .... 11 Human health Human nutrition 12	
502	Who provided the extension / information services? *Circle the appropriate code.* *More than one response may be given.*	Government (agriculture and livestock) .... 1 Government (human health) .... 2 Project staff .... 3 NGO staff .... 4 Community-based extension workers .... 5 Other (specify) .... 96 [ ]	

Appendix C. Record sheet for chicken numbers and child health and breastfeeding status in enrolled households, completed by Community Assistants during twice-monthly visits [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

TWO-WEEKLY HOUSEHOLD REGISTRATION SHEET

CODES

District [ ] Ward [ ] Village [ ] Sub-village [ ]

Chicken numbers

Date	Household code	Gender (owner)	Chickens <2 months		Chickens >2 months		Comments
			Number owned	Number vaccinated	Number owned	Number vaccinated	

Child health and breastfeeding status

Household code	Child code	Criteria	Date of data collection				Comments
			1	2	3	4	
		Health status					
		Breastfeeding status					
		Health status					
		Breastfeeding status					
		Health status					
		Breastfeeding status					
		Health status					
		Breastfeeding status					
		Health status					
		Breastfeeding status					
		Health status					
		Breastfeeding status					

Notes:

Health status: Record any episodes of illness in the previous fortnight:
H = healthy, D = diarrhoea, I = other illness, P = passed away
Breastfeeding status: B = exclusively breastfed, M = mixed feeding (breast milk and other foods), Z = zero breastfeeding

Definitions:

Exclusive breastfeeding – no other food or drink, not even water, except breast milk for 6 months of life, but allows oral rehydration solutions, drops and syrups (vitamins, minerals and medicines). (WHO WHA55 A55/15)

Diarrhoea – passage of three or more loose or liquid stools per day (or more frequent passage than is normal for the individual). Frequent passing of formed stools is not diarrhoea, nor is the passing of loose, "pasty" stools by breastfed babies. (WHO Fact sheet N°330)

Appendix D. Community Vaccinator record sheet [English version]

NEWCASTLE DISEASE VACCINATION RECORD

District ____ Ward ____ Village ____ Sub-village ____ Vaccinator name ____

Name of head of household	Sex of household head	**First campaign.** Vaccine batch no. _________				**Second campaign.** Vaccine batch no. _________				**Third campaign.** Vaccine batch no. _________			
		Number of chickens registered	Number of chickens vaccinated	Number of chickens owned	Payment made	Number of chickens registered	Number of chickens vaccinated	Number of chickens owned	Payment made	Number of chickens registered	Number of chickens vaccinated	Number of chickens owned	Payment made
		Month: __________	Month: __________			Month: __________	Month: __________			Month: __________	Month: __________		

Appendix E. Visual diary [English version]

	 Breastfeeding mother	 Pregnant woman	 Child enrolled in study
 Chicken			
 Eggs			

Appendix F. Question guide used as a basis for semi-structured interviews with mothers of enrolled children

KEY INFORMANT INTERVIEWS

Aim:

To explore findings arising from quantitative data collection in participating households in Sanza and Majiri Wards, Tanzania, with a focus on chicken-keeping practices and diets of young children.

Method:

A subset of around 5 mothers from each of 8 villages (around 40 in total) will be purposively selected, guided by children's dietary and growth patterns, illness frequency, chicken ownership and poultry management practices. Interviews of no more than 30 minutes in length will be conducted at times and locations to avoid excessive inconvenience to women (eg. household visits).

Guide questions:

Breastfeeding

You have told us that your child was exclusively breastfed until __ months of age, and that you continued breastfeeding until __ months of age. Is this correct?

Did you manage to breastfeed the way you were planning to? The number of times per day? Did you feel that you had enough milk and that your child was satisfied?

Have you ever had trouble breastfeeding your baby? Who have you spoken to / who would you speak to if you were having trouble breastfeeding? Have you, or anyone you know, received advice about what to do if you were having difficulties with breastfeeding?

How did you decide when it was the right time to introduce other foods to your baby? Do you know if your mother started giving food at the same age that you started giving food to your child? Is there a difference? Why? What do you think is the impact of these changes if any? Why?

Government health workers often recommend exclusive breastfeeding until 6 months of age, but we know that it is common for people to introduce other foods earlier, sometimes from 3 months of age or even earlier. Why do you think this is?

Is there anything else about breastfeeding you would like to talk about?

Children's diets

We are interested in the types of foods which are eaten by children, especially in the first few years of life. From our data collection last year, you have told us that your child was eating eggs / chicken in the month of __. Is it common to eat eggs / chicken in your family? When would you be more likely to eat eggs / chicken?

When did you first give your child egg to eat? Is there any special reason why you would avoid feeding eggs to a young child? How do you prepare it? Do you give it on its own? Do you give the whole egg? Are all women doing the same? What can be the differences? Why? Women have told us previously that it is common to introduce the yolk before the white part of the egg. Is this something you would do? Why?

When you first started giving foods other than breastmilk to your child, you told us you gave porridge with ___ added. Is this correct? When did you start to give other foods? [Prompt with specific foods: *kipari* or *mlenda*, tomatoes, sweet potato, beans, chicken meat, other meat, liver, eggs, milk].

Do you think your child eats different foods to other children in the community?

We know that there have been poor rains recently, which have had a big impact on crop production. Is this correct? Has this made it difficult to provide food for your family? Has this affected the foods eaten by your children?

Is there anything else about children's diets you would like to talk about?

Children's growth

As you know, we have been measuring your child every 6 months as part of our project. We use these measurements to compare your child's growth to other children of the same age and gender.

Are there special foods that you try to give to your child to help with growth and health?

From our measurements, we can see that your child:

(a) Seems to be quite tall, compared to other children of the same age and gender. This suggests that he / she may be eating foods which have helped with growth and development.

(b) Seems to be quite short, compared to other children of the same age and gender. Sometimes this is because other people in the family are also short (short parents often have short children), but it may also be a sign that the foods your child is eating are not helping with growth, or that your child has been unwell frequently or over a long period of time.

(c) Seems to have previously been growing well, compared to other children of the same age and gender, but has not been growing so well recently.

Do you have any thoughts on this?

[For children with poor linear growth or growth faltering (b and c)]:
Has your child been sick? Have there been problems which have made it difficult to feed your child?

Is there anything else about your child's growth that you would like to talk about?

Impact of child gender

The information that we have collected tells us that there are sometimes differences between male and female children, in terms of how their growth changes as they get older. This is a common finding in other parts of Africa as well.

Your child in our study is (male / female). Do you have other children? Are they male or female?

What are the differences between boys and girls in relation to their childhood? Can you explain the difference between boys and girls in relation to the way they eat, to the way they play, the way they behave, the way they understand what you tell them?

Is there a difference in the preferences of boys and girls in relation to food? Are there some foods which are particularly important for male children, or for female children? Are there some foods which should be avoided by male children, or by female children? Why? Do you feed your children differently based on whether they are male or female?

Can you think of any other differences in the way you, or people you know, take care of a young child, depending on whether they are male or female?

Impact of language group

Do you think people from different language groups treat children differently to how you treat them? Can you give me some of the differences you know or you have noticed personally? Differences in relation to caring, breastfeeding, preparing food, the timing of the introduction of food…?

The information you have given us has told us that there seems to be differences in the growth of children from Gogo families and children from Sukuma families. Does this surprise you? Why do you think there might be differences in the growth of children from Gogo and Sukuma households?

Are there foods that your household would eat, that (Gogo / Sukuma) households would not eat?
Are there foods that you would eat more or less often, compared to (Gogo / Sukuma) households?
Are there differences in farming between Gogo and Sukuma households?

Is there anything else about language groups you would like to talk about?

Chicken ownership

As you know, our community assistants have been asking questions about your chickens every two weeks to help us understand how chicken numbers change through the year. Over the past two years:

(a) Your chicken flock has increased from around __ to up to __ birds. Is this correct? Why are you keeping more chickens than previously? Do you vaccinate your chickens? What are your experiences with vaccines? Do you sell chickens / eggs? Do you eat chickens / eggs in your household?

(b) Your chicken flock has decreased from around __ to __ birds. Is this correct? Why are you keeping less chickens than previously? When you had chickens, did you vaccinate them? Why or why not? Do you eat chickens / eggs in your household?

(c) You have kept chickens in small numbers only, or not at all. Are you interested in keeping chickens? What are your reasons for not keeping chickens? When you had chickens, did you vaccinate them? Why / why not? Do you eat chickens / eggs in your household?

Is there anything else about chicken-keeping that you would like to talk about?

Chicken management

In our questionnaires, we have been asking you where you keep your chickens at night.

(a) You have told us that you keep your chickens ___ overnight. Why is this? Would you like to keep more chickens? If you had more chickens, where would you keep them?

(b) You have told us that previously you kept your chickens ___ but more recently you have been keeping them ___. Is this correct? Why did you decide to change the location where you keep your chickens?

Do you have any questions for me?

Thank you for your time and your kindness.

Appendix G. Letter of approval, National Medical Research Institute (Tanzania)

THE UNITED REPUBLIC OF
TANZANIA

National Institute for Medical Research
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NIMR/HQ/R.8a/Vol. IX/1690

20th February, 2014

Dr Halifa Msami
Tanzania Veterinary Laboratory Agency
Mandela Road, Temeke,
P O Box 9254,
DAR ES SALAM

CLEARANCE CERTIFICATE FOR CONDUCTING MEDICAL RESEARCH IN TANZANIA

This is to certify that the research entitled: Strengthening Food and Nutrition Security though Family Poultry and Crop Integration in Tanzania and Zambia, (Msami H *et al*), has been granted ethical clearance to be conducted in Tanzania.

The Principal Investigator of the study must ensure that the following conditions are fulfilled:

1. Progress report is submitted to the Ministry of Health and the National Institute for Medical Research, Regional and District Medical Officers after every six months.
2. Permission to publish the results is obtained from National Institute for Medical Research.
3. Copies of final publications are made available to the Ministry of Health & Social Welfare and the National Institute for Medical Research.
4. Any researcher, who contravenes or fails to comply with these conditions, shall be guilty of an offence and shall be liable on conviction to a fine. NIMR Act No. 23 of 1979, PART III Section 10(2).
5. Site: Sanza and Majiri Wards in Manyoni District, and Vunta Ward in Same District.

Approval is for one year: 20th February 2014 to 19th February 2015.

Name: Dr Mwelecele N Malecela

Signatu
CHAIRPERSON
MEDICAL RESEARCH
COORDINATING COMMITTEE

Name: Dr Donan Mmbando

Signature
CHIEF MEDICAL OFFICER
MINISTRY OF HEALTH, SOCIAL WELFARE

CC: RMO
DED
DMO

Appendix H. Letter of approval, The University of Sydney Human Research Ethics Committee

THE UNIVERSITY OF SYDNEY

Research Integrity
Human Research Ethics Committee

Monday, 31 March 2014

Assoc Prof Robyn Alders
Vet Science Faculty; Faculty of Veterinary Science
Email: robyn.alders@sydney.edu.au

Dear Robyn

I am pleased to inform you that the University of Sydney Human Research Ethics Committee (HREC) has approved your project entitled "**Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia**".

Details of the approval are as follows:

Project No.: **2014/209**

Approval Date: **31 March 2014**

First Annual Report Due: **31 March 2015**

Authorised Personnel: **Alders Robyn; Aongola Agnes; Msami Halifa; Li Mu; Simpson Judith; McConchie Robyn; Mor Siobhan; De Bruyn Julia; Kimboka Sabas; Lumbwe Hilda;**

Documents Approved:

Date Uploaded	Type	Document Name
04/03/2014	Interview Questions	G PRA / PIA
04/03/2014	Other Instruments/Tools	B Anthropometric data sheet
04/03/2014	Other Instruments/Tools	H ND vaccination registration form
04/03/2014	Other Instruments/Tools	Overview of research tools
04/03/2014	Participant Consent Form	A1, A2, B MCHN Informed Consent
04/03/2014	Participant Consent Form	C Blood Testing Informed Consent
04/03/2014	Participant Consent Form	D Annual Household QuestionnaireInformed Consent
04/03/2014	Participant Consent Form	E, F, H Informed Consent
04/03/2014	Participant Consent Form	G PRA / PIA Informed Consent
04/03/2014	Participant Info Statement	Information for community leaders
04/03/2014	Participant Info Statement	Parental Information Statement
04/03/2014	Participant Info Statement	Participant Information Statement
04/03/2014	Questionnaires/Surveys	A1 MCHN baseline questionnaire
04/03/2014	Questionnaires/Surveys	A2 MCHN follow-up questionnaire
04/03/2014	Questionnaires/Surveys	D Household two-weekly registration sheets
04/03/2014	Questionnaires/Surveys	E Annual Household Questionnaire
04/03/2014	Questionnaires/Surveys	F Visual Diary
04/03/2014	Questionnaires/Surveys	I Listing of households / census
04/03/2014	Safety Protocol	Research Team Security Plan

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E ro.humanethics@sydney.edu.au
sydney.edu.au

ABN 15 211 513 464
CRICOS 00026A

HREC approval is valid for four (4) years from the approval date stated in this letter and is granted pending the following conditions being met:

Special Condition/s of Approval

- It will be a condition of approval that independently certified translations of the public documents are forwarded to the HREC. The translations must be certified by a person who is not associated with the research project (either an applicant or other persons identified in the application) and has no conflict of interest. They need to indicate that the translated documents are a true and accurate representation of the English language versions submitted to the HREC. A statutory declaration to this effect (if not a registered translator or a staff member with the appropriate expertise) would be acceptable if they are not an official translator. A statutory declaration form can be found at http://www.ag.gov.au/STATDEC
- Please ensure that all public documents carry the appropriate University of Sydney branding.

Condition/s of Approval

- Continuing compliance with the National Statement on Ethical Conduct in Research Involving Humans.
- Provision of an annual report on this research to the Human Research Ethics Committee from the approval date and at the completion of the study. Failure to submit reports will result in withdrawal of ethics approval for the project.
- All serious and unexpected adverse events should be reported to the HREC within 72 hours.
- All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.
- Any changes to the project including changes to research personnel must be approved by the HREC before the research project can proceed.
- Note that for student research projects, a copy of this letter must be included in the candidate's thesis.

Chief Investigator / Supervisor's responsibilities:

1. You must retain copies of all signed Consent Forms (if applicable) and provide these to the HREC on request.
2. It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.

Please do not hesitate to contact Research Integrity (Human Ethics) should you require further information or clarification.

Yours sincerely

Professor Glen Davis
Chair
Human Research Ethics Committee

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007), NHMRC and Universities Australia Australian Code for the Responsible Conduct of Research (2007) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

Appendix I. Letter of approval, The University of Sydney Animal Ethics Committee

THE UNIVERSITY OF SYDNEY

RESEARCH INTEGRITY
Animal Ethics Committee
Web: http://sydney.edu.au/ethics

Ref: DA/GQ

22 October 2013

A/Prof Robyn Alders
Faculty of Veterinary Science
C01a-JI Shute – Camden
The University of Sydney
Email: robyn.alders@sydney.edu.au

Dear A/Prof Robyn Alders,

I am pleased to inform you that the Animal Ethics Committee (AEC) reviewed and approved your protocol entitled **"Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia"** at its meeting on **17 October 2013**.

Details of the approval are as follows:

AEC Approval Number: **6065**

Current Approval Period: **October 2013 – October 2018**

Annual Report Due: **31 October 2014**

Authorised Personnel: **A/Prof Robyn Alders**
Dr Hallfa Msami,Dr Francis Mulenga,

Species/Strain	**TOTAL animals approved for duration of project**
Chickens / Village chickens	70,000

Animal House/Location where Animals will be held: **Field Study – as specified in the Application Form submitted to the Ethics Office**

Documents Approved: **As provided with the application**

The approval of this project is conditional upon you adhering to the conditions outlined in this letter and your continuing compliance with the Animal Research Act (1985 – Animal Research Regulation 2010) and the 'Australian code of practice for the care and use of animals for scientific purposes' (7th Edition 2004).

The project is approved for an initial period of **12 months** with approval for up to **(5) years** following receipt of the appropriate report (refer to clauses 2.2.37 and 2.2.38 "Reporting of projects", of the Australian code of practice).

Special Condition/s of Approval Applicable to this Project

- *Please remove IV injection of air as a euthanasia technique, as it is generally regarded as a painful and unreliable method. Only cervical dislocation is approved as a euthanasia technique.*

Address for all correspondence:
Level 6 Jane Foss Russell Building G02
The University of Sydney NSW 2006
AUSTRALIA
T: +61 2 8627 8174
E: animal.ethics@sydney.edu.au

Animal Welfare Veterinarian
Jinny Oh
T: +61 2 8627 8132
E: jinny.oh@sydney.edu.au

ABN 15 211 513 464
CRICOS 00026A

THE UNIVERSITY OF SYDNEY

Conditions of Approval Applicable to All Projects

1. The Animal Ethics Committee (AEC) reviews and approves protocols for their compliance with the NSW Animal Research Act (and its associated Regulations) and the 2004 NHMRC 'Australian code of practice for the care and use of animals for scientific purposes'. All personnel named on the protocol should be conversant with these documents.

2. This approval is in accordance with your original submission together with any additional information provided as part of the approval process.

3. Any changes to the protocol must be approved by the AEC before continuation of the experiment (refer to website http://sydney.edu.au/ethics/ for a Modification Form). This includes notifying the AEC of any changes to: named personnel, source of animals, animal numbers, location of animals and experimental procedures.

4. All cages/pens/tanks/paddocks used for holding animals must be clearly labelled with the Chief Investigator's name, approval number, title of project and cage/pen/tank number.

5. A copy of this approval letter, together with all relevant monitoring records, must be kept in the facility where your animals are housed. These records must be updated regularly as breeding and husbandry events occur and current copies must be maintained in the animal house. Monitoring sheets must contain a section where expected post-operative effects are identified and observations recorded. Where relevant, the box number must be recorded on the monitoring sheet to ensure that affected animals can be easily located. Where electronic breeding records are kept instead of records on cage cards, printed copies of the records should be placed in a folder in the relevant animal house, where they can be inspected by the AEC.

6. Data should be accurately recorded in a durable and appropriately referenced form that complies with established legislation, policy and guidelines. Consent forms must be retained in a secure location, such as a locked filing cabinet, at the University of Sydney for a period of seven (7) years.

7. Investigators should promptly notify the AEC of any unexpected adverse events that may impact on the wellbeing of an animal in their care (refer to Clauses 2.2.28 and 3.1.12 in the 'Australian code of practice'). Please refer to the website http://sydney.edu.au/research_support/ethics/animal/forms.shtml and complete a "Report of adverse or unexpected events during the conduct of an approved project" form, in accordance with the AEC Adverse Event Reporting Procedures (GL003) located on the website - http://sydney.edu.au/research_support/ethics/animal/sop/index.shtml.

8. In the event an animal dies unexpectedly, or requires euthanasia for welfare reasons, an autopsy should be performed by a person with appropriate qualifications and/or experience and the AEC should be notified promptly.

9. All animals must be provided with environment enrichment appropriate for their species, unless approved by the AEC.

10. Animals should not be housed singly unless approved by the AEC.

11. Animals must not be euthanised within sight or sound of other animals (refer to Clause 3.3.20, of the Australian code of practice).

12. The AEC will make regular announced inspections of all animal facilities and/or specific research protocols. The Animal Welfare Manager will be conducting unannounced inspections of all animal facilities and/or specific research protocols.

Please do not hesitate to contact Research Integrity (Animal Ethics) Office should you require further information or clarification.

Yours sincerely

Professor David Allen
Chair
Animal Ethics Committee

Appendix J. Informed Consent Statement, Maternal and Child Health and Nutrition Questionnaire [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

THE UNIVERSITY OF SYDNEY

INFORMED CONSENT STATEMENT
Maternal and Child Health and Nutrition Questionnaire

Principal Investigator:	Robyn Alders
Co-investigators:	Wende Maulaga (Tanzania) & Hilda Lumbwe (Zambia)

You are being invited to participate in a study to understand the ways that your family's health can be improved by improving the productivity of your chickens and crops.

Questions we ask in this survey will focus on the health and nutrition of you and your child who has been selected to participate in our project. There will be questions about your current or recent pregnancies, breastfeeding, and services provided by health facilities. We will also ask about different types of food you and your child consume.

Participation in this study is entirely voluntary and you will not be paid for participating. If you agree to participate, you can change your mind at any time. We will ask you a series of questions at six-monthly intervals. With your permission, we would also like to measure and weigh you and your child. On some occasions, we may ask to take some photographs of your participation to illustrate our research activities.

If you do not feel comfortable answering any questions, just tell us and we will move on to the next question. If you have any questions about the study, feel free to ask them at any time.

Whatever information you provide will be kept strictly confidential.

At this time, do you want to ask me anything about the survey?

May I begin the interview now?

Name of interviewee: ________________________________

Signature or thumbprint of interviewee: ________________________________

Date: _____/_____/___________

TO BE COMPLETED BY THE INTERVIEWER:

The information in the consent form was read aloud and the respondent clearly understood the contents and agreed to participate.

Name of interviewer: ________________________________

Signature of interviewer: ________________________________

Date: _____/_____/___________

Appendix K. Informed Consent Statement, Annual Livelihood Questionnaire [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

THE UNIVERSITY OF SYDNEY

INFORMED CONSENT STATEMENT
Annual Livelihood Questionnaire

Principal Investigator:	Robyn Alders
Co-investigators:	Wende Maulaga (Tanzania) & Hilda Lumbwe (Zambia)

You are being invited to participate in a study to understand the ways that your family's health can be improved by improving the productivity of your chickens and crops.

You have been selected to participate in this survey because we would like to interview an even number of men and women. We will be asking you questions about your household livelihood and your chickens' production.

Your participation is completely voluntary and you may choose not to participate. You can withdraw from the interview at any moment. If you are willing to share information about your household with us, your responses will not be disclosed and will only be used for research purposes. On some occasions, we may ask to take some photographs of your participation to illustrate our research activities.

Signing this form indicates that you understand what will be expected of you and are willing to participate in this household survey.

Do you have any questions for me about the survey?

Do you agree to participate in the survey?

May I begin the interview now?

Name of interviewee: ________________________________

Signature or thumbprint of interviewee: ________________________________

Date: _____/_____/__________

TO BE COMPLETED BY THE INTERVIEWER:

The information in the consent form was read aloud and the respondent clearly understood the contents and agreed to participate.

Name of interviewer: ________________________________

Signature of interviewer: ________________________________

Date: _____/_____/__________

Appendix L. Informed Consent Statement, Key Informant Interviews [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

INFORMED CONSENT STATEMENT
Key Informant Interviews

Sub-project: *Healthy chickens, healthy children? Exploring contributions of village poultry to the diets and growth of young children in rural Tanzania* (Julia de Bruyn, University of Sydney).

Thank you for your participation in our study over the past two years. Information you have provided is helping us to understand the ways that your family's health can be improved by increasing the production of your chickens and crops.

Today I would like to ask some more questions about how your household deals with the challenge of eating a nutritious diet – especially during difficult times, such as when there is poor rainfall, poor harvest or when animals are not available. I am especially interested in the ways that you share food within your household and in the foods which are eaten by your young children.

Participation in this interview is entirely voluntary and you will not be paid for participating.

With your permission, I would like to take written notes and make an audio recording of our conversation to make sure that we have a good record of your answers. I would also like to take some photographs of your participation to illustrate our research activities.

If you do not feel comfortable answering some of the questions, just tell us and I will move on to the next question. You can withdraw from the interview at any moment without giving any explanation. If you have any questions about the study, feel free to ask them at any time.

If you have concerns, you can speak to our Tanzanian Country Coordinator, Wende Maulaga (+255 787 166 020), or the principal investigator in Australia, Robyn Alders (+61 467 603 370). You can also call the Tanzanian National Institute for Medical Research Human Ethics Committee (+255 222 121 400), or the University of Sydney Human Research Ethics Committee (+61 2 8627 8176). Ethics committees consist of people with different backgrounds that are responsible for making sure that your rights are respected.
Do you have any questions?

Do you agree to participate in this interview? ☐ Yes ☐ No
Do you agree to have photographs taken? ☐ Yes ☐ No

Date: ____________________ Village: ____________________

Name of participant: ____________________

Signature or thumbprint of participant: ____________________

To be completed by the interviewer:
The information in the consent form was read aloud and the respondent clearly understood the contents and agreed to participate.

____
Signature of the Interviewer

____
Date

Appendix M. Participant Information Statement [English version]

Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia

Ms Wende Maulaga

Country Coordinator
Project Office
Tanzania Veterinary Laboratory Agency
Temeke, Dar es Salaam
TANZANIA
Telephone: +255 22 286 1152
Facsimile: +255 22 286 4369
Email: wendesamanga@gmail.com
Web: http://www.tvla-tz.org/

Associate Professor Robyn Alders

Chief Investigator
Room 4114
Charles Perkins Centre (Building No D17)
The University of Sydney
NSW 2006 AUSTRALIA
Telephone: +61 2 9351 7100
Facsimile: +61 2 9351 1618
Email: robyn.alders@sydney.edu.au
Web: http://www.sydney.edu.au/

PARTICIPANT INFORMATION STATEMENT

(1) What is the study about?

You are invited to participate in a study that aims to reduce childhood undernutrition by analysing and testing opportunities to enhance the key role that women play in improving poultry and crop integration and efficiency to strengthen household nutrition.

(2) Who is carrying out the study?

The study is being conducted by Ms Wende Maulaga of the Tanzania Veterinary Laboratory Agency, Dr Sabas Kimboka of the Tanzania Food and Nutrition Centre and Associate Professor Robyn Alders of the University of Sydney.

(3) What does the study involve and how much time will it take?

This study will run until December 2018. During this time the following activities will be implemented in the study area:

- Questionnaires on human nutrition and household livelihoods in households with children under 2 years of age at the start of the project – this will take approximately 1 hour every 6 months;
- Nutrient levels will be monitored by pricking the skin (like testing for malaria) of children once a year and this will take approximately 15 minutes [Sanza Ward only];
- Monitoring the health of children participating in the project every 2 weeks by community assistants during a short 15 minute visit;
- Monitoring the status of chickens every 2 weeks by community assistants during the same 15 minute visit as above;
- Discussion groups with 20 participants with and without children involved in the study from different parts of the study area will be held once a year and will run for 1 to 2 hours. Audio recordings may be used to ensure accurate collection of responses;
- With participant consent, photographs may be taken to illustrate research activities;
- Community meetings lasting 30 to 60 minutes will be held every 4 months to organise and monitor Newcastle disease vaccination campaigns;
- On a monthly basis, meetings lasting 30 to 60 minutes will be held with community leaders and those involved in ongoing data collection to monitor progress and receive community feedback.

(4) Can I withdraw from the study?

Being in this study is completely voluntary - you are not under any obligation to consent and - if you do consent - you can withdraw at any time without affecting your relationship with the Tanzania Veterinary Laboratory Agency or the University of Sydney.

You may stop interviews at any time if you do not wish to continue, the audio and/or video recording will be erased and the information provided will not be included in the study. You may also request that any unprocessed data generated be destroyed.

If you take part in a focus group and wish to withdraw, as this is a group discussion it will not be possible to exclude individual data once the session has commenced.

(5) Will anyone else know the results?

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(6) Will the study benefit me?

There are no direct benefits to households who assist the project by completing questionnaires and participating in discussion groups. The whole community will benefit from research activities that will include the vaccination of chickens against Newcastle disease by community vaccinators on a fee for service basis and improved crop production.

(7) Can I tell other people about the study?

You may share information about this study with other people.

(8) What if I require further information about the study or my involvement in it?

When you have received this information, Ms Wende Maulaga or her colleagues will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Wende via mobile phone 0787-166-020.

(9) What if I have a complaint or any concerns?

Any person with concerns or complaints about the conduct of a research study can contact:

1. The Director, National Institute for Medical Research, Dar es Salaam on +255 22 2121400 (Telephone); +255 22 2121380 (Facsimile) or headquarters@nimr.or.tz (Email);
2. The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep

Version 1; 27 January 2014