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Enhancing the evaluation of integrated, nutrition-sensitive strategies to improve maternal and child nutrition and health

By

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Doctor of Philosophy

Graduate Division of Biological and Biomedical Sciences

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Abstract

Enhancing the evaluation of integrated, nutrition-sensitive strategies to improve maternal and child nutrition and health

By Julie L. Self

There is a critical gap in the evidence base for the estimated impact of nutrition-sensitive strategies. The objective of this dissertation is to demonstrate how path analysis and economic evaluation of integrated, nutrition-sensitive programs can enhance understanding about their role in improving maternal and child nutrition and health. We use path analysis to assess the mechanisms of effect for the Action Against Malnutrition through Agriculture (AAMA) Project in Nepal and assesses the cost-effectiveness of the Mama-SASHA Project in Kenya. The AAMA Project combined a nutrition-sensitive agriculture intervention with behavior change communication. Cross-sectional endline survey data were used to measure variables along the hypothesized Program Impact Pathway, from inputs through outcomes of interest, including child nutritional status, maternal underweight, child diarrhea, maternal night blindness, and maternal and child hemoglobin. Survey respondents included mothers with children aged 12-48 months. We used path analysis to assess the relative contribution of specific mechanisms of effect on nutrition and health. A reduced model for height-for-age z-score fit the data well (RMSEA=0.027; CFI=0.945), while the model for child hemoglobin (RMSEA=0.073, CFI=0.913) was a moderate fit, and some models did not achieve adequate fit. Areas of weak association and poor model fit may be attributed to weaknesses in measurement, intervention fidelity, and contextual factors unaccounted for in the models. The Mama-SASHA project aims to improve the health and nutrition of pregnant/lactating women and children <2 years through an integrated orange-flesh sweetpotato (OFSP) and health service strategy in Western Kenya. We estimated the incremental cost-effectiveness ratio (ICER) of the intervention, which includes OFSP vouchers provided at antenatal care (ANC) visits, nutrition education, and pregnant women's clubs, compared to status quo ANC services. Effectiveness data from a quasi-experimental study and estimates from the literature were used to estimate DALYs for a range of benefits. We used ingredients-based micro-costing to estimate economic costs of agriculture, health and community interventions, including opportunity costs of labor. Annual net economic costs were USD $145,589. 72 DALYs were averted per year, mostly attributable to improvements in stunting and anemia. The ICER was USD $2,015 per DALY averted, which meets cost-effectiveness criteria established by WHO.

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Chapter 1: Introduction

Nutrition-sensitive programs are those that address the underlying causes of undernutrition by drawing on complementary sectors such as agriculture and healthcare [1]. These programs can have synergistic effects through a number of pathways to improve nutrition and health outcomes for women and children [2, 3]. There is a critical gap in the evidence base related to the potential for nutrition-sensitive agricultural strategies and the estimated impact they may have on nutritional intakes and nutrient status. Nutrition-sensitive strategies like household food production have largely been implemented and studied by non-governmental organizations (NGOs) such as Helen Keller International (HKI), World Vision, and Heifer International. These organizations conduct program evaluations, but sophisticated analyses are usually not conducted due to time and resource constraints. A limited number have been implemented or evaluated by research institutions such as the Consultative Group on International Agricultural Research (CGIAR) or universities.

Program reports and peer-reviewed literature often report program evaluation results but many lack appropriate controls or baseline data, have limited sample sizes, and inadequately assess for confounding, among other methodological weaknesses [4, 5]. Furthermore, in spite of experts recognizing that the nutrition and health benefits of nutrition-sensitive programs result from a network of interrelated factors, most analyses focus on difference-in-difference estimates or individual linear relationships through regression analyses. The integrated nature of nutrition-sensitive strategies also limits the ability to conduct cost-effectiveness analysis because it is difficult to capture and quantify the full scope of benefits for a robust and appropriate economic evaluation, so economic evaluations of nutrition-sensitive interventions are extremely limited.

The research described in the following chapters, conducted at the interface of research and programming, demonstrates underutilized analytic strategies to clarify the pathways through which nutrition-sensitive programs achieve their effects and evaluate the cost-effectiveness of nutrition-sensitive programs with a wide variety of benefits. The aims of the research presented here are:

Research Aim 1:

To assess the impact pathways of the Action Against Malnutrition through Agriculture (AAMA) Project, a Homestead Food Production (HFP) intervention implemented by Helen Keller International (HKI) in Far Western Nepal.

The Action Against Malnutrition through Agriculture (AAMA) Project is an Enhanced Homestead Food Production Project implemented by Helen Keller International and local partners in Far Western Nepal that combined a nutrition-sensitive agriculture intervention with behavior change communication to improve nutrition and health. Chapter 3 describes the application of a novel analytic approach, path analysis, to evaluate the relative strength of various mechanisms by which the AAMA Project is hypothesized to affect child height-for-age z-score. Chapter 4 applies path analysis to multiple outcomes of interest from the AAMA Project and discusses areas of improvement for project design and evaluation in future HFP programs.

Research Aim 2:

To investigate the cost-effectiveness of the Mama-SASHA Project, an integrated nutrition, agriculture and health service delivery intervention focused on orange-flesh sweetpotato production (OFSP) in Western Kenya.

The Mama-SASHA project aimed to strengthen maternal and child nutrition services, with an emphasis on improving vitamin A intake through OFSP production and consumption in the Busia and Bungoma Districts of Western Kenya. The project integrated agriculture and nutrition interventions into existing antenatal health care services to maximize the potential benefits of OFSP on the health status of mothers and children less than 2 years of age. Chapter 5 describes a cost-effectiveness evaluation of the Mama-SASHA project. The analysis adopts a societal perspective and incorporates the opportunity costs of all resources used to deliver health and agriculture services to beneficiaries, while capturing both health and economic benefits associated with participation in the intervention.

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Chapter 2: Background

The Burden of Malnutrition

Global trends and consequences of malnutrition

Malnutrition, including energy, protein and micronutrient deficiencies, contributes substantially to the global disease burden, affecting health outcomes, quality of life, and economic potential of more than 2 billion people [1, 2]. Undernutrition results in stunting, severe wasting, and intrauterine growth restriction, which combined contribute to 3 million deaths each year, 45% of all child deaths in 2011, and 21% of disability-adjusted life-years (DALYs) for children younger than 5 year [3, 4]. Additionally, one billion people are chronically hungry, and two billion people regularly experience food insecurity [5]. Nearly one third of children under 5 in the developing world are vitamin A deficient, and one fifth of maternal deaths are associated with iron deficiency anemia [2].

Undernutrition in the form of inadequate energy intake, especially protein intake, is associated with inadequate physical growth in childhood and leads to lower educational achievements, reduced human capital, and shorter adult stature. Three indicators are typically used to represent child undernutrition, each reflecting different aspects of undernutrition. Stunting, which reflects height relative to age, is a cumulative outcome of impaired growth. The overall impact of undernutrition on height is likely to be more severe and permanent when deprivation occurs during key periods of growth, is severe and/or persists over long periods [6-9]. Undernutrition affects growth even during gestation, with a woman's nutritional status before and during pregnancy influencing the growth of the fetus [3]. In fact, the effect of malnutrition on linear growth is strongest during gestation and the first two years of life, often known as the "first 1000 days" or the "window of opportunity."

Catch-up growth is limited after 3-5 years of age [3, 10-12]. For children age 2 and older who are already stunted, chances of observing changes in linear growth due to an intervention are low, even if the intervention has positive effects on nutrition. However, for children less than two years, including during gestation, it is more likely that changes in the nutrition and health environment will lead to changes in linear growth.

Stunting, underweight and wasting are associated with the same underlying concern: inadequate energy intake to meet physiological needs, but the severity and duration and timing of this experience lead to different sequelae. Underweight reflects weight relative to age, and wasting reflects weight relative to height. Wasting can be an acute condition, with rapid changes in energy status due to disease or seasonal changes in food availability leading to observable changes in weight-for-height in a short period of time [13, 14]. As well, it is also reasonable for an effective intervention to reduce wasting within a matter of months.

Micronutrient malnutrition

Deficiencies of vitamins and minerals also contribute to a number of poor health outcomes and affect the growth and development of children. Iron, vitamin A and iodine deficiencies have been identified by the World Health Organization (WHO) as the three most common micronutrient deficiencies, with at least one third of the world population affected by one of these nutritional deficiencies [2]. Poor access to quality foods is a leading contributor to micronutrient deficiencies throughout the world. In many parts of the developing world, micronutrient deficiencies do not exist alone and are paired with inadequate energy intake [3, 15].

Iron deficiency is highly prevalent throughout the world, especially in women and young children. The WHO estimates that 2.4% of all Disability-Adjusted Life Years

(DALYs) worldwide are due to iron deficiency, which amounts to approximately 35 million healthy life-years lost [16]. Additionally, iron deficiency causes median total losses to Gross Domestic Product (GDP) of approximately 4% due to the impact of iron deficiency on mental impairment and low work productivity [17]. The primary consequence of iron deficiency is iron-deficiency anemia (IDA). Anemia is a multi-factorial condition that can be caused by a number of vitamin and mineral deficiencies and other factors, but it often develops after prolonged iron deprivation [18].

Anemia affects 1.62 billion people, particularly in Africa and Asia [19]. In southeast Asia alone it is estimated that approximately 315 million women of reproductive age and preschool-age children are anemic [19]. The prevalence of iron deficiency is almost twice that of anemia, and the World Health Organization (WHO) estimates an additional billion cases of iron deficiency without anemia worldwide [18]. People of low socioeconomic status, women and children are especially susceptible to having poor iron status and frequently also lack other vitamins and minerals [19-21].

Anemia has several consequences throughout the life cycle that can affect physical and cognitive development, work productivity and economic well-being [22]. Before birth and during the first year of life, iron deficiency can result in permanent damage to an infant's central nervous system [23]; it affects growth, neurodevelopment and cognitive performance [24, 25], and increases susceptibility to infections [26]. For adults it causes increased loss of healthy, productive life due to its effects on work and physical capacity [27]. Pregnant women with iron deficiency are at risk of complications, including perinatal mortality, low birth weight and preterm birth [28-30]. In addition, maternal iron deficiency impairs infant development throughout intergenerational effects and by negatively affecting interactions between mother and child and [31-33].

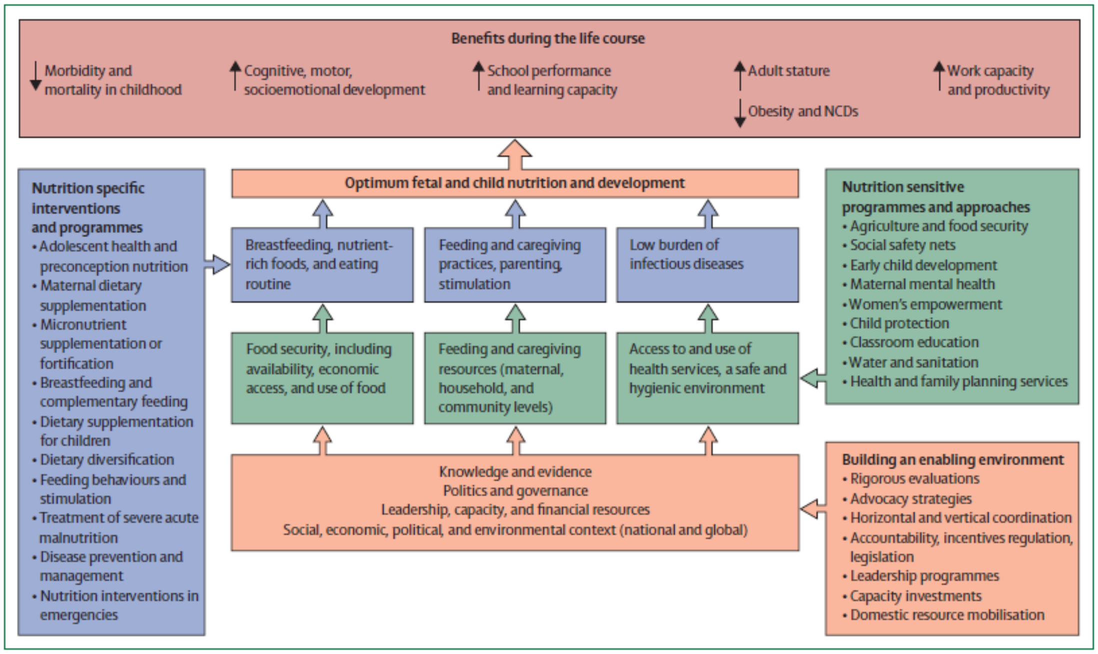
Vitamin A is the nutrient whose deficiency is most strongly associated with childhood mortality [3, 15]. Vitamin A deficiency (VAD) causes vision problems, reduces the capacity of the immune system to fight infection, and can also lead to anemia. An estimated 1.8% of DALYs globally can be attributed to VAD, and 5.3% of DALYs in children under 5 years are attributable to VAD [3, 34]. Women and children in low-income countries are at greatest risk for developing VAD [1].

Vitamin A is also found in animal-source foods (ASF) as pre-formed vitamin A. Beta-carotene and other carotenoids found in fruits and vegetables can be converted to vitamin A in the body, but with lower bioefficacy than pre-formed vitamin A. The current recommendation indicates that 12μg of beta-carotene has the same retinol activity as 1μg of pre-formed vitamin A, but some experts consider this to be an overestimate for certain foods such as dark green leafy vegetables. However, plants are important sources of vitamin A in most of the developing world due to the cost of ASF [35, 36].

Causes of malnutrition and conditions for optimal nutrition

Malnutrition is caused by a variety of interrelated factors. The framework depicted in Figure 1 describes the factors necessary to support optimal child nutrition and development [4]. Nutritious diet and feeding practices are two immediate factors necessary for optimal nutrition. Access to nutritious foods, and sufficient knowledge about the types and amount of foods that should be consumed to maintain health are necessary to support optimal diets and feeding practices. As well, many underlying factors are necessary to optimize nutrition and health, such as financial resources and a supportive socio-political environment, and their absence may contribute to malnutrition [3, 4].

Figure 1: Framework for actions to achieve optimum fetal and child nutrition and development. From Black 2013.



Inadequate access to nutritious food is a key contributor to stunting, wasting, poor iron status, vitamin A deficiency, and other micronutrient deficiencies. The richest sources of bioavailable iron, vitamin A, and other important micronutrients are ASF. However, ASF are often inaccessible to poor populations.

Malnutrition and poor health are linked to food security, which is defined as "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire foods in socially acceptable ways [37]. Household food insecurity does not necessarily stem from insufficient quantity of the food supply, but from inadequate access to nutritious foods, often associated with poverty [38]. Household food security may be obtained by a household's self-sufficiency in food production or by the ability of a household to generate sufficient income to purchase needed foods, or some combination of these. Furthermore, individual food security depends on these factors as well as the intrahousehold allocation of food [39]. The relationship between food security and child growth and development extends beyond the immediate availability of healthy food to include paths through the effects of food insecurity on maternal mental health and caregiving practices [40-42].

In addition to a nutrient-rich diet, absence of other health conditions is necessary for optimal nutrition and development. Nutrition and infection interact in a vicious cycle. Inadequate nutrition can cause susceptibility to infection, but infection also affects nutrient status through increased demand, increased losses, reduced appetite, and impaired absorption. For example, diarrheal disease is known to inhibit absorption and increase losses of some nutrients. Fever increases the body's requirements for energy and micronutrients. Infections, including parasites and other infections such as HIV, can affect nutrient absorption and metabolism [43].

Strategies for improving nutrition and food security

Nutrition-specific strategies

There are efficacious strategies for improving one or more malnutrition problems through targeted interventions. For example, supplementary feeding programs, micronutrient supplementation and fortification interventions, have proven efficacy and are effective in many populations. Iron supplementation dramatically improves iron status and reduces anemia. The estimated cost per person per year for iron supplementation is between USD $2.00 and USD $5.00 [15]. High-dose vitamin A supplementation is a widely used and cost-effective strategy to treat vitamin A deficiency [1, 44]. It is delivered twice per year and targeted to children and postpartum women, with an estimated cost of USD $1.20 per person per year in Sub-Saharan Africa [1, 44, 45]. Fortification of foods with iron, vitamin A and other micronutrients also contributes to significant improvements in micronutrient status and health outcomes and can be a very cost-effective intervention. The cost-effectiveness of flour fortification, which often includes iron, is USD $0.12 per person per year [15].

However, limits to these strategies include large gaps in service, limited long-term feasibility, risk of nutrient toxicity, and heavy dependency on external resources [2, 44]. High-dose supplementation has been effective in reducing the prevalence and sequelae of iron and vitamin A deficiencies and can result in quick repletion of nutrient levels, but there is a risk of toxicity when consumed in high doses or when multiple strategies to deliver the same nutrients overlap [46, 47]. Micronutrient fortification is advantageous because it does not require behavior change within the population, but the chemical properties of some nutrients, such as iron, make it difficult to use them as fortificants without affecting the sensory characteristics of the food vehicle or risking their degradation while in processing or storage [2]. Also, adequate coverage of fortified foods may be limited by low availability and consumption of industrially fortified foods, such as in rural areas and among young children who do not consume enough of the fortified foods to receive the full benefit [1, 45].

The long-term feasibility, sustainability and coverage of supplementation and fortification are limited. Experts recommend that complementary strategies are needed to address the underlying causes of malnutrition and further improve nutrient status and health [1, 48, 49]. Additionally, supplementation and fortification often target one or a limited combination of micronutrients, and aggressive treatment of one deficiency may mask the presence of or contribute to another deficiency. For example, high levels of folate in fortified foods may mask vitamin B12 deficiency in some populations, and high levels of iron supplementation may impair zinc absorption and lead to zinc deficiency [50-54]. In areas with widespread multiple micronutrient deficiencies, as well as food insecurity and energy insufficiency, more comprehensive approaches are needed.

The evidence base for effectiveness and cost-effectiveness for many nutrition interventions is developed using carefully controlled and intensively implemented randomized-controlled trials (efficacy studies), so the reported effectiveness and cost-effectiveness may be based on idealistic conditions rather than realistic scaled-up programs. Often, program effectiveness is reduced in the "real world" by problems of implementation, coverage and compliance [55, 56]. For example, the limited availability of some fortified foods in rural areas and the fact that young children may not consume enough of the fortified foods to receive the full benefit, means that those who need it most are least likely to benefit [1, 45, 57].

Supplementation, fortification, and improved infant and young child feeding practices are important strategies to treat deficiencies and reduce the burden of malnutrition. A recent report in the Lancet identified ten core nutrition interventions that, if scaled up to 90% coverage, could reduce stunting by 20% [58]. However, additional strategies are needed to complement these interventions and further improve nutrition outcomes, especially by addressing the underlying causes of malnutrition.

Nutrition-sensitive strategies

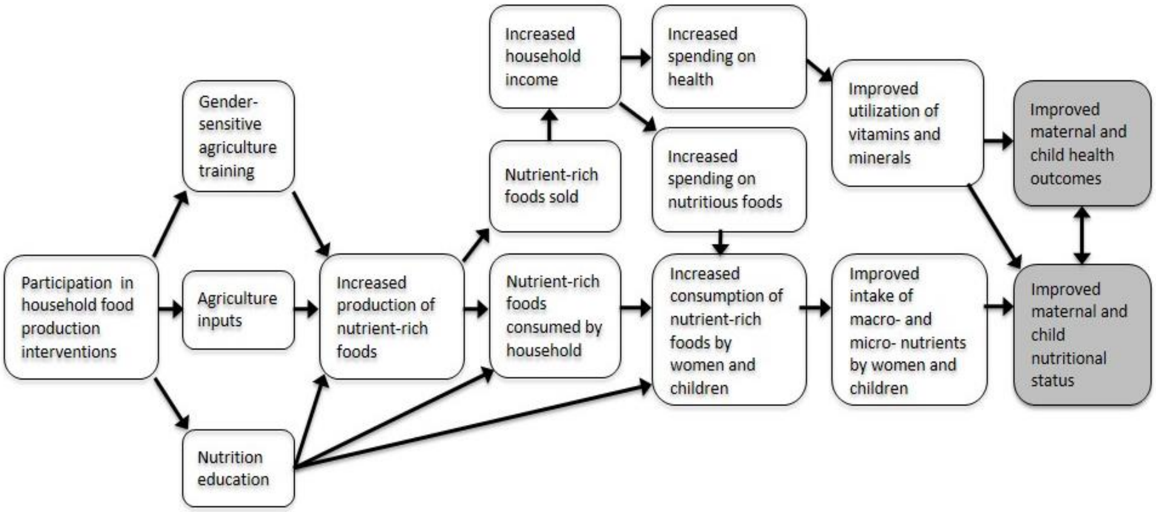
Experts recommend that complementary strategies are needed to complement nutrition-specific strategies by addressing the underlying causes of malnutrition to further improve nutrient status and health [1, 44, 48]. In areas with widespread multiple micronutrient deficiencies, as well as food insecurity and energy insufficiency, more comprehensive approaches are needed. Nutrition-sensitive programs are those that address the underlying causes of undernutrition by drawing on complementary sectors such as agriculture and healthcare [59]. These programs can have synergistic effects through a number of pathways to improve nutrition and health outcomes for women and children [60, 61].

Household food production programs are an example of a potentially sustainable and preventative strategy for improving dietary quality and health as a complement to nutrition-specific strategies, but evidence for their effectiveness is limited [2, 48, 62, 63]. Household food production programs aim to improve nutrition and health by improving home gardening and animal husbandry practices to increase the availability and accessibility of nutrient-rich foods. Household food production strategies are uniquely suited to address both energy and micronutrient deficiencies while also addressing household food insecurity. They often address underlying causes of malnutrition such as poverty and health by integrating strategies for income generation by selling or trading surplus production, gender empowerment, health services or sanitation and hygiene [48, 64, 65].

Impact pathways of nutrition-sensitive strategies

Nutrition-sensitive strategies typically have integrated designs and may improve nutrition and health through several inter-related mechanisms. The relative influence of any one pathway may depend on many contextual factors, including the baseline health and nutritional status of the target population, access to resources such as land and health services, and socio-cultural factors such as food preferences and women's empowerment. For example, Figure 2 describes a hypothesized model for the effects of a household food production intervention [66]. The most straightforward path for improving nutrition and health through household food production is through the increased production and consumption of nutritious and diverse foods leading to improved nutritional status.

Figure 2: Hypothesized model for household food production interventions [66].



However, this effect is often enhanced by or reliant upon nutrition education, which improves knowledge of nutrition and leads to healthier dietary decisions for the household. As well, households may sell foods they produce and use the money on other nutrient-rich foods that are not grown or raised at home. Especially when women are empowered as household decision makers, income generated from household food production strategies may be directed towards other nutritious foods and health care. Access to health care may reduce the burden of infection, thus contributing to improvements in nutrition by breaking the malnutrition-infection cycle. Explicit strategies for women's empowerment, such as implementing the programs through women and educating women about nutrition and health may improve nutrition by ensuring that women and children receive high-quality foods [67, 68].

Evidence for the effectiveness of household food production programs

Existing evidence for nutritional and health impacts of household food production strategies is weak and varied, primarily due to methodological limitations in the research. Home gardening projects that incorporate nutrition education have been ranked as high to moderate for achieving desired nutrition outcomes in a 2004 review of the effectiveness of household food production interventions to improve nutrition outcomes [69]. Likewise the World Bank reports that home gardening interventions can lead to improved maternal and child nutrition outcomes, particularly in Asia and Africa [70]. A 2008 Lancet review of the most effective interventions for maternal and child undernutrition considers there to be inadequate evidence of effectiveness for household food production strategies, but a 2013 Lancet article emphasizes the important potential contributions of nutrition-sensitive strategies [12, 59].

Recent reviews of household food production strategies have found that the programs are generally successful at increasing production and consumption, but the evidence for nutritional or health impacts is varied, and any positive effects tend to be small [56, 71]. However, the lack of effectiveness in many studies is attributed to methodological limitations such as small sample sizes, lack of appropriate control groups, inadequate time to detect an effect, and limited consideration of participation levels [66, 69, 71]. Economic evaluations for household food production strategies are extremely rare and usually limited to reporting of total program costs and total number of beneficiaries reached.

Only a limited number of studies have assessed impact using robust biological indicators of micronutrient status and complex modeling strategies that take into account clustering, random effects and confounding [72-74]. In addition to the difficulty in collecting high quality samples in the field and the cost of analyzing the sample, it may be difficult for nutrition-sensitive strategies like household food production interventions to detect effects on health and nutrition because the effect pathway is long [75]. Furthermore, experts increasingly recognize that improvements in nutrition and health result from a network of interrelated factors, but most analyses focus on individual linear relationships through regression analyses. Olney et al. qualitatively assess the stages of a hypothesized Program Impact Pathway (PIP), but they do not quantitatively assess the linkages in the path [76, 77].

HKI reports that the HFP programs in Bangladesh, Nepal, Cambodia and the Phillipines produce 216,000 metric tons of fruits and vegetables annually [78]. However, the current evidence for effectiveness of this program to improve nutritional outcomes is less consistent and subject to the limitations discussed above. The efficacy of orange-flesh sweetpotatoes (OFSP) to improve vitamin A status has been established by research in several sub-Saharan African countries, but the effectiveness and cost-effectiveness have not been assessed at the programmatic level [73, 74, 79].

There is some evidence that home garden programs, especially those that emphasize orange sweetpotatoes, can impact serum retinol, night blindness and Bitot's spots. However, several studies fail to detect improvements, and there is no obvious association between intervention design and effectiveness [66]. Household food production strategies such as dietary diversification and home gardening are potentially important for improving dietary quality and improving several health outcomes in a sustainable manner [2], but further investigation is necessary to determine the impact and economics of household food production programs and contribute to the knowledge and best-practices in this field.

Factors influencing the effect of household food production interventions

Many factors can diminish or modify the effects of a household food production intervention. Most simply, the level of implementation and adoption by participants can each influence the success of the intervention, and household food production strategies require considerable behavior change. Additionally, nutrient bioavailability and other health factors such as infections can influence the physiological impact of the intervention. Other interventions that target nutrition, hygiene and health may modify the effects of household food production interventions. For example, children and postpartum women are often targeted for vitamin A supplementation, and the effects of supplementation may overshadow any effects of household food production on vitamin A outcomes. Alternatively, a sanitation and hygiene intervention that reduces diarrheal disease may enhance the effects of household food production by reducing the effects that diarrhea has on inhibiting nutrient absorption and increasing nutrient losses.

Household factors such as socioeconomic status and land ownership, and village-level factors such as quality of health or agriculture education and agro-ecological conditions may have an influence on intervention effectiveness by affecting how easily and fully the targeted households can participate. For example, socioeconomic status and land ownership may influence the extent to which households can participate in the intervention because families without access to land or the means to purchase agricultural inputs with have more difficulty maintaining the desired garden.

Many village level factors may also influence program effectiveness. Villages that are very spread out may find it more difficult for women to regularly attend the nutrition and agriculture education meetings. Likewise, even when spacing within a village makes it easy to attend meetings, an ineffective village health worker may influence program effectiveness at the village level. As well, latitude, altitude, rainfall, and terrain all influence growing conditions at a village or regional level.

Evaluation of nutrition-sensitive programs

Theory-driven evaluation of complex programs

Nutrition-sensitive interventions are often complex in their design, and therefore can be difficult to implement and evaluate [80]. Theory-based program design and evaluation is historically lacking in nutrition programs, but the hypothesized pathways through which nutrition-sensitive strategies affect nutrition and health are increasingly being identified through the use of Program Impact Pathways (PIPs) which explicitly describe the mechanisms through which program inputs are believed to impact the project outcomes [80-82]. The PIP demonstrates the theory behind the intervention design by tracking what is happening between the initial program inputs through the expected impacts. The PIP goes beyond the traditional LogFrame, or Logical Framework, approach to program planning and evaluation by visually representing the causal connections between the program inputs and outcomes [82]. In theory-driven program evaluation, the hypothesized causal model shapes the planning, implementation and evaluation of the program. However, most program evaluations remain limited to an individual analysis of each step along the pathway rather than a comprehensive analysis to assess the relationships among path variables that contribute to the program outcomes. In order to better understand the contribution of complex interventions such as household food production strategies, it is important to determine, not just whether they are effective, but also why, how, and how they could be more so [83].

Path analysis of nutrition-sensitive programs

Path analysis is an analytic strategy commonly used in social science research because it estimates the relative effects of hypothesized causal pathways to clarify their contributions to an outcome of interest, and it is a potentially useful analytic strategy to analyze theory-driven, complex interventions. Path analysis of public health interventions allows for modeling the more complex relationships between all of the program inputs, activities, and intermediate outcomes to better understand how they work together to achieve the program's outcomes of interest. Path analysis can be used to improve programmatic strategies in several ways, including detecting areas in which improved program evaluation is needed, selectively identifying programmatic components that need to be strengthened or added for greater effectiveness, understanding the relative strength of program components to achieve the desired outcomes, and comparing resources used with the benefits attributable to specific program components.

Path analysis provides a unique approach for comprehensively assessing a theoretical path model. A comprehensive introduction to path analysis and Structural Equation Modeling (SEM) can be found in Kline's Principles and Practice of Structural Equation Modeling [84]. In short, path analysis is a type of SEM that assesses the strength of different causal pathways and estimates path coefficients between measured variables (in contrast to latent variables) from the regression analyses that make up the path model. It is an extension of regression modeling in that it not only estimates linear associations between path variables, but also provides estimates of the total, direct and indirect effects of a path model [85]. Path analysis begins with a theoretical model that depicts the hypothesized causal relationships among measureable variables. Using path analysis, we can estimate parameters of the model (direct and indirect effects), assess model fit (goodness of fit statistics), and make adjustments to the model as needed to improve the fit. Estimating the model parameters and model fit statistics can help identify the mechanisms through which the program is operating and clarify the extent to which each hypothesized pathway contributes to the outcome of interest. This information can guide programmatic improvements by identifying bottlenecks in implementation or helping program decision makers determine how limited program resources can be applied most effectively.

After the path model has been specified, path coefficients are estimated from the set of regression equations that describe the path model. Path coefficients represent partial regression coefficients after controlling for prior variables in the model. Standardized beta coefficients are often used to facilitate comparison of the relative magnitude of causal paths within a model. Direct effects within a model are estimated by regressing an endogenous variable on all of the explanatory variables with direct paths leading to it. The associations within the model can be decomposed to estimate indirect effects, which are the effects of explanatory variables on outcome variables that are mediated through another variable in the path model. Indirect effects are estimated by multiplying the path coefficients for the paths between the predictor and mediator variables and between the mediator and outcome variables [86, 87].

Model fit statistics are used to assess how well the hypothesized model fits the data. When model fit statistics indicate a “good” fit, this can be interpreted that the hypothesized model adequately explains the relationships among model variables. For poorly fitting models, model fit may be improved by revising the theoretical model, or possibly by improving measurement of the model. This then moves the analysis from a confirmatory to a more exploratory analysis [84, 85]. Estimating model fit is useful for programmatic research because it indicates whether or not the hypothesized model fits the data. Identifying components of the model that do not fit well can aid in the detection of implementation bottlenecks or help refine the theoretical model to better reflect the mechanisms through which the program operates.

Economic evaluation of nutrition-sensitive programs

In an era focused on evidence-based and cost-effective interventions, it is essential to rigorously evaluate the cost-effectiveness of nutrition-sensitive interventions to identify cost-effective strategies and inform their role in improving nutrition and livelihoods. The purpose of economic evaluation is to understand the impact of an intervention in light of the resources that were required to achieve that change. In spite of the importance of economic evaluation, nutrition-sensitive programs are difficult to assess and require comprehensive economic evaluation methods due to the integrated nature of their design.

Economic evaluations can adopt any number of "perspectives," indicating which types of costs are included in the analysis. For example, a funder perspective focuses on the implementation costs that would be paid for by a funder, and the opportunity costs of shared or volunteer labor or beneficiary time would not be included. Likewise, a health sector perspective may focus exclusively on the costs relevant to the Ministry of Health (MOH), possibly including shared or volunteer labor costs affiliated with MOH activities but excluding the costs for beneficiaries or other sectors. Alternatively, a societal perspective is the broadest viewpoint and includes costs from all participating sectors, including volunteers and beneficiaries [88]. In light of the integrated approach of many nutrition-sensitive programs, a societal perspective is used for this research.

There is no single ideal measure of effectiveness for assessing the cost-effectiveness of nutrition-sensitive strategies, primarily because these interventions are designed to produce a variety of benefits to their participants and the community. Unlike some nutrition interventions that target one particular nutrient, such as vitamin A supplementation, iron drops, or iodized salt, nutrition-sensitive interventions often have several intended outcomes, including improvements in dietary quality, infant and child feeding practices, nutritional status, food security, women's empowerment, and household economics. Therefore, using any single indicator to assess the effectiveness and cost-effectiveness of the program under-represents the full spectrum of benefits derived from the program and is likely to underestimate the cost-effectiveness. There are several potentially useful types of economic evaluation, each with their own set of strengths and limitations: cost-effectiveness analysis, cost-utility analysis, cost-benefit analysis, and multi-attribute utility analysis.

Cost-effectiveness analyses traditionally assess the costs necessary to achieve a unit change in one specific outcome of interest [88]. For many nutrition-specific interventions, such as micronutrient supplementation and fortification, this may be appropriate because the interventions are designed with one primary outcome of interest. However, most nutrition-sensitive strategies are designed to meet several nutrition, livelihoods and other social outcomes, and therefore have multiple inter-related outcomes of interest. As such, conducting traditional effectiveness and cost-effectiveness analyses based on a single outcome indicator can over-simplify the impacts of the program and lead to inappropriate conclusions.

Stunting has multiple etiologies, and linear growth is often used as an indicator of living standards because it can be influenced by nutrition, infection and economic condition [89]. Increasing income and better nutritional status lead to the greater attainment of an individual's genetic potential for growth, and growth failure is an important indicator that other physiological functions may be impaired due to common nutritional causes [90-92].

Furthermore, growth failure is associated with increased risk of infection, higher mortality, and reduced economic potential [12, 93]. However, using stunting as a single indicator is still likely to underestimate the benefits of a nutrition-sensitive intervention because it does not respond quickly to changes in exposures [89, 94, 95]. The 2013 Lancet series on maternal and child nutrition indicates that even if ten core evidenced-based nutrition interventions are scaled up to 90% coverage, they would only reduce stunting by 20% [58].

Another problem with cost-effectiveness research for nutrition-sensitive programs is that they fail to properly consider the time frame in which the intervention is designed to operate. For micronutrient supplementation, the costs and benefits can both be observed almost immediately, but to maintain a positive impact the inputs are needed regularly. For example, vitamin A supplementation is highly effective and cost-effective, but it is recommended that children receive this intervention every six months [15, 96, 97]. Likewise fortification is highly effective and cost-effective, but inputs to maintain effectiveness are required regularly [2, 15, 98, 99].

On the other hand, many suggest that nutrition-sensitive strategies such as household food production are a sustainable intervention strategy to improve nutrition outcomes over the long term [2, 48, 62, 63]. For household food production interventions, the initial costs required for developing and implementing these interventions are often high but decrease once implementation is well under way, while the benefits tend to accrue over time rather than being evident immediately. In spite of this, evaluations of household food production programs often are not designed to measure the cumulative effects over long periods, primarily due to resource constraints.

Furthermore, the evidence base for many nutrition-specific interventions is developed using carefully controlled randomized-controlled trials, so cost-effectiveness may be based on idealistic conditions rather than realistic scaled-up programs. Often, program effectiveness is reduced in the "real world" by problems of implementation, coverage and compliance [55, 56]. Since true efficacy studies are difficult to conduct for multi-faceted nutrition-sensitive interventions, the effectiveness and cost-effectiveness reported for such interventions typically reflect their realistic achievements in large scale programs rather than idealistic conditions.

Due to the fact that many potential outcomes of nutrition-sensitive interventions are not easily quantified or well-documented in the data, it is impossible to capture the full range of costs and benefits associated with these programs. However, there are several strategies that may be used to better account for a wider variety of benefits [2, 88]. Cost-benefit analyses allow for comparison of multiple outcomes and benefits by converting all costs and benefits into monetary values. This is useful for assessing interventions that have multiple tangible outcomes, including changes in livelihoods and other non-health related monetary benefits, such as time lost from work [2, 88]. However, it can be difficult to apply to intangible outcomes such as food security and gender empowerment because these benefits may not be easily measured or monetized [100].

Another potential strategy for better reflecting the full scope of benefits that result from nutrition-sensitive strategies comes from the social sciences. Multi-attribute Utility Analysis (MAUA) is less commonly used than other economic evaluation methods, but it is designed for situations in which you need to compare programs that produce benefits along multiple dimensions. MAUA allows for ranking or weighting of multiple outcomes without directly monetizing the outcomes by determining utility through an iterative group process through which stakeholders articulate evaluation criteria for the object of evaluation, as well as the level of comparative importance of each criterion" based on perceived social values

[100]. There are obvious strengths to MAUA, including the ability to attribute value to social outcomes and respecting the perceptions of stakeholders. However, primary limitations are the large amount of subjectivity and time involved in the determination of "utility," and the fact that the results are only relevant for comparisons with the same scope of benefits [100]. For example, MAUA would allow us to account for multiple benefits associated with a nutrition-sensitive program, but because of the process of defining and weighing the evaluation criteria, comparisons could not be made with other interventions that have a different set of evaluation criteria.

Cost utility analysis is an example of cost-effectiveness analysis that converts morbidity and mortality into a single measure of utility, the "disability-adjusted life year" (DALY). Any year of life lost due to early death is equivalent to one DALY. Morbidity conditions are ascribed disability weights that represent the severity of the disability, with a higher weight reflecting greater disability. In this way, early death and disease or disability conditions can be accounted for in a single measure. However, disability weights typically are not estimated for risk factors of disease – only the actual morbidity and mortality outcomes. For vitamin A deficiency, xerophthalmia and corneal scarring are assigned disability weights, measles is sometimes included, but other conditions and risk factors associated with vitamin A deficiency are not captured, such as the increased risk of infection [15, 101]. Furthermore, mortality due to vitamin A deficiency may not be fully captured. Research suggests that in areas with a high prevlance of vitamin A deficiency, vitamin A supplementation can reduce child mortality by 23% [15], and undernutrition is an underlying factor in more than 50% of deaths of children under 5 years [102], but as an underlying factor, deaths would not be attributed directly to vitamin A deficiency and counted in DALY estimates. Therefore, in interventions that measure effectiveness by intermediate outcomes such as reducing a risk factor, traditional cost utility analysis is likely to underestimate the effects of the intervention. Furthermore, DALYs apply specifically to health outcomes and would not reflect changes in livelihoods or other social outcomes that result from nutrition-sensitive interventions. Here, cost-utility is used to describe a specific type of cost-effectiveness analysis to better illustrate the pros and cons of this approach. However, it is common in the literature to refer to analyses that use DALYs as the outcome measure as cost-effectiveness analyses, and we will adopt this language going forward.

Nutrition-sensitive interventions included in this research

The AAMA Project, Nepal: Helen Keller International (HKI)

HKI works with communities in Asia and Africa on a 3-year program cycle to establish homestead food production gardens (HFP) that promote nutritional self-sufficiency in those areas. Animal husbandry and nutrition education are also included in the program to maximize nutritional benefits. HKI partners with local NGOs and provides technical and managerial support and start-up supplies to help communities integrate HFP into their regular activities. Development of these gardens aims to improve food security, diet quality and variety, and to reduce micronutrient deficiency-related health outcomes such as night blindness. This approach is believed to have additional benefits of job creation, income generation, capacity building, and women's empowerment.

The Action Against Malnutrition through Agriculture (AAMA) Project was implemented in the Baitadi district of Far Western region of Nepal from 2009 to 2012. It targeted mothers of infants and young children 0-23 months to support households in establishing diversified home gardens and small animal husbandry, complemented by nutrition education and counseling. Development of these gardens aims to improve maternal and child nutrition and health by improving food security, diet quality and variety. Eight Ilakas (sub-districts) were selected based on comparable characteristics and pair-wise assigned randomly to intervention or control; approximately 30 Village Model Farms (VMFs) were established in each intervention Ilaka. The HFP intervention includes the establishment of VMFs in Village Development Committees (VDCs) throughout each intervention Ilaka, and Female Community Health Volunteers (FCHVs) who lead them are trained by the project in food production, nutrition, and behavior change communication. Women who are pregnant or have a child less than 2 years at recruitment are eligible for enrollment in the project as HFP beneficiaries. Each VMF leader supports approximately 40 HFP beneficiaries by organizing monthly women's group meetings and disseminating agriculture and nutrition education. Beneficiaries also receive agriculture inputs including seeds and chickens.

The AAMA Project was conducted as a community-randomized effectiveness trial and evaluated using a repeated cross-sectional design at the community level in intervention and control communities. A baseline survey was conducted in August 2009, and an endline survey was conducted August through September 2012. Village development committees (VDCs) were selected as the primary sampling unit, and 14 VDCs from each study arm were randomly selected for baseline and endline surveys. Baseline and endline cross-sectional surveys assessed children ages 12-48 months at the time of the survey and their mothers to include children who would have had the maximum opportunity to benefit from the two years of program implementation. In households with multiple children ages 12-48 months, the youngest eligible child was selected. Survey respondents were randomly selected using a stratified, three-stage probability proportional to size methodology. The project had a goal to achieve maximum spillover into the community, so any household meeting the inclusion criteria of having a child 12-48 months could be included in the survey, irrespective of whether they directly participated in the AAMA Project as an HFP beneficiary.

The impact evaluation of the AAMA Project reports significant improvements for intervention areas compared to controls in intermediate variables such as household food production food security, nutrition knowledge and complementary feeding practices. They also found significant improvements in women's underweight and anemia, but no significant changes were found in adjusted regressions for child anthropometry, and only borderline significant improvements in child anemia [103].

We conduct a secondary analysis of data from the endline survey of the AAMA Project to assess the pathways of impact on maternal and child nutrition and health. The pathways assessed are based on the PIP designed *a priori* for the AAMA Project.

The Mama-SASHA project, Kenya: PATH and International Potato Center (CIP)

The Sweetpotato Action for Security and Health in Africa (SASHA) project is a multi-faceted project promoting uptake of OFSP to reduce malnutrition among children. They are targeting 10 million households in 17 sub-Saharan African countries. The Mama-SASHA project, one of several initiatives of the SASHA project, is being implemented by PATH, the International Potato Center (CIP) and the Kenyan Agricultural Research Institute (KARI). Mama-SASHA integrates agriculture and public health interventions to maximize the potential benefits of OFSP on the health status of mothers and children less than 2 years of age. Working with the established Population and Health Integrated Assistance Program (APHIA II) public health services, the Mama-SASHA program aims to strengthen maternal and child nutrition services, with an emphasis on improving vitamin A intake through OFSP production and consumption in the Busia and Bungoma Districts of

Western Kenya. The Mama-SASHA project strengthens existing health services' capacity to provide education on vitamin A rich foods, nutritional benefits of OFSP and maternal and child nutrition by providing enhanced training and "information, education and communication" (IEC) materials to facility-based health workers and community health workers (CHW) in the project districts. In the Mama-SASHA intervention, agricultural activities and community-based peer support are added through a free vouchers system to obtain OFSP vines and pregnant women clubs, respectively. The OFSP vine vouchers are redeemed through local, community-based vine multipliers established by the project. Women receive training to grow the OFSP and are supported by agricultural extension services. Collectively, these activities are expected to improve antenatal care (ANC) visit attendance, vitamin A intake, micronutrient status and health outcomes in mothers and children involved in the program.

The Mama-SASHA project was a cluster-randomized study which was evaluated through cross-sectional baseline (March-April 2011) and endline (March-April 2014) surveys of > 2700 mother child pairs (BL-EL) and a nested cohort study (COVA), which collected data from mother-child pairs from early/mid-pregnancy (n=505) through 9 months postpartum (n=384) January 2012 through June 2014. These evaluation strategies were complemented with monthly program monitoring and operational research conducted April to August 2012 [104]. Eight divisions across the Bungoma and Busia Districts in Western Kenya were chosen by the program for participation, with two large divisions and two smaller divisions chosen per district and randomized for intervention or control. For the BL-EL evaluation, households were selected using stratified random sampling from project and control villages. BL-EL surveys include questions about agricultural practices, diet, OFSP consumption, anthropometry, and child vitamin A status and health. The COVA study also measured biological indicators of anemia and vitamin A status, including hemoglobin and serum retinol binding protein (RBP), respectively.

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CHAPTER 3: Assessing pathways of effect for household food production interventions to improve maternal and child nutrition and health: applying path analysis to the Program Impact Pathway for the Homestead Food Production program in Nepal.

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Introduction

There is a critical gap in the evidence base related to the potential for nutrition-sensitive agricultural strategies and the estimated impact they may have on nutritional intakes and nutrient status. Nutrition-sensitive programs address the underlying causes of undernutrition by drawing on complementary sectors such as agriculture [1]. These programs can improve child health through a number of synergistic pathways [2, 3]. There is a need for rigorous theory-driven evaluation of nutrition-sensitive programs [4, 5]. Positive program impacts are more commonly observed in integrated interventions, but understanding the contributions of the different mechanisms or pathways by which the outcomes are achieved is weak [2, 4, 5]. Rigorously evaluating large-scale effectiveness trials is methodologically difficult and expensive, especially for complex, integrated interventions [6]. However, the demand for evidence of the effectiveness of integrated, nutrition-sensitive interventions must be met, and evaluation strategies that clarify the mechanisms of effect are increasingly important.

Homestead food production (HFP) projects promote homestead gardens and, increasingly, animal husbandry. HFP programs often integrate agriculture with nutrition behavior change communication, sanitation and hygiene, and/or gender empowerment strategies [4, 7, 8]. HFP projects are viewed as long-term nutrition strategies that complement nutrition-specific strategies such as supplementation and fortification strategies because they are especially suited to simultaneously address multiple micronutrient deficiencies, energy insufficiency and food insecurity [9-11]. Nutrition-sensitive agricultural strategies such as HFP may also confer benefits related to development, empowerment, income generation and sustainability [12].

Recent reviews examining the linkages between agricultural interventions and nutrition outcomes highlight significant limitations in the evidence base, namely weak study designs, insufficient power, lack of appropriate counterfactuals, and lack of adjustment for confounding and modifying factors [1, 4, 5, 13]. Additionally, only a few studies have assessed impact using robust biological indicators of micronutrient status and complex modeling strategies that take into account clustering, random effects and confounding [14-16]. Furthermore, experts increasingly recognize that improvements in nutrition and health result from a network of interrelated factors, but most analyses focus on simple relationships using regression analyses. An exception is Olney et al., who assess qualitatively the Program Impact Pathways (PIP) to complement the regression analyses of program effectiveness [17].

Many nutrition and health projects are moving toward the use of a PIP to describe the theory behind the intervention design. A PIP describes the mechanism by which the program inputs are expected to impact the outcomes of interest. The PIP goes beyond the traditional Logical Framework approach to program planning and evaluation by visually representing the causal connections between the program inputs and outcomes [18]. In theory-driven program evaluation, the hypothesized causal model shapes the planning, implementation, and evaluation of the program. In order to better understand the contribution of complex interventions such as household food production strategies, it is important to determine, not just whether they are effective, but also why, how, and how they could be more so [19].

Path analysis, a type of Structural Equation Modeling (SEM), allows for modeling these more complex relationships to understand better how they work together to achieve the program's outcomes. Path analysis can be used to (1) detect areas in which improved program evaluation is needed, (2) identify program components that need to be strengthened or added, (3) understand the relative strength of program components to achieve the desired outcomes, and (4) compare resources used with the benefits attributable to specific program components.

Path analysis provides a unique approach for comprehensively assessing a theoretical path model. A comprehensive introduction to path analysis and SEM can be found in Kline's Principles and Practice of Structural Equation Modeling [20]. In short, path analysis is a type of SEM that assesses the strength of different causal pathways and estimates path coefficients between measured variables (in contrast to latent variables) from the regression analyses that make up the path model. It is an extension of regression modeling in that it not only estimates linear associations between path variables, but also provides estimates of the total, direct and indirect effects of a path model [20, 21]. Path analysis begins with a theoretical model that depicts the hypothesized causal relationships among measureable variables, which is called specification of the model. Using path analysis, we can estimate parameters of the model (direct and indirect effects), assess model fit (goodness of fit statistics), and make adjustments to the model as needed to improve the fit (respecification) [20-22].

After the path model has been specified, path coefficients are estimated from the set of regression equations that describe the path model. Path coefficients represent partial regression coefficients after controlling for prior variables in the model. Standardized beta coefficients are often used to facilitate comparison of the relative magnitude of causal paths within a model. Direct effects within a model are estimated by regressing an endogenous variable on all of the explanatory variables with direct paths leading to it. The associations within the model can be decomposed to estimate indirect effects, which are the effects of explanatory variables on outcome variables that are mediated through another variable in the path model. Indirect effects are estimated by multiplying the path coefficients for the path between the predictor and mediator variables and the mediator and outcome variables [23, 24].

Model fit statistics are used to assess how well the hypothesized model fits the data. When model fit statistics indicate a “good” fit, this can be interpreted that the hypothesized model adequately explains the relationships among model variables. For poorly fitting models, model fit may be improved by revising the theoretical model. However, a respecified model must still be consistent with the theoretical framework [20, 25]. This moves the analysis from a confirmatory to a more exploratory analysis.

In this paper we demonstrate the use of path analysis to enhance theory-driven evaluation research for nutrition-sensitive strategies. We present a model based on a PIP for assessing the relative influence of the pathways that contribute to height-for-age z-score using program evaluation data from an HFP intervention by Helen Keller International

(HKI) in Nepal. The PIP for the AAMA Project is shown in Figure 3. The use of these techniques can help define the role of agricultural food-based program in the context of nutritional and development interventions and be useful for program managers, researchers and policy makers.

Methods

This study includes secondary analysis of data from the endline survey of the Action Against Malnutrition through Agriculture (AAMA) Project, an HKI Enhanced Homestead Food Production (E-HFP) intervention in the Baitadi District of Far Western Region of Nepal. Overall, the impact evaluation of the AAMA Project reports significant improvements for intervention areas compared to controls in intermediate variables such as household food production, food security, nutrition knowledge, and complementary feeding practices. They also found significant improvements in women's underweight and anemia, but no significant changes were found in adjusted regressions for child anthropometry, and only borderline significant improvements in child anemia [26]. Relevant details of the program implementation and evaluation are summarized below.

Intervention design and implementation

HKI works with communities in Asia and Africa on a 3-year program cycle to establish HFP activities that promote nutritional self-sufficiency. HKI partners with local NGOs and Ministries of Health and Agriculture and provides technical and managerial support and start-up supplies to help communities integrate HFP into their regular activities. HKI began supporting home gardening projects in the early 1990's to increase access to micronutrient rich fruits and vegetables. HKI later incorporated animal husbandry to further improve access to micronutrient rich foods. Further improvements to incorporate a stronger link with health services and promotion of Essential Nutrition Actions has led to the E-HFP model [7].

The AAMA Project was conducted from 2009 to 2012. It targeted mothers of infants and young children ages 0-23 months to support households in establishing diversified home gardens and small animal husbandry, complemented by nutrition education and counseling. Development of these gardens aims to improve maternal and child nutrition and health by improving food security, diet quality and variety.

Eight Ilakas (sub-districts) were selected based on comparable characteristics and pair-wise assigned randomly to intervention or control; approximately 30 Village Model Farms (VMFs) were established in each intervention Ilaka. The HFP intervention includes the establishment of VMFs in Village Development Committees (VDCs) throughout each intervention Ilaka, and Female Community Health Volunteers (FCHVs) who lead them are trained by the project in food production, nutrition, and behavior change communication. Women who are pregnant or have a child less than 2 years at recruitment are eligible for enrollment in the project as HFP beneficiaries. Each VMF leader supports approximately 40 HFP beneficiaries by organizing monthly women's group meetings and disseminating agriculture and nutrition education. Beneficiaries also receive agriculture inputs, including seeds and chickens.

Evaluation design and implementation

The AAMA Project was conducted as a community-randomized effectiveness trial and evaluated using a repeated cross-sectional design at the community level in intervention and control communities. A baseline survey was conducted in August 2009, and an endline survey was conducted August through September 2012. VDCs were selected as the primary sampling unit, and 14 VDCs from each study arm were randomly selected for baseline and endline surveys.

Baseline and endline cross-sectional surveys assessed children ages 12-48 months at the time of the survey and their mothers to include children who would have had the maximum opportunity to benefit from the two years of program implementation. In households with multiple children ages 12-48 months, the youngest eligible child was selected. Survey respondents were randomly selected using a stratified, three-stage probability proportional to size methodology. The project had a goal to achieve maximum spillover into the community, so any household meeting the inclusion criteria of having a child 12-48 months could be included in the survey, irrespective of whether they directly participated in the AAMA Project as an HFP beneficiary. Sample size was determined based on detecting a 10 percentage point difference in stunting prevalence for children in intervention versus control communities ($1-\beta= 0.80$, $\alpha=0.05$, design effect = 2, upward adjustment = 10%).

The study was approved by the Nepal Health Research Council (Nepal's ethics review board). Additional approval was not required for the research presented here as this was secondary analysis of data.

Measurement and indicators

It is important to note that these analyses are different than impact analyses conducted in most intervention research. Instead of including a dichotomous variable to distinguish whether a respondent was in an intervention or control area, the intervention components were included in the model as scales that represent the intensity of each intervention component. Therefore the analyses presented here are not assessing whether there is a difference in intervention versus control communities for intermediate or final outcomes, but how the relative influence of various predictors and paths in the model contribute to the outcome of interest.

Selection of variables to be included in the path models was based on the expected strength of association according to the theory/literature, measurement quality, and strength of bivariate associations among components of the theoretical model in the dataset, with preference for continuous variables when possible. Three summative scales were created to reflect the key program inputs: agriculture inputs, agricultural training, and nutrition education. Possible agriculture inputs included seeds, saplings, chicks and goats. Resulting variables for each input were coded as 1 if received and 0 if not, and these variables were summed to create an agriculture input variable with range 0-4. Similarly, the agricultural training variable was a scale variable with a range of 0-3, with training on home gardening, poultry rearing/egg production, and livestock topics each contributing one point if received. The nutrition education scale represented the number of nutrition topics covered by the FCHV (eg. importance of breastfeeding and importance of animal source foods) as well as some direct nutrition services provided by the FCHV (eg. provision of vitamin A capsule for the child). A variable for each topic or service was coded as 1 if received and 0 if not, and these variables were summed to create the nutrition education scale variables. The nutrition education scale ranges 0-14 and includes pregnancy and maternal nutrition topics that the mother reported receiving under the assumption that improvements in maternal nutrition would translate into improved child nutrition during pregnancy or lactation.

The nutrition knowledge scale has a range 0-18 and includes topics about maternal nutrition as well as topics such as breastfeeding, complementary feeding, whether an ill child should be fed less, the same amount or more food than usual. The scale also reflects the respondent's ability to give examples of nutritious food categories and correctly answer questions about maternal or child diet, with one point awarded for each correct answer. For example, one point was awarded if the respondent mentioned yellow, orange or green vegetables or fruits as nutritious foods, and another point was awarded for mentioning eggs. Likewise, one point was awarded if a respondent correctly answered the question "should a pregnant woman consume less, the same amount or more food than usual?"

Volume and variety of food variables are based on respondent self-report for the past two months. Volume of foods produced (kg) was not normally distributed, so we used the natural log-transformed value of the total volume of all vegetables produced in the home garden during the last 2 months. Likewise, our variable for the variety of food produced is the natural log-transformed measure of the total number of vegetable varieties growing in the home garden in the last 2 months.

Household food security was measured using the Household Food Insecurity Access Scale (HFIAS) which assesses the extent to which households experienced food insecurity within the last 30 days. It uses nine questions that respondents can rank in terms of the severity with which they experienced that situation from never true (0) to often true (3), creating a total possible score up to 27, with higher values reflecting increasing food insecurity [27].

Child dietary diversity was measured on a scale 0-8 based on consumption during the previous day of foods in eight categories: dairy, grain, VA-rich veg, other FV, eggs, meat/poultry/fish, legumes/nuts, and oils/fats.

The primary outcome for this application of path analysis was HAZ. Height and weight were measured, and HAZ was calculated according to the WHO Child Growth

Standards [28]. Path analyses of the full set of intervention outcomes and the programmatic implications are presented elsewhere [29].

The models controlled for common socio-economic and household variables including household assets, maternal education level, number of children in the household, maternal age and access to a safe source of drinking water. The models also controlled for child-specific variables includ child age, child sex, whether the child had bloody stool in the past 2 weeks, and whether the child received a vitamin A capsule in the past 6 months. Additional potential confounders were assessed and included in the final model if significant. HAZ models were adjusted for maternal height.

Theoretical models, simple mediation and path analyses

A hypothesized path model was proposed for HAZ based on the PIP and other previously specified models in the literature [2, 4, 5]. Hypothesized path models for specific outcomes may vary slightly from overarching theoretical models to account for the theoretical underpinning of each individual outcome variable and data availability. For example, child diarrhea was included in the model for HAZ based on the documented association between diarrheal disease and growth, but it may be excluded from models for other outcomes if there is not a theoretical justification linking it with the outcome of interest [30]. The hypothesized path model for HAZ is shown in Figure 4.

After the hypothesized model was developed, it was necessary to refine the model and determine which variables from the dataset would be used to represent the concepts in the model. Basic mediation analyses were conducted to better understand the relationships between model variables at multiple points within the path model. When multiple variables or multiple ways to measure a variable existed for components of the model, we used the strength of basic correlations among potential model variables and the mediation analysis results to select the most appropriate variables and refine the path model to be tested. These analyses were conducted using Stata 13.1 (StataCorp, 2013).

Mediation assesses the relationship between two predictor variables and an outcome, with the mediating variable being one that accounts for or explains at least part of the relationship between the predictor variable and the outcome variable. Mediation is a building block of path analysis because it addresses the question of how or why an effect occurs. Figure 5 shows a simple mediation model, identifying the predictor, mediator and outcome variables, and describing the hypothesized relationships between them. Mediation analysis can help determine whether an effect of a predictor variable (X) on an outcome variable (Y) took place through a mediator variable (M), or how much of the effect of X on Y can be explained by Z. To assess mediation for any given model, first the basic relationship between the predictor and outcome variables is assessed (c). If it is significant, the relationship between the predictor variable and the mediating variable is measured (b). Finally, the outcome variable is modeled with the predictor and the mediator variable, and the coefficient for X's effect on Y represents the direct effect of X on Y, while the indirect effect (i) can be calculated by multiplying the effect of X on M (a) and the effect of M on Y (b). If the direct relationship between X and Y is no longer significant after accounting for M, the relationship is partially mediated [31].

Path analyses were conducted with M-plus 7.2 (Muthen & Muthen, 2014) to examine the direct and indirect relationships in the theoretical model. We used maximum likelihood (MLR) estimation method, the default estimation method for SEM programs, to obtain path coefficients for each model [32]. Path coefficients, both standardized and unstandardized, can be interpreted similarly to regression coefficients. Standardized coefficients indicate the strength of a path relative to other paths in the model, and unstandardized coefficients indicate the amount of change in the outcome variable associated with a one unit change in the predictor variable. Due to mathematical limitations inherent in estimating the path models, standardized coefficients could not be obtained for the HAZ model because it included a binary endogenous variables (presence of diarrhea in past two weeks). For models with binary variables, we can only report unstandardized path coefficients.

Likewise, model fit estimates are not available using MLR methods when the model includes binary endogenous variables. We used a weighted least-squares (WLSMV) estimation method which uses a latent response variable underlying the binary observed variable to obtain model fit statistics [33]. Model fit statistics (and their desired values) include: chi square goodness of fit (χ^2, $p>0.05$), root mean square error of approximation (RMSEA, <0.1 indicates fair fit, and <0.07 indicates good fit), and the comparative fit index (CFI, >0.90 indicates fair fit, and >0.95 indicates good fit) [22, 34]. We further simplified the model as needed and repeated these analyses to identify the best fitting model.

Mediation and path analyses include all respondents from the endline evaluation, including HFP beneficiaries, households in the intervention area that meet the criteria for having a child 12-48 months but were not direct HFP beneficiaries, and households from control areas. All analyses control for clustering at the VDC (village) level to account for unmeasured differences between VDCs, and significance is determined at $p<0.05$.

Results

Data were available for 2,614 women and their children from 171 VDC clusters. The intraclass correlation coefficient (ICC) for HAZ was 0.058. Table 1 summarizes the means and prevalences of model variables. Exogenous input variables include agricultural training (mean±SD; 0.65±0.93), agricultural inputs (0.71±0.94), and nutrition education (12.20±3.05). Endogenous path variables include nutrition knowledge (7.73±1.89), variety of vegetables produced (1.73±0.52 ln(#)), volume of vegetables produced (3.09±0.83 ln(kg)), food insecurity (4.58±4.68), and child dietary diversity (3.86±1.05). The primary outcome is HAZ (-2.21±1.28), and the prevalence of stunting in the sample is 59.5%.

Refining the path model and variable selection

Several components of the hypothesized model had to be dropped from the path model because we lacked a relevant variable or had such low variability that the strength of bivariate associations was poor. For example, the endline survey did not collect data on gender empowerment, and as such this concept could not be included in the path analyses. Also, the number of beneficiaries who reported household income from HFP sales was low (5.5% for garden produce, 6.8% for poultry products), so there was inadequate variability to include these variables in the models.

Based on the bivariate associations and simple mediation analyses, the full HFIAS scale was the best variable to represent food insecurity, even compared to other child-specific questions about food insecurity. Child dietary diversity score was selected as the variable to represent consumption of nutritious foods. This variable was selected over feeding frequency and other child feeding variables that are expected to relate to child growth because it was the best fit in bivariate associations and mediation analyses. Likewise, the variable 'diarrhea in the past 2 weeks' was more strongly associated with other model variables than 'any illness in the past two weeks' (data not shown).

Since endline survey respondents included direct HFP beneficiaries in the AAMA Project (34%), women who lived in the intervention communities but were not beneficiaries

(16%), as well as women in control villages (50%) who may or may not have received some other type of agriculture or nutrition support, the variables do not strictly reflect intervention assignment. Instead, they represent the actual level of engagement in project activities. Furthermore, since the evaluation used a cross-sectional design, the path analyses reflect current status at endline for each variable rather than the change over the life of the project.

Simple mediation analyses

Mediation was assessed for multiple relationships along the full path model (Figure 6). These analyses show a small but significant relationship between agriculture training and height-for-age z-score (B=0.056, p=0.008) and indicate that the relationship is mediated by the variety of vegetable varieties grown in the home garden. The indirect effect explains 59.2% of the total effect of agricultural training on HAZ. This relationship is partially mediated by nutrition knowledge, which explains 48.5% of the total effect of nutrition education on dietary diversity. Because the dichotomous variable diarrhea in this model prevents us from estimating standardized coefficients, we cannot directly compare the relative strength of different path coefficients.

Path analyses

The full path model for HAZ fit the data poorly: $\chi^2(31)=255.5$, $p<0.001$; RMSEA=0.053; CFI=0.794, so the model was respecified and tested for fit. Reducing the model by excluding the diarrhea variable (the only dichotomous variable in the model) did not greatly improve model fit: $\chi^2(24)=526.6$, $p<0.001$; RMSEA=0.090; CFI=0.869. A reduced model that excluded volume of home garden production and household food insecurity provided a better fit: $\chi^2(19)=55.8$, $p<0.001$; RMSEA=0.027; CFI=0.945 (Figure 7).

The path coefficient for variety of home garden production and child dietary diversity was 0.713 ($p<0.001$), indicating that a one unit increase in the natural log of the variety of fruits and vegetables produced would correspond with an increase in child dietary diversity score of 0.713. The path coefficient from child dietary diversity to HAZ was 0.054, which was insignificant ($p=0.059$). The paths from nutrition knowledge through diarrhea to HAZ were small (-0.086 and -0.170, respectively) but statistically significant ($p<0.001$ and $p=0.033$, respectively). All three program inputs had statistically significant path coefficients, with agricultural training being the smallest. A one point increase in the agriculture training scale corresponds with the natural log of the variety of foods produced increasing by 0.073 ($p=0.008$), while a one point increase in the agriculture input scale is associated with the natural log of the variety of foods produced increasing by 0.229 ($p<0.001$). A one point increase in the nutrition education scale corresponds with a 0.313 increase in the nutrition knowledge scale ($p<0.001$), and a one point increase in the nutrition knowledge scale led to increasing the natural log of the variety of foods produced by 0.017 ($p=0.001$).

Discussion

We apply path analysis to test the hypothesized model of an HFP program and assess the influence of the pathways that contribute to HAZ scores. The path analysis indicates a good fit for a simplified model that excluded volume of production and food security from the original path model tested. Removing important components of the hypothesized model in order to obtain a good fit raises several questions about the differential importance of some components of the intervention as well as whether measurement, contextual factors, or implementation fidelity may be the cause of poor fit for some variables. Areas of weakness in a path model may be attributed to weaknesses in program design and implementation, a bottleneck due to contextual factors, or inadequate measurement. In order for path analysis findings to be useful for program planning and evaluation, it is necessary to distinguish between these potential causes. In situations where adding a variable to the path would significantly reduce fit despite strong theoretical support for its inclusion, the first factor to consider is measurement validity. If measurement validity is unlikely, limiting contextual factors and problems with intervention design and fidelity should be considered.

Using the example of agriculture training, which had a significant but weak effect in the model, program planners and evaluators may review the survey questions about agricultural training and conclude that the questions did not adequately assess the full scope and intensity of agricultural training that the program provides, and therefore the survey should be revised to better measure agricultural training in future interventions. If program decision makers conclude that the agriculture training variable was sufficiently measured, determining whether the weak effects of agricultural training were due to inadequate implementation such as poorly conducted trainings, or to contextual factors such as inadequate household resources to act on the training. These decisions should be informed by qualitative research and monitoring records.

Another example in which a variable's poor fit in the models could be due to implementation and contextual factors or to issues with measurement is the role of HFP sales in the causal path to improve nutrition and health outcomes. Income from HFP sales was unable to be tested in the path model because there were an insufficient number of beneficiaries who reported HFP sales for the variable to be included. There are several potential explanations for the limited amount of HFP sales: the intervention did not adequately prepare beneficiaries to sell garden produce, sales have seasonal variability and did not correspond with the timing of the survey, families preferred to use all garden produce within the household or did not produce surplus for selling, and /or lack of formal markets and inadequate infrastructure made HFP sales unfeasible. As well, the survey questions about HFP sales were asked in a way that did not capture the informal trade of HFP goods among community members even though this may have contributed to improved diet quality and positive outcomes for nutrition and health through an economic pathway. In this case, knowledgeable program staff, community stakeholders, and qualitative research can complement the path analysis findings to help determine the extent to which HFP sales could better contribute to the model, either through changes in implementation or measurement.

Some variables had adequate variability and strength of bivariate associations with other path variables to be tested in the models but were not included in the final model for HAZ because the path model fit poorly when it was included. Household food insecurity is an example of this. The HFIAS scale is a commonly used and validated measure of household food insecurity, but after accounting for the contributions of other variables that preceeded it in the model, the HFIAS score was not a good fit in the model. One interpretation is that even though food insecurity is associated with variables along the pathway, it is not casually or mechanistically linked to the AAMA program's effects on HAZ, meaning that the impacts of the intervention are not achieved through changes in food security. The poor fit of the HFIAS scale in the HAZ indicates that program planners should consider whether the intervention is adequately designed to affect child growth through changes in food security.

This study is the first of its kind to use path analysis for evaluating theory-driven, nutrition-sensitive strategies. The study used program evaluation data from a rigorously designed community-randomized effectiveness trial that included an adequate sample size, appropriate counterfactual, and measurement of robust nutrition and health outcome indicators. The quality of data collection allowed us to control for clustering and potentially confounding variables. The *a priori* PIP was based on a strong theoretical foundation to explain the hypothesized pathways from intervention components to key nutrition and health outcomes.

However, other measurement issues are also likely to influence the model fit and reduce the strength of associations between variables throughout the path model, as reflected by low path coefficients. The HFP operates on a 3 year plan. By relying exclusively on endline survey data for measuring model variables, a long time elapsed between many intervention inputs and early intermediate outcomes and their measurement. Poor recall of early events may reduce the reliability of those variables and the strength of their associations within the model. Using monitoring data or conducting a midline assessment to measure the intervention inputs and early output indicators would strengthen measurement of these model components and increase the ability to detect relationships among model parameters. An additional benefit of midline data collection is that preliminary analyses could highlight weaknesses in implementation or assessment that could be remedied while implementation is still active. Finally, collecting data at multiple time points throughout program implementation could also strengthen causal inferences by clearly demonstrating the temporal relationships among variables, which was not possible in these analyses due to the cross-sectional nature of the data.

Furthermore, using data from a cross-sectional endline survey prevents us from assessing changes over time at the individual or household level. Even though the counterfactual communities were carefully selected and similar to the intervention areas, the path analyses focus on paths operating at the individual and household level, so we cannot assess changes over time using cross-sectional endline data. Future program evaluations can better support path analyses if they are designed to assess change over time at the individual or household level.

The analyses presented here focus specifically on the PIP to explain outcomes of interest, and we treat any variables outside of these key pathways of impact as confounders. However, future analyses could potentially increase explanatory power of the path model by including certain variables that are likely to account for additional variability in the model or influence the strength of the hypothesized relationships in the causal pathways. Furthermore, assessment for moderators and stratified analyses may better identify factors outside of the intervention pathways that influence the strength of the path relationships. For example, household factors such as wealth and land access may influence the extent to which beneficiaries can engage in the desired food production and feeding behaviors, while inadequate sanitation and hygiene may limit the positive effect of improved diet on nutrition and health outcomes. Assessing these variables as moderators instead of simply controlling for them as confounders may lead to improved model fit and a better understanding of how the intervention operates in context. Additionally, the path models tested in this research assume that the three program input variables act independently, which does not accurately reflect how the program is implemented. Future analyses could account for this by specifying a correlation between the exogenous program input variables or assessing how one program input variable moderates another.

Path analysis does not replace the need for rigorous evaluation methodologies, including qualitative and quantitative process and impact evaluations. Indeed, this analysis did not assess whether the intervention was effective, but how well the hypothesized model of program impact fit the data collected for the impact evaluation. Rather, path analysis can be used to enhance our understanding of complex, nutrition-sensitive strategies by providing a unique analytic tool that builds upon a strong theoretical PIP and a rigorously evaluated intervention. This work builds on the work of Olney et al., which applied qualitative methods to evaluate the components of a PIP for an HFP intervention in Cambodia. Using semi-structured interviews and focus group discussions, they identified opportunities for improving delivery and utilization of the program components to increase the potential impact of the intervention on nutrition outcomes. Olney's approach is particularly important because the qualitative research can identify barriers that may not be assessed quantitatively, but path analysis can complement and expand Olney's work and traditional impact evaluations in several ways.

First, path analysis can estimate the extent to which components of the model co-vary to clarify which pathways are contributing to the changes observed. In difference-in-difference (DID) analyses of path variables, it is possible to quantify differences between intervention and comparison communities, and adjusted regression analyses allow for more refined estimates such as controlling for confounding. However, these analyses do not identify mediating variables or indicate the extent to which different pathways contribute to the outcome of interest. Furthermore, the results of a path analysis, i.e. the path coefficients, are typically presented on the path diagram, providing a comprehensive, quantitative representation of the results in a single diagram. This approach is practical for communicating a large amount of information in a simple manner and may facilitate comprehension and programmatic decision making.

This research demonstrates the feasibility and utility of complementing traditional nutrition-sensitive program research with path analyses to identify potential bottlenecks in program implementation and strengthen understanding about the mechanisms through which nutrition-sensitive programs operate to improve nutrition and health outcomes. Simple modifications to evaluation design can better facilitate path analysis, including using a longitudinal study design with monitoring data or midline surveys, collecting robust data on all aspects of a PIP, and ensuring that all aspects of a PIP can be represented with continuous variables. Future work could include an expansion to full Structural Equation Modeling techniques for nutrition-sensitive program, which allows latent variable constructs and more advanced multi-level modeling techniques. This approach would allow for community level and contextual variables to be included in the models to better understand the interactions between the intervention and the environment in which it operates.

Chapter 3 Tables and Figures

Figure 3: Program Impact Pathway for Helen Keller International's Homestead Food Production Intervention

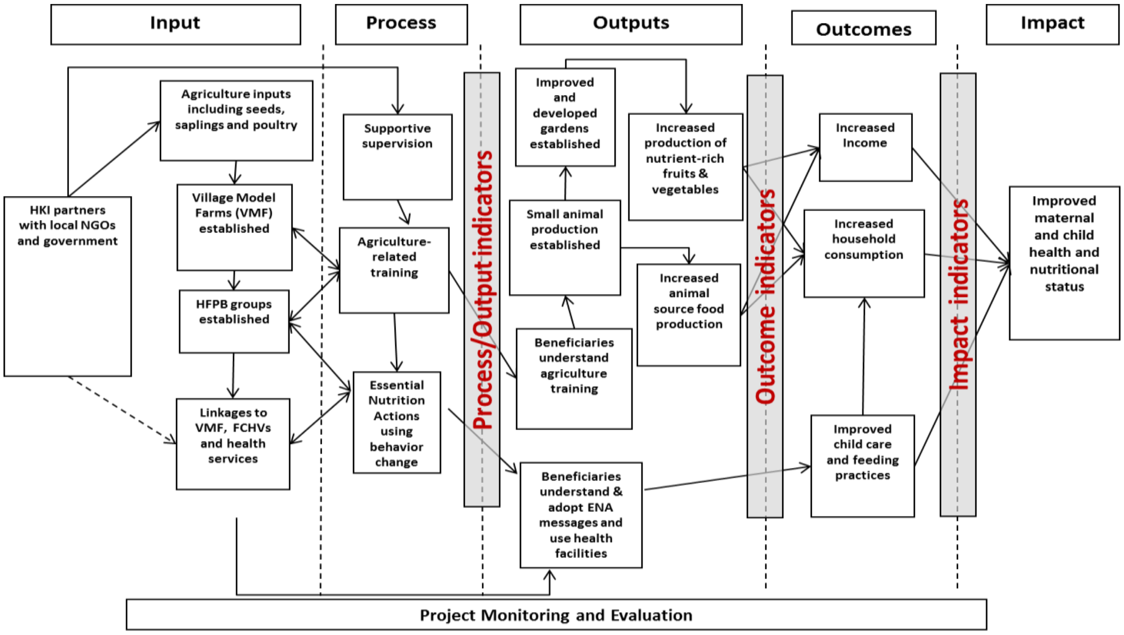


Figure 4: Theoretical path model of homestead food production's effect on height-for-age z-score.

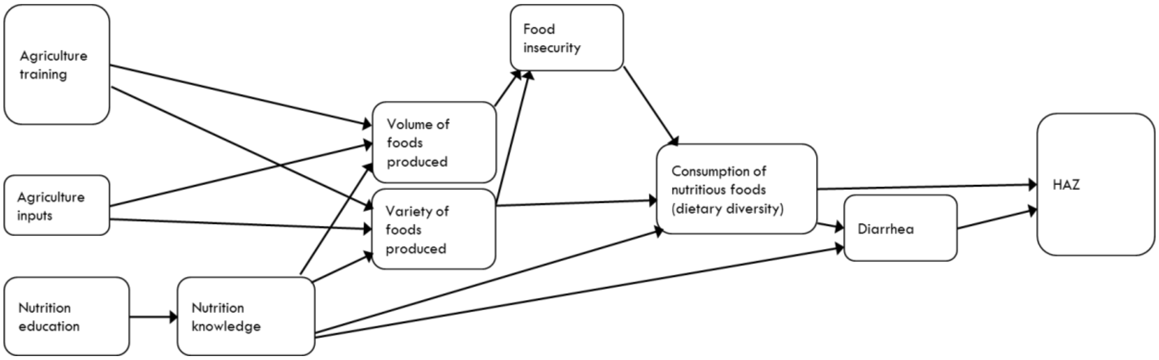


Table 1: Summary statistics for path model variables and prevalence of stunting.

Path variables		
Variable (range or unit)	**n**	**Sample mean (SD) or prevalence**
Exogenous (input) variables		
Agricultural training (0-3)	2614	0.65 (0.93)
Agricultural inputs (0-4)	2614	0.71 (0.94)
Child nutrition education scale (0-14)	2614	12.20 (3.05)
Endogenous path variables		
Maternal knowledge of child nutrition scale (0-18)	2614	7.73 (1.89)
Variety of vegetable production (#), natural log	2266	1.73 (0.52)
Volume of vegetable production (kg), natural log	2211	3.09 (0.83)
Household food insecurity (0-27)	2614	4.58 (4.68)
Child dietary diversity (0-8)	2614	3.86 (1.05)
Child diarrhea (yes/no)	2614	16.6%
Outcome variable and related classification		
HAZ	2596	-2.21 (1.28)
Prevalence of stunting	*2596*	*59.5%*

*Stunting is defined as HAZ <-2.

Figure 5: Example mediation model.

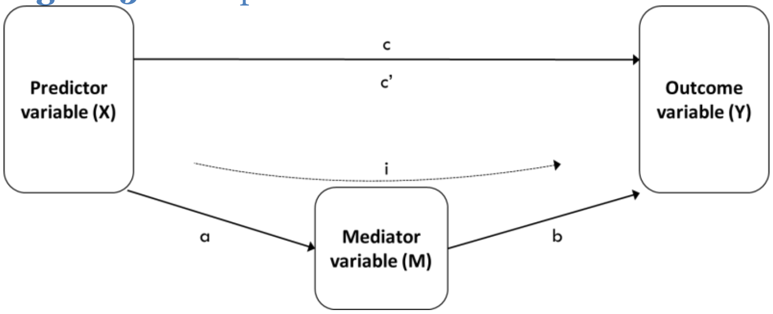


Figure 6: Simple mediation models within the height-for-age path model. A) The relationship between agriculture training and height-for-age z-score is mediated by the number of vegetable varieties grown in the home garden. The indirect effect explains 59.2% of the total effect. B) The relationship between nutrition education and dietary diversity is partially mediated by nutrition knowledge. The indirect effect explains 48.5% of the total effect.

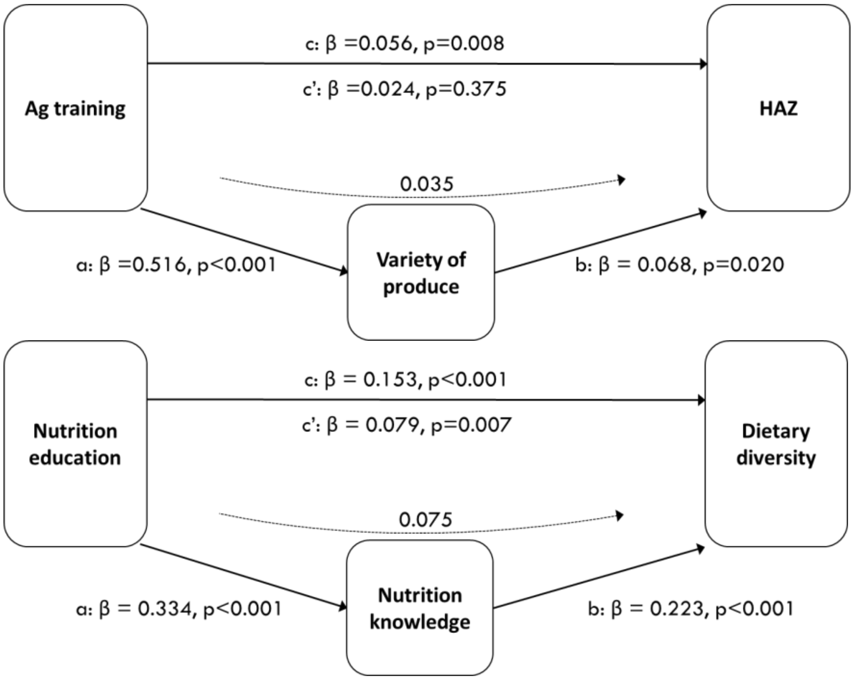
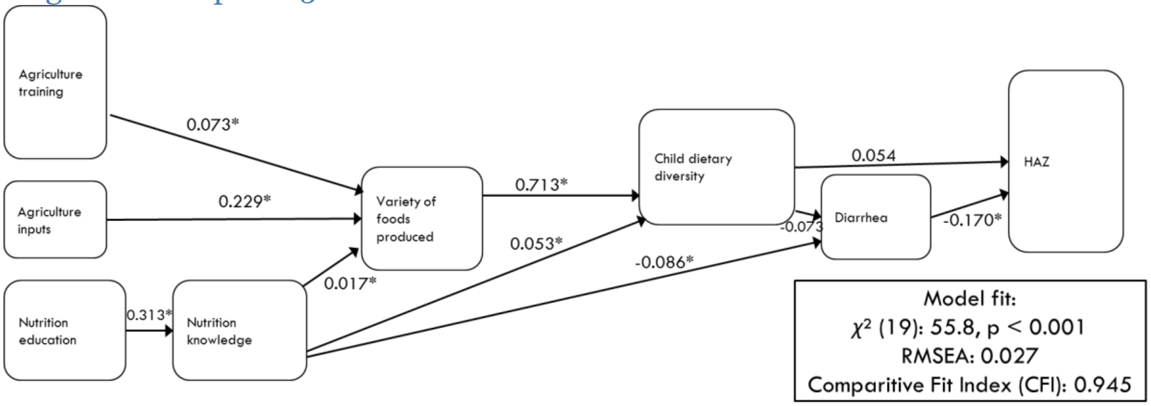


Figure 7: Path analytic model of homestead food production's effect on height-for-age z-score. Unstandardized path coefficients are provided for all paths. *Significant at p<0.05.



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CHAPTER 4: How does Homestead Food Production improve maternal and child nutrition? Path analysis of the AAMA Project in Nepal.

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Introduction

Poor access to quality foods is a leading contributor to micronutrient deficiencies throughout the world, and deficiencies of multiple micronutrients, as well as energy and protein, are common. While micronutrient supplementation and fortification are effective to address micronutrient deficiencies in many contexts, community food-based strategies such as Helen Keller International's (HKI's) Homestead Food Production (HFP) interventions are thought to be appropriate complementary strategies because they are considered comprehensive and sustainable [1-3]. HFP programs are viewed as long-term strategies to improve nutrition, food security and health by supporting diets with nutritionally rich foods. They are uniquely suited to address multiple micronutrient deficiencies, energy insufficiency and food insecurity [1, 2]. This type of strategy is believed to confer several additional benefits related to development, empowerment, income generation and sustainability.

However, evidence for program effectiveness is mixed, and understanding of the mechanisms by which HFP achieve their effects is limited. Home gardening projects that incorporate nutrition education have been ranked as high to moderate for achieving desired nutrition outcomes in a 2004 review of the effectiveness of household food production interventions to improve nutrition outcomes [4]. Likewise the World Bank reports that home gardening interventions can lead to improved maternal and child nutrition outcomes, particularly in Asia and Africa [5]. However, a review of the most effective interventions for maternal and child undernutrition consider there to be inadequate evidence of effectiveness for household food production strategies [6]. Recent reviews of household food production strategies have found that the programs are generally successful at increasing production and consumption, but the evidence for nutritional or health impacts is varied and any positive effects tend to be small. The lack of effectiveness in many studies is attributed to methodological limitations such as small sample sizes, lack of appropriate control groups, inadequate time to detect an effect, and limited consideration of participation levels [4, 7, 8]. HKI has reported that the HFP programs in Bangladesh, Nepal, Cambodia and the Phillipines produced 216,000 metric tons of fruits and vegetables annually [9]. However, the current evidence for effectiveness of HFP programs to improve nutritional outcomes is less consistent and subject to the limitations discussed above, and evidence about how the program affects change are even more limited [10, 11].

The Action Against Malnutrition through Agriculture (AAMA) Project was a three-year HFP intervention implemented by HKI in Far Western Nepal. HKI works with communities in Asia and Africa on a 3-year program cycle to establish HFP gardens that promote nutritional self-sufficiency, food security and diet quality. This nutrition-sensitive strategy provides agricultural inputs, agricultural training, and nutrition education to promote home production and consumption of nutrient-rich vegetables and animal-source foods. The AAMA Project was designed as a community-randomized effectiveness trial with a robust evaluation design to more rigorously assess the effects of the HFP intervention.

Experts increasingly recognize that improvements in nutrition and health result from a network of interrelated factors, but most analyses focus on individual linear relationships through regression analyses. In order to better understand the contribution of complex interventions such as HFP programs, it is important to determine, not just whether they are effective, but also why, how, and how they could be more so [12]. The overall effect of the program may be attributable to multiple pathways, and evidence to identify the contributions of the different pathways, or bottlenecks in the pathways, may lead to improvements in program design and implementation.

HKI uses a Program Impact Pathway (PIP) to describe the interrelated mechanisms through which they aim to improve nutrition and health, including agricultural training to produce nutrient-rich crops, nutrition education, income generation and women's empowerment [13]. Using the HFP PIP as the theoretical model for the intervention's effects and data from the endline evaluation of the AAMA project, this research employs path analysis to assess the relative influence of the pathways that contribute to changes in maternal and child nutrition and health. A detailed description of the use of path analysis to assess the HFP PIP is available [14].

Path analysis is a type of Structural Equation Modeling that assesses the strength of different causal pathways using standardized beta weights from regression analyses to estimate path coefficients. Path analysis of public health interventions allows for consideration of the more complex relationships between these factors to better understand how they work together to achieve the program's outcomes. Each construct along the pathway is represented by one variable, and this type of analysis allows you to estimate the direct effect of one variable on another and assess the relative strength of the various paths.

Findings from path analysis can be used to improve programmatic strategies in several ways, including (1) detecting areas in which improved program evaluation is needed, (2) selectively identifying programmatic components that need to be strengthened for greater effectiveness, (3) understanding the relative strength of program components to achieve the desired outcomes, and (4) comparing resources used with the benefits attributable to specific program components. The complexity of HFP interventions and other nutrition-sensitive strategies is often cited as a reason that their impacts are understudied, so path analysis is a potentially important tool in helping understand their role in improving nutrition and health.

Methods

AAMA Project description

HKI's HFP programs primarily operate through home gardening, animal husbandry and improved child feeding practices. HKI partners with local NGOs and provides technical and managerial support and start-up supplies to help communities integrate HFP into their regular activities. HFP programs promote nutritional self-sufficiency, food security, and diet quality to improve micronutrient deficiency-related health outcomes such as anemia and night blindness. This approach is designed to have additional benefits through job creation, income generation, capacity building and women's empowerment [13].

The AAMA Project was conducted from 2009 to 2012 in Baitadi district, in the Far Western Region of Nepal. A detailed description of the program can be found in the final evaluation report, and the PIP for the AAMA Project is shown in Figure 8 [15]. Eight Ilakas (sub-districts) were selected based on comparable characteristics and pair-wise randomly assigned to intervention or control. Approximately 30 Village Model Farms (VMFs) were established throughout multiple Village Development Committees (VDCs) in each intervention Ilaka. Each VMF leader supports approximately 40 HFP beneficiaries by organizing monthly women's group meetings and disseminating agriculture and nutrition education. Beneficiaries also receive agriculture inputs including seeds and chickens. The program also provides supplementary training for Female Community Health Volunteers (FCHVs) to assist beneficiaries in food production, nutrition, and behavior change communication. Women who are pregnant or have a child less than 2 years at recruitment are eligible for enrollment in the project as HFP beneficiary.

Evaluation design and data collection

A detailed description of program evaluation methods and findings are documented in the project's final evaluation report [15]. In brief, the AAMA Project was conducted as a community-randomized effectiveness trial and evaluated using cross-sectional design at the community level in intervention and control communities. The primary sampling unit was the VDC, and baseline and endline surveys were conducted in 14 VDCs each from intervention and control in August 2009 and August through September 2012, respectively. Cross-sectional surveys assessed children ages 12-48 months at the time of the survey and their mothers to include children who would have had the maximum opportunity to benefit from the two years of program implementation during critical periods of child growth. The surveys included any household meeting the inclusion criteria of having a child 12-48 months, irrespective of whether they directly participated in the AAMA Project as an HFP beneficiary, due to the program's intention for the agricultural and feeding practices to spillover from HFP beneficiaries into the broader community.

Survey respondents were randomly selected using a stratified, three-stage probability proportional to size methodology. Sample size was determined based on detecting a 10 percentage point difference in stunting prevalence for children in intervention versus control communities (1-β= 0.80, α=0.05, design effect = 2, upward adjustment = 10%). In households with multiple children ages 12-48 months, the youngest eligible child was selected as the index child.

The study was approved by the Nepal Health Research Council (Nepal's ethics review board). Additional approval was not required for the research presented here as this was secondary analysis of data.

Measurement

The primary outcomes assessed using path analysis include maternal and child hemoglobin, maternal and child anthropometry, maternal night blindness during pregnancy, and child diarrhea. Child nutritional status indicators were measured and calculated according to the WHO Child Growth Standards and included height-for-age z-score (HAZ), weight-for-age z-score (WAZ), and weight-for-height z-score (WHZ) [16]. Maternal Body Mass Index (BMI) was calculated for non-pregnant women using field measurements of height and weight, and only non-pregnant women were included in BMI path analyses. Hemoglobin was measured in the field using the HemoCue ® analyzer for mothers and children, and values were adjusted for altitude and pregnancy as recommended by Sullivan et al. [17]. Maternal night blindness during pregnancy (with index child) and child diarrhea during the prior two weeks were recorded as binary (yes/no) variables based on respondents' self-report.

Variable selection and measurement of path variables has been previously described [14]. In short, each program component (agriculture inputs, agricultural training, and nutrition education) was measured by creating a summative scale to reflect the extent to which those services were received. The nutrition education scale used for child outcomes ranges 0-14 and includes pregnancy and maternal nutrition topics that the mother reported receiving under the assumption that improvements in maternal nutrition would translate into improved child nutrition during pregnancy or lactation. For maternal path analyses, the nutrition education scale ranges 0-8 and focuses exclusively on advice or support specific to mothers' nutrition.

Nutrition knowledge scales reflect the respondent's ability to give examples of nutritious food categories and correctly answer questions about maternal or child diet, with one point awarded for each correct answer. For example, one point was awarded if the respondent mentioned yellow, orange or green vegetables or fruits as nutritious foods, and another point was awarded for mentioning eggs. Likewise, one point was awarded if a respondent correctly answered the question "should a pregnant woman consume less, the same amount or more food than usual." The maternal nutrition knowledge scale has a range 0-6, while the maternal knowledge of child nutrition scale has a range 0-18 and includes topics about maternal nutrition as well as topics such as breastfeeding, complementary feeding, whether an ill child should be fed less, the same amount or more food than usual.

Volume and variety of foods produced were not normally distributed, so each variable was natural log-transformed. Volume of foods produced reflects the natural log-transformed total volume of all vegetables produced in the home garden during the last 2 months preceding the survey, while the variety of food produced is the natural log-transformed measure of the total number of vegetable varieties growing in the home garden at the time of the survey. Both volume and variety of food variables are based on respondent self-report.

Household food insecurity was measured using the Household Food Insecurity Access Scale (HFIAS) which assesses the extent to which households experienced food insecurity within the last 30 days [18]. Dietary diversity was measured separately for mothers and children and on an 8-point scale based on consumption during the previous day of foods in eight categories: dairy, grain, VA-rich veg, other FV, eggs, meat/poultry/fish, legumes/nuts, and oils/fats.

All models controlled for clustering and common socio-economic and household variables including household assets, maternal education level, number of children in the household, maternal age and access to a safe source of drinking water. Analyses of child outcomes additionally controlled for child age, child sex, whether the child had bloody stool in the past 2 weeks, and whether the child received a vitamin A capsule in the past 6 months. Additional potential confounders were assessed for each outcome and included in the final model if significant. Models for HAZ, WAZ, and WHZ were further adjusted for maternal height; models for child hemoglobin were further adjusted for deworming; and models for maternal night blindness were further adjusted for whether the mother received a vitamin A capsule after delivery.

Model specification and testing

Path analysis was conducted separately for each outcome of interest. A thorough description of the model specification process has previously been reported [14]. First, an initial path model was proposed for each primary outcome of interest based on the HFP PIP, with adjustments to account for data availability and the theoretical underpinning of each individual outcome variable [8, 11]. Initial path models, or "full models," are shown in Figure 9.

After the initial models were developed for each outcome, we refined the models by determining which variables from the dataset would be used to represent each concept in the model. Basic mediation analyses were conducted using Stata 13.1 (StataCorp, 2013) to better understand the relationships between model variables at multiple points within the path model. When multiple variables or multiple ways to measure a variable existed for components of the model, variables were selected based on the strength of basic correlations among potential model variables and the simple mediation analysis results.

All initial path models included both volume and variety of foods produced in the home garden to represent the home gardening intermediary outcome. The models for HAZ, WAZ, and WHZ included child diarrhea in the causal pathway to represent the underlying health status. For the child diarrhea model, anthropometric indicators (HAZ, WAZ and WHZ) were assessed for inclusion to reflect the effect of child nutritional status on infection. We included HAZ in the causal pathway as an indicator of net nutritional exposures based on the path coefficients and model fit statistics. The models for child hemoglobin and all maternal outcomes excluded child diarrhea, and no other general health variables were available that fit the models.

The full model specified for each outcome was assessed for model fit using M-plus 7.2 (Muthen & Muthen, 2014) which reports several model fit indices, including chi square goodness of fit (χ^2, p>0.05 indicates good fit), root mean square error of approximation (RMSEA, <0.1 indicates fair fit, and <0.07 indicates good fit), and the comparative fit index (CFI, >0.90 indicates fair fit, and >0.95 indicates good fit) [19, 20]. The chi-square fit index is sensitive to large sample sizes, so we report it with other goodness of fit indices but focus on RMSEA and CFI to determine model fit. Maximum likelihood (MLR) estimation is the default estimation method for most structural equation modeling programs and was used to obtain model fit statistics for all model with exclusively continuous endogenous variables, including maternal and child hemoglobin and maternal BMI [21]. However, for any model that includes endogenous binary variables (child nutritional status, child diarrhea and maternal night blindness), model fit statistics were generated using weighted least-squares (WLSMV) estimation method which uses a latent response variable underlying the binary observed variable to obtain model fit statistics [22].

For each outcome, if the initial path model was not a good fit, we tested reduced versions of the model to identify the best possible fitting model that is consistent with the theoretical framework. We report path coefficients and model fit statistics for the best fitting path model for each outcome of interest. Unstandarized coefficients were available for all models using maximum likelihood (MLR) estimation methods, but standardized coefficients were only available for models that do not have binary variables. We report both coefficients when available and use the standardized path coefficients from the relevant models to assess the relative strength of various paths.

Results

Child nutrition and health status

Data were available for 2,614 women and their children from 171 VDC clusters. Table 2 summarizes the means and prevalences of all model variables. Exogenous input variables include agricultural training (mean±SD; 0.65±0.93), agricultural inputs (0.71±0.94), child-related nutrition education (12.20±3.05) and maternal-related nutrition education (6.81±1.97). Endogenous path variables include maternal knowledge of child nutrition (7.73±1.89), maternal nutrition knowledge (4.89±1.21), variety of vegetables produced (1.73±0.52 ln(#)), volume of vegetables produced (3.09±0.83 ln(kg)), food insecurity

(4.58±4.68), child dietary diversity (3.86±1.05), and maternal dietary diversity (3.89±1.32). Child outcome variables include HAZ (-2.21±1.28), WAZ (-1.77±1.02), WHZ (-0.78±1.03), hemoglobin (11.20±1.22), and diarrhea in the last 2 weeks (prevalence, 16.6%). Maternal outcome variables include BMI (19.84±2.00), hemoglobin (12.49±1.38), and night blindness during pregnancy (17.8%).

Path analysis results for all outcomes indicated that the relationships among model variables were in the expected directions based on the theoretical framework. To obtain a good fit, the volume of food produced in the home garden and food insecurity had to be removed from the models for HAZ, WAZ, and WHZ. The unstandardized coefficients and model fit indices (RMSEA=0.027; CFI=0.945) for HAZ are shown in Figure 10. Dietary diversity did not have a significant association with HAZ in the model (B=0.054, p=0.059), but diarrhea did have a positive inverse path coefficient (B=-0.170, p=0.033). Path coefficients and model fit indices for WAZ and WHZ path models are consistent with those shown for HAZ (data not shown).

The path model for child hemoglobin (Figure 11) obtained an adequate fit after removing the volume of food produced in the home garden but leaving food insecurity in the model (RMSEA=0.073; CFI=0.913). Child dietary diversity was significantly associated with child hemoglobin in the model (B=0.131; β=0.112; p<0.001).

Like child nutritional status, the path model for child diarrhea (Figure 12) fit better when volume of food produced in the home garden and food insecurity were excluded (RMSEA=0.050; CFI=0.813). Child dietary diversity (B=-0.122, p=0.047) and HAZ (B=-0.112, p=0.031) were each significantly associated with diarrhea. The effect of nutrition knowledge on diarrhea operated through net nutritional status (represented by HAZ) in addition to the path through dietary diversity.

Agriculture inputs (B=0.229, β=0.417, p<0.001) and nutrition education (B=0.313, β=0.334, p<0.001) contributed most strongly to the model outcomes. Nutrition education had a strong coefficient on the path leading to nutrition knowledge. However, the association between nutrition knowledge and variety of foods produced in the model was significant but weak (B=0.017, β=0.095, p=0.001), meaning that the total association between nutrition education and variety of foods produced was weak (B=0.005; β-0.032) compared to the direct relationship between agriculture inputs and variety of foods produced.

Maternal nutrition and health status

In spite of testing numerous variations of the models, none of the maternal health outcome models achieved a good fit according to both RMSEA and CFI. The maternal BMI model with the best fit was the unreduced model (Figure 13), which included volume of home garden production and food insecurity (RMSEA=0.099; CFI=0.855). However, the path between maternal dietary diversity and BMI was not significant (B=0.048, β=0.031, p=0.145).

Like child hemoglobin, the maternal hemoglobin model with the best fit (Figure 14) excluded the volume of food produced in the home garden but included food insecurity in the model (RMSEA=0.097; CFI=0.857). The path from maternal dietary diversity to maternal hemoglobin was significant (B=0.079, β=0.075, p=0.005).

The best fitting model for maternal night blindness (Figure 15) was the most simplified model (RMSEA=0.045; CFI=0.862), which excluded the volume of food produced in the home garden and food insecurity. The path from maternal dietary diversity to night blindness was significant (B= -0.117, p=0.015), but the overall model did not adequately explain the variation in night blindness in this dataset.

A summary of final path models for each outcome of interest and their model fit statistics is provided in Table 3.

Discussion

Models for child outcomes fit the data relatively well after being reduced (ie. removing the variables for volume of foods produced, and in some cases household food insecurity), while models for maternal outcomes did not achieve a good fit, even when reduced. These findings are useful for applied programmatic research because they add to the body of literature about how HFP programs achieve their effects, allow us to identify areas for improvement in program implementation, evaluation design and measurement, and can help identify situations in which PIP components may be more relevant in certain contexts than others. When a variable or a path model has a poor fit, identifying whether it is the theoretical model, the program implementation or evaluation that most needs to be improved can be accomplished by using results from impact evaluations, monitoring, qualitative research, an understanding of program context, and the literature.

Several components of the HFP PIP were unable to be assessed with path analysis because we did not have measured variables or there was inadequate variability to include them in the path models [14]. Gender empowerment was not addressed in the evaluation survey, so this aspect of the intervention could not be assessed. Future evaluations, especially if they include that domain in the PIP, should be designed to assess the extent to which this aspect of the program is well-implemented, as well as to measure any improvements to women’s control of household resources or other important targets of the gender empowerment component.

We did have data on household income related to HFP sales, but the number of households who reported selling their garden or animal products was low, so we were unable to include those variables in the models. Baitadi district is remote and has limited connectivity to formal markets, so it is possible that the AAMA Project operated in a context in which HFP sales were not feasible. However, HFP households may still experience economic benefits from informal markets such as trading, and these potential benefits were not captured in the survey. To capitalize on the potential contributions of increased household income to improved nutrition and health outcomes, future HFP interventions taking place in areas with low connectivity to formal economic markets may need to invest in developing potential markets to see changes in this component of the PIP. As well, assessment methods that capture informal economic activity are needed.

Standardized coefficients allow us to directly compare the strength of various pathways in a path model, or the relative contribution of each intervention component to the outcomes of interest. We find that overall, the program components with the strongest pathways are nutrition education and agricultural inputs. In these path models, agricultural training has a lower standardized coefficient and contributes relatively little to the outcomes of interest. The limited contribution of agricultural training may result from inadequate implementation, prior knowledge on the subject by HFP beneficiaries, or an inability of HFP beneficiaries to put their training into practice. However, we note that the survey included few questions about the extent of the agricultural training, so the scale for agricultural training has a limited range and likely does not adequately reflect the variety of topics that may have been covered or the frequency of trainings. It is possible that measuring the number of trainings that a respondent participated in or the variety of topics to which they were exposed would increase the explanatory strength of agricultural training in the path models without unduly adding to the length or complexity of the survey.

For variables about production practices, the variety of foods produced in the home garden in the past two months had stronger associations in the path model than the volume of foods produced in the home garden in the past two months. In fact, the volume variable was excluded in most of the final models. This may have several explanations, including programmatic issues such as a heavy emphasis on variety of foods produced and not enough focus on volume in the agriculture and nutrition education components, contextual issues such as insufficient land availability, or measurement issues such as inaccurate recall of production or the mass of foods produced being a poor reflection of the overall nutritional value of the foods. These issues can be further explored using qualitative research.

Likewise, the models do not include any variables about animal husbandry practices because no relevant variables fit the models well, and overall there was a low level of animal husbandry reported. To increase animal husbandry to the point that it significantly contributes to the path model, it may be necessary to overcome cultural or economic barriers by improving messaging about animal-source foods or providing additional ongoing technical support for animal husbandry.

Dietary diversity was the strongest dietary consumption variable available in the dataset, and it had a statistically significant but relatively small path coefficient in path models for maternal and child anemia, child diarrhea and maternal night blindness. It was not significant in maternal BMI or child nutritional status path models. In such resource-limited areas, it is possible that individuals are consuming adequate dietary diversity and meal frequency without enough energy or protein intake to support growth. In future studies, estimating energy and protein intake or other variables that reflects the total amounts of food consumed may improve model fit for child nutrition status and maternal weight. Likewise, quantifying specific foods or nutrients such as the frequency of consuming animal-source foods and vitamin A-rich foods or the amount of retinol equivalents consumed is likely to improve the explanatory power of the models for outcomes such as anemia and night blindness.

Household food insecurity had to be excluded from several path models to obtain an adequate fit, and the path coefficients associated with this variable are weak in models that do include it. The literature strongly supports the importance of food security to achieve optimal nutrition and health, so inclusion of this variable in the theoretical model is justified. However, it is possible that without stronger efforts to address poverty, access to land, food storage or other issues affecting the HFP communities, the HFP intervention is unable to improve food security enough to have a meaningful effect on the nutritional and health outcomes of interest. On the other hand, it is possible that measurement issues affect the fit of this variable. The HFIAS tool for measuring food insecurity is a valid and reliable indicator, but food insecurity fluctuates seasonally, so data collected during the endline survey may not accurately reflect the food insecurity experienced over time, and the effects of food insecurity on the outcomes of interest may be cumulative [18]. Finally, while food insecurity does include a domain of quality, it emphasizes issues of quantity. As mentioned above, we did not have a good continuous measure of diet quantity to include in the model, and there were weaknesses in measuring the volume of production variable as well. Food insecurity may have been a poor fit in the path models simply because it addressed a different domain than the other variables that fit in the path models.

These findings offer important insights into the function of HFP programs. In order to apply this information and make changes to improve the path models, the next step is to identify the root of any issues, such as measurement, program fidelity, or context. Impact analysis, qualitative research, a thorough understanding of program context and the literature may complement the path analyses and help program leadership prioritize changes. Furthermore, additional path analyses on other HFP projects can refine the PIP and identify commonalities upon which more general conclusions may be based about the strength of various paths to achieve nutritional and health outcomes or the changes that are needed to improve consistency between the PIP and evaluation findings. Since this is the first time that path analysis has been used to assess an HFP program, it is important to consider how changes in evaluation design or measurement may influence the results of the path analyses before making drastic changes to the implementation strategy.

Path analysis can be used to better understand how a program achieved its effects, but it is not a replacement for impact evaluation. Impact evaluation addresses the question of whether there is a difference in intervention vs. control, while path analysis asks whether the hypothesized model adequately explains the variation in the outcome of interest. For example, we find that the reduced hypothesized models do fit the data for child anemia and stunting in spite of the impact evaluation failing to detect a difference between intervention and control. On the other hand, the impact evaluation does demonstrate a difference between intervention and control communities for maternal anemia and underweight even though the path analysis for these outcomes did not achieve a good fit [15].

There are a few possible interpretations of this finding. In these analyses, we did not include a variable for assignment to intervention or control. Instead, we used scale variables to represent the three components of the HFP program. First, it is possible that the mechanism by which the significant effects were achieved are not reflected in the path model, either because they were not hypothesized in the PIP or they were excluded from the path models because they did not have relevant variables in the evaluation data. Similarly, the model fit could have been compromised because the measurement of path variables was inadequate for this type of analysis even though the baseline-endline evaluation indicated a significant improvement for intervention communities compared to control communities. Specifically, path analysis prefers continuous variables, and the use of binary or scale variables with a limited range may lead to a poor fit.

On the other hand, a good model fit without a corresponding significant difference between intervention and control communities could be attributed to natural variation in the variables used for program components irrespective of intervention assignment. For example, FCHVs throughout Nepal offer varying degrees of nutrition education and other health services in their communities. Stronger education and support services from FCHVs may contribute to higher HAZs even if the HFP intervention did not cause the improved nutrition education. Path analysis is based on covariance among path variables. The path model did not include a variable for intervention assignment, and covariation among model variables may occur without a significant difference between intervention and control communities. This circumstance lends support for the theoretical model but indicates the need for stronger implementation or the ability to address contextual factors to ensure that the predictor variables are adequately influenced by the intervention. For example, if the path analysis indicates a good model fit for child anemia but the impact evaluation did not detect a difference between intervention and control, the model fit may reflect natural variation in the "program component" variables such as nutrition education even if high levels of nutrition education are not due to the intervention.

Olney et al. used qualitative methods to evaluate the PIP for an HFP intervention in Cambodia. She identified weaknesses in implementation quality, such as in the nutrition and health trainings, as well as gaps in translating changes in production practices to changes in consumption [11]. Olney's research is important for qualitatively assessing barriers and contextual limitations that can be addressed to improve program effectiveness. Path analysis can complement this qualitative research and impact evaluations by succinctly and quantitatively demonstrating the extent to which changes in one path variable can be explained by changes in preceding path variables. Clarifying the relationships among variables in a path model furthers our understanding of the mechanisms by which complex interventions operate, which is cited as a key area of research needed for nutrition-sensitive interventions programs [7, 8, 23, 24].

This research applies path analysis an HFP intervention to test the PIP and apply the findings for improving program delivery and evaluation, but it is not without its weaknesses. Data included in these analyses are from the endline program evaluation, which was not designed with path analysis in mind. Not all parts of the PIP were directly measured, and information about the early intervention components had to be recalled several years after they took place. Survey questions designed for impact analysis included non-continuous variables which were less ideal for path analysis. Furthermore, using only endline data means these analyses do not reflect changes over time. While path analysis does assess the mechanisms by which changes in the outcome variables are achieved, the covariation we observe may not be exclusively due to the intervention.

In spite of these limitations, this work makes important contributions to the understanding of integrated interventions like HFP and provides practical suggestions for improving HFP intervention design and evaluation. The AAMA Project used a robust evaluation strategy including a large sample size and high quality data on many variables throughout the PIP as well as potential confounders. To improve future path analyses of HFP programs, we recommend using continuous variables or creating appropriate scales when possible, measuring all components of the PIP including multiple aspects of diet quality, gender empowerment and informal economic effects. Future HFP projects with improved measurement can further assess the strength of the theoretical model.

Furthermore, future analyses could include assessment of effect modification or subset analysis to better understand how the mechanisms of effect might differ in different contexts or for different subsets of the population. Considering contextual factors that influence program uptake and effectiveness in the intervention design and evaluation could strengthen the ability of the program to achieve its stated goals as well as the ability of path analysis models to demonstrate alignment between evaluation data and theoretical models. Finally, these analyses could be conducted in conjunction with detailed economic evaluation to determine the relative value of different program components.

This research offers a unique approach to identifying opportunities for improvement in program implementation and evaluation and clarifying how the program components interact to achieve program results. It provides a basis upon which we can build a stronger understanding of how integrated interventions work.

Chapter 4 Tables and Figures

Figure 8: Program Impact Pathway for HKI's Homestead Food Production Intervention

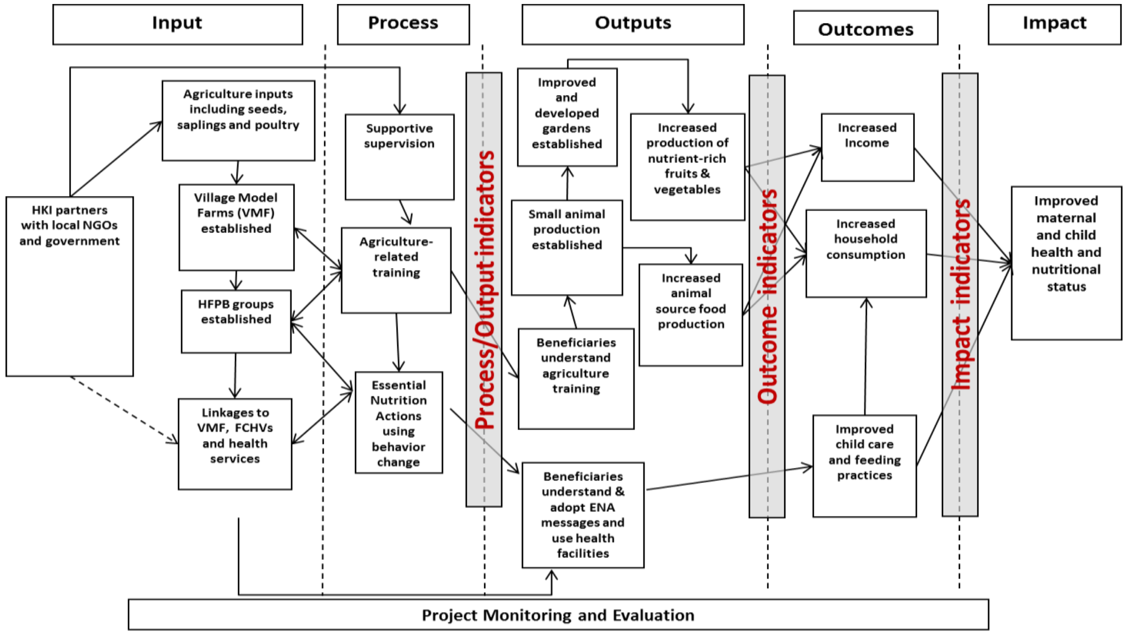
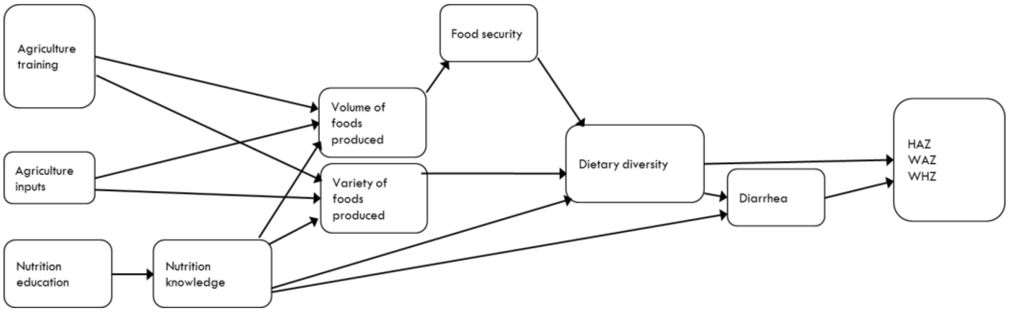


Figure 9: Initial path models: A) full model tested for child nutritional status outcomes. The initial model for child diarrhea reverses the diarrhea and HAZ variables. B) full model tested for child hemoglobin and all maternal outcomes.

A.



B.

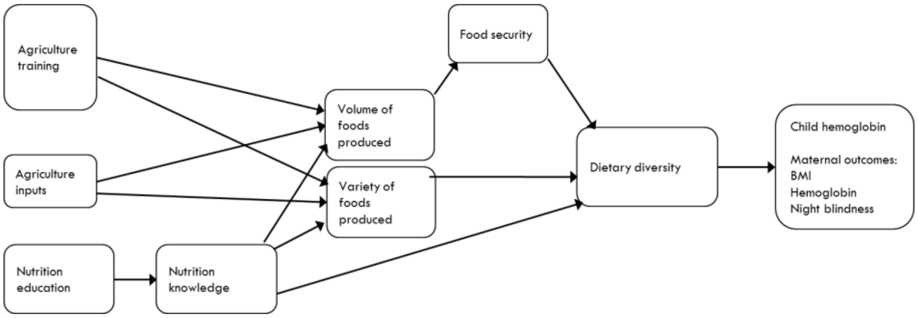


Table 2: Summary statistics for path model variables. Continuous outcome variables are reported with the corresponding prevalence of relevant condition.

Path variables		
Variable (range or unit)	**n**	**Sample mean (SD) or prevalence**
Exogenous (input) variables		
Agricultural training (0-3)	2614	0.65 (0.93)
Agricultural inputs (0-4)	2614	0.71 (0.94)
Child nutrition education scale (0-14)	2614	12.20 (3.05)
Maternal nutrition education scale (0-8)	2614	6.81 (1.97)
Endogenous path variables		
Maternal knowledge of child nutrition scale (0-18)	2614	7.73 (1.89)
Maternal nutrition knowledge scale (0-6)	2614	4.89 (1.21)
Variety of vegetable production, natural log	2266	1.73 (0.52)
Volume of vegetable production (kg), natural log	2211	3.09 (0.83)
Food insecurity (0-27)	2614	4.58 (4.68)
Child dietary diversity (0-8)	2614	3.86 (1.05)
Maternal dietary diversity (0-8)	2614	3.89 (1.32)

Outcome variables and related classification		
Variable (range or unit)	**n**	**Sample mean (SD) or prevalence (%)**
HAZ	2596	-2.21 (1.28)
Prevalence of stunting	*2596*	*59.5%*
WAZ	2613	-1.77 (1.02)
Prevalence of underweight	*2613*	*40.8%*
WHZ	2603	-0.78 (1.03)
Prevalence of wasting	*2603*	*10.1%*
Child hemoglobin (g/dL)	2614	11.20 (1.22)
Child anemia	*2614*	*39.6%*
Child diarrhea (yes/no)	2614	16.6%
Maternal BMI (kg/m^2)	2361	19.84 (2.00)
Low BMI	*2361*	*24.8%*
Maternal hemoglobin (g/dL)	2614	12.49 (1.38)
Maternal anemia	*2614*	*30.2%*
Maternal night blindness (yes/no)	2591	17.8%

*Stunting is defined as HAZ <-2, underweight is WAZ <-2, and wasting is WHZ <-2. Child anemia is defined as hemoglobin <11g/dL, and maternal anima is defined as hemoglobin < 12g/dL after adjusting for altitude and trimester of pregnancy (Sullivan 2008). Low maternal BMI is defined as BMI <18.5 kg/m^2 and excludes pregnant women.

Figure 10: Path model for height-for-age z-score (unstandardized path coefficients).

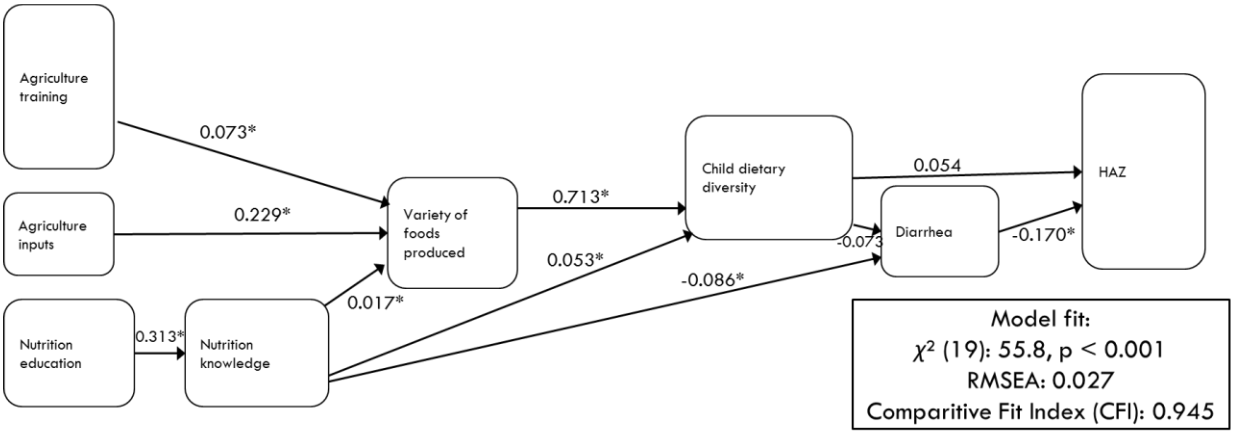


Figure 11: Path model for child hemoglobin, showing unstandardized path coefficients followed by standardized path coefficients.

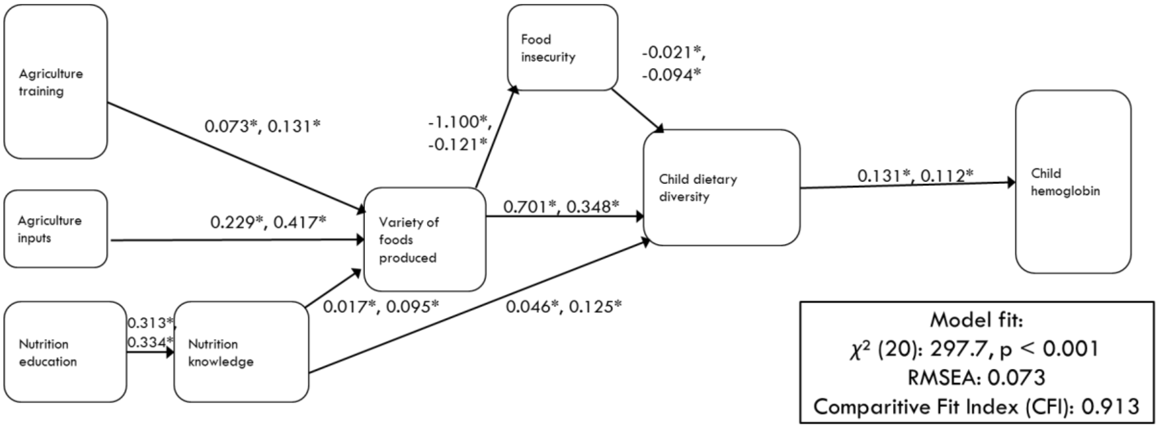


Figure 12: Path model for child diarrhea

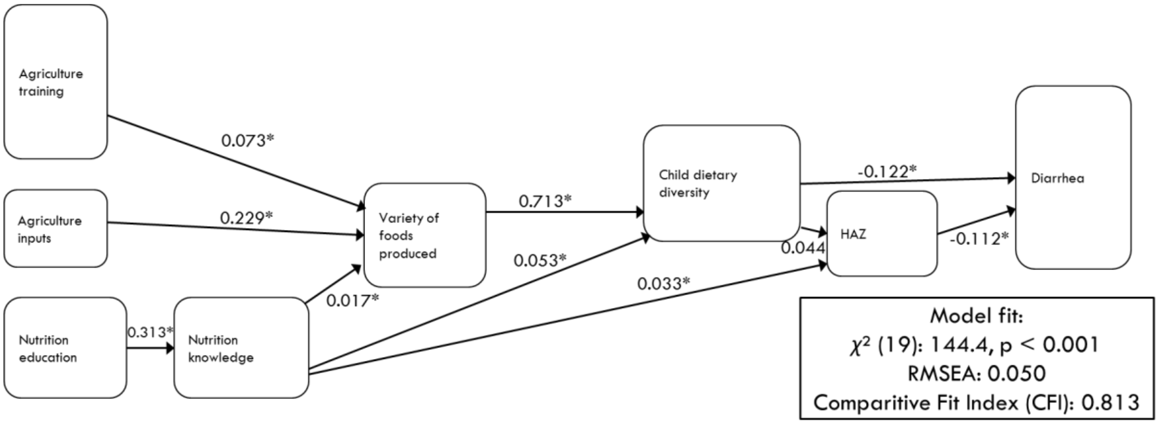


Figure 13: Path model for maternal BMI

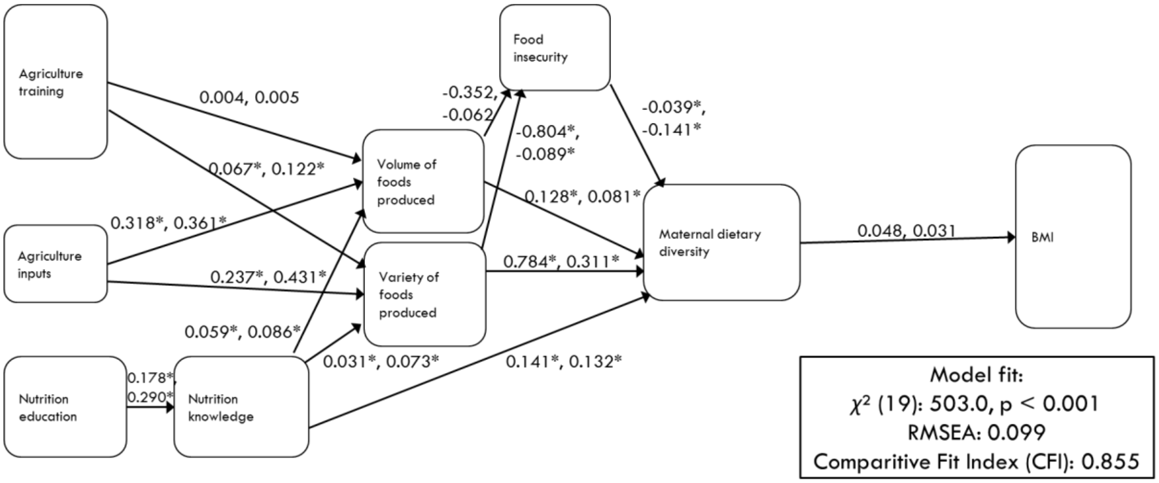


Figure 14: Path model for maternal hemoglobin

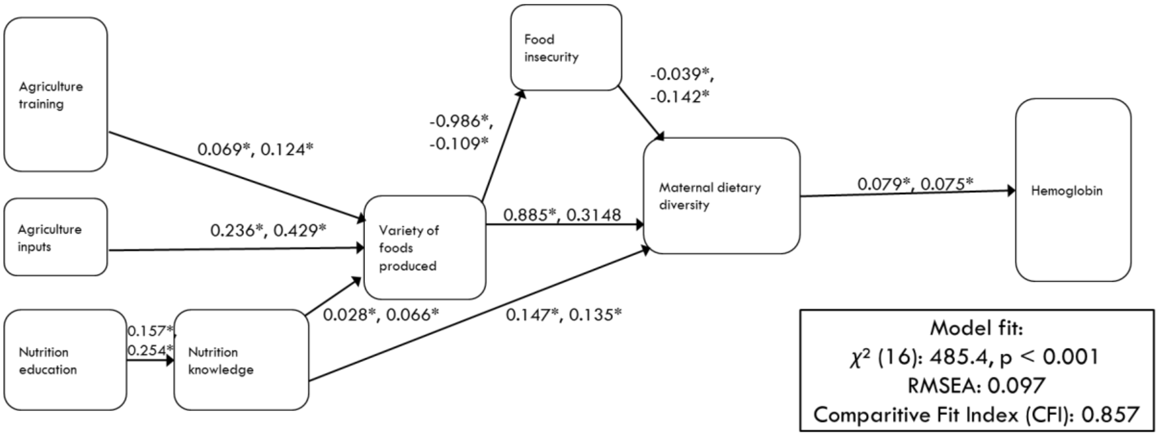


Figure 15: Path model for maternal night blindness

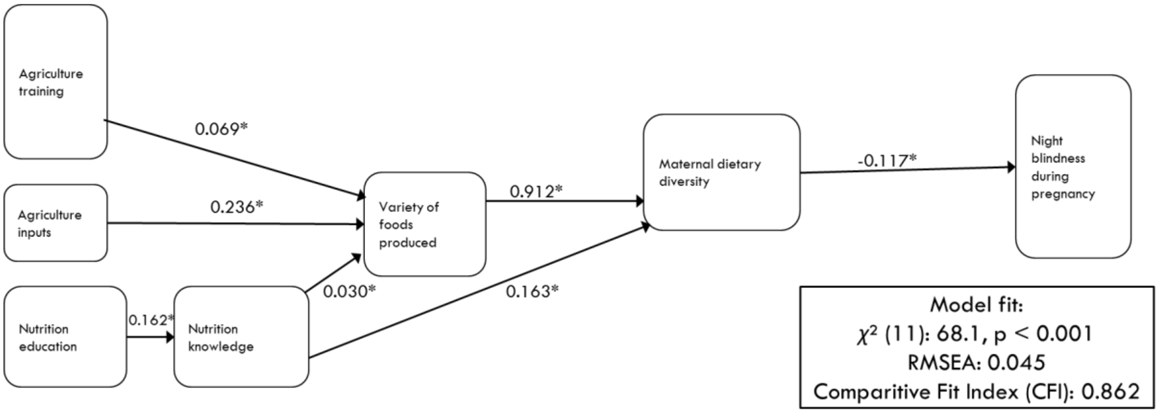


Table 3: Summary of best path model and fit indices for each outcome.

	Best model	(χ^2)[1]	RMSEA[2]	CFI[3]
Child outcomes				
HAZ	Reduced 2	55.8, df=19, p<0.001	0.027	0.945
WAZ	Reduced 2	60.0, df=19, p<0.001	0.029	0.945
WHZ	Reduced 2	60.8, df=19, p<0.001	0.029	0.929
Hemoglobin	Reduced 1	297.7, df=20, p<0.001	0.073	0.913
Diarrhea	Reduced 2	144.4, df=19, p<0.001	0.050	0.813
Maternal outcomes				
BMI	Full maternal	503.0, df=19, p<0.001	0.099	0.855
Anemia	Maternal reduced 1	305.9, df=16, p<0.001	0.084	0.894
Night blindness	Maternal reduced 2	68.1, df=11, p<0.001	0.045	0.862

Models are defined as: Full model includes ag training, ag inputs, nutrition education, nutrition knowledge, volume of production, variety of production, food insecurity, dietary diversity, diarrhea and the outcome. **Reduced 1** includes all variables from full model *except* the volume of production. **Reduced 2** includes all variables from full model *except* (1) volume of production and (2) hfias. **Full maternal model** includes the same variables as the full model except child diarrhea, and it replaces child nutrition knowledge with maternal nutrition knowledge, and child DD with maternal DD. **Maternal reduced 1** includes all variables from full maternal model *except* the volume of production. **Maternal reduced 2** includes all variables from full maternal model *except* (1) volume of production and (2) hfias. Good model fit using χ^2 provides an insignificant result at $\alpha=0.05$. RMSEA <0.01 indicates fair fit, and <0.7 indicates good fit. CFI >0.90 indicates fair fit, and >0.95 indicates good fit.

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CHAPTER 5: Cost-effectiveness of Mama-SASHA: a project to improve health and nutrition through an integrated orange-flesh sweetpotato production and health service delivery model

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Introduction

Nutrition-sensitive programs address the underlying causes of undernutrition by drawing on complementary sectors such as agriculture and health, and recent reviews on maternal and child undernutrition have called for more rigorous evaluation of nutrition-sensitive strategies [1-3]. In particular, the cost-effectiveness of nutrition-sensitive strategies is understudied, partly due to the complexity of integrated, cross-sector interventions and the difficulty in measuring the full scope of relevant benefits [2, 4]. The purpose of this study is to estimate the cost-effectiveness of the Mama-SASHA Project, an integrated agriculture, health, and nutrition intervention in Western Kenya.

Nutrition-specific strategies such as supplementation and fortification have proven effectiveness and cost-effectiveness to improve status for many micronutrients, but the coverage, long-term feasibility and sustainability can be limited in low income countries. Experts recommend that complementary strategies are needed to address these limitations and further improve nutrient status and health [5-7]. In areas with widespread multiple micronutrient deficiencies, as well as food insecurity and energy insufficiency, more comprehensive approaches are needed. Nutrition-sensitive strategies, especially those that integrate agriculture and health services, can be viewed as long-term strategies that complement supplementation and fortification strategies. They are especially well suited to address multiple micronutrient deficiencies, energy insufficiency and food insecurity, as well as strengthening health service delivery and creating opportunities for household income generation.

Orange-flesh sweetpotatoes (OFSP) address vitamin A deficiency as well as energy insufficiency and food insecurity because of their high energy and β-carotene content. The efficacy of OFSP to improve vitamin A status has recently been established by research in several sub-Saharan African countries, but evidence of effectiveness and cost-effectiveness of various intervention strategies at the programmatic level is lacking [8-10].

The goal of the Mama-SASHA project was to improve the health status of pregnant women and the nutritional status of children up to two years through an integrated OFSP and health service-delivery strategy. The health component worked through an existing health program (formerly APHIA II and then APHIAplus) in Bungoma and Busia counties of Western Kenya. The project integrated agriculture and nutrition interventions into antenatal health care services to maximize the potential benefits of OFSP on the health status of mothers and children less than 2 years of age.

Here, we assess cost-effectiveness from a societal perspective by estimating the Disability-Adjusted Life Years (DALYs) averted for vitamin A-related functional outcomes as well as child growth and maternal and child iron-deficiency anemia, and other health outcomes to demonstrate the wide variety of benefits that may be attributable to integrated, nutrition-sensitive strategies. Due to the complexity of their design, it is often difficult to assess the cost-effectiveness of integrated, nutrition-sensitive strategies in a manner comparable to nutrition-specific strategies such as micronutrient supplementation and fortification programs. However, in an era focused on evidence-based, cost-effective and sustainable interventions, estimating the cost-effectiveness of integrated, nutrition-sensitive strategies is important to inform their use in improving nutrition and health.

Description of the intervention

The Sweetpotato Action for Security and Health in Africa (SASHA) was a multi-partner project led by the International Potato Center (known by its Spanish acronym, CIP - Centro Internacional de la Papa) and designed to improve the food security and livelihoods of poor families in sub-Saharan Africa by exploiting the untapped potential of sweetpotato. The Mama-SASHA project, one of several initiatives of the SASHA project, was implemented by PATH, the International Potato Center (CIP), and the Kenyan Agricultural Research Institute (KARI). Mama-SASHA integrates agriculture and public health interventions to achieve sustained improvements in health. Working with the established USAID/Kenya AIDS, Population and Health Integrated Assistance Program (APHIA II and APHIAplus) public health services, the Mama-SASHA program aimed to strengthen maternal and child nutrition services, with an emphasis on improving vitamin A intake through OFSP production and consumption in the Busia and Bungoma Districts of Western Kenya. The Mama-SASHA project complemented the existing health services by providing training on vitamin A rich foods, nutritional benefits of OFSP, and maternal and child nutrition to facility-based health workers and community health workers (CHW) in the project districts. In the Mama-SASHA intervention, agricultural activities and community-based peer support were added through a free voucher system to obtain OFSP vines and pregnant women's clubs PWCs), respectively. Vouchers for OFSP planting materials were provided to women during antenatal care (ANC) visits and the first post-natal care (PNC) visit. Women were eligible to receive one voucher per visit for 100 cuttings of each OFSP variety, Kabode and Vita. The OFSP vine vouchers were redeemed through vine multipliers (VMs) established by the project, and women received training to grow the OFSP. Access to OFSP was expected to improve ANC visit attendance, vitamin A intake, micronutrient status and health outcomes in mothers and children involved in the program. A detailed description of the intervention design and implementation is available from conference proceedings [11].

Methods

This cost-effectiveness analysis adopts a societal perspective, which means that it considers the health and well-being of society as a whole, as compared to focusing on a specific sector or stakeholder. To do this, the analysis incorporates the opportunity costs of all resources used to deliver health and agriculture services to beneficiaries, while capturing both the health and economic benefits associated with participation in the intervention.

Costs

An activity-based micro-costing approach was used to estimate the financial and economic costs incurred to implement the three-year program (2011-2013). We used an expenditure approach to capture the financial costs associated with planning, training, materials development and delivery of community, health and agriculture support services. We reviewed project documents, collected expense reports, and interviewed key organizational representatives from the implementing partners CIP, PATH, and two Kenyan non-governmental organizations (NGOs)—the Appropriate Rural Development Agriculture

Programme (ARDAP) and the Community Research in Environment and Development Initiatives (CREADIS). We focused on the timing and frequency of activities and personnel time allocated to specific Mama-SASHA activities, both to define activity and input codes and to clarify data entry and analysis. Key inputs include labor, supplies, transport, vehicles and other capital equipment, and overhead [12]. Expense reports were transcribed into an excel template. All data were entered by organization and assigned input and activity codes. Each line item was coded as a start-up or recurrent cost, and separate codes were designated for whether or not the line item was a research cost or not, to facilitate exclusion of the latter.

For the Mama-SASHA project, the main difference between the financial and economic cost analyses is that the economic analyses include the value of all personnel time by collaborating partners and beneficiary time, whether the project paid for it or not. Thus, to estimate the economic costs, we added the opportunity cost of time for shared personnel from the Ministries of Health and Agriculture (MOH and MOA), volunteer labor from the community, and the beneficiary labor for participating in the program. In order to estimate these costs, we conducted focus group discussions (FGDs) and semi-structured interviews (SSIs) to obtain information on time allocation from key implementing agents and beneficiaries. ANC nurses' time included training for Mama-SASHA, additional time spent with patients at ANC visits due to Mama-SASHA, project coordination and integration, nutrition counseling, and community outreach. Community health extension worker (CHEW) time included training for Mama-SASHA, community outreach, project coordination and integration, and attending PWC meetings. Agricultural extension officers supported training, visiting VMs and beneficiaries, project coordination and integration, community sensitization, field and food preparation demonstrations and community outreach. VM time included training for Mama-SASHA, project coordination and integration, planting and maintaining OFSP plots, meeting with pregnant women or their representatives to redeem vouchers for OFSP, demonstrations, and community outreach. CHW volunteer time included participating in training, community outreach to recruit beneficiaries, hosting PWCs and conducting home visits, attending monthly feedback meetings and delivering health and nutrition talks at the health facility. Beneficiary time included ANC visits, redeeming vouchers, planting and maintaining OFSP plots, and attending PWC meetings.

Time use data were validated with information from operational research and project monitoring data [13]. For salaried employees in health and agriculture, we estimated the value of time based on the average annual salaries plus allowances. The average salaries were USD $12,473 for ANC nurses, USD $8,377 for CHEWs, and USD $6,847 for AEOs. For CHWs, VMs, and pregnant women beneficiaries, we used the average agricultural daily wage rate as reported in SSIs of 100 Kenyan shillings (USD $1.19) per day. Costs were reported in local Kenyan currency and converted into 2013 USD using an exchange rate of 84 KES/USD [14]. All data were entered and analyzed using Microsoft Excel (Microsoft 2013).

We estimate the incremental costs of establishing an integrated agriculture and health intervention, building on existing health and agriculture capacity and infrastructure for the relevant project components. For example, for the health and community activities, we estimated the incremental financial costs to the existing ANC and PNC services, as well as to community based activities, where APHIA II and APHIAplus had already established cadres of CHWs. For the new components that fell outside the purview of either the MOH or the MOA, we included the NGO costs for managing the receipt and redemption of vouchers, as well as initiating and supervising agricultural activities for establishing vine multiplication of new varieties of OFSP.

Health outcomes

The primary health outcomes of interest that were measured for the Mama-SASHA project include vitamin A deficiency, child anthropometry, and diarrheal disease. The Mama-SASHA project was a cluster-randomized study which was evaluated through cross-sectional baseline (March-April 2011) and endline (March-April 2014) surveys of > 2700 mother child pairs (BL-EL) and a nested cohort study (COVA), which collected data from 384 mother-child pairs from early/mid-pregnancy through 9 months postpartum January 2012 through June 2014. These evaluation strategies were complemented with monthly program monitoring and operational research conducted April to August 2012 [13].

Eight divisions across the Bungoma and Busia Districts in Western Kenya were chosen by the program for participation, with two large divisions and two smaller divisions chosen per district and randomized for intervention or control. For the BL-EL evaluation, households were selected using stratified random sampling from project and control villages. BL-EL surveys include questions about agricultural practices, diet, OFSP consumption, anthropometry, and child vitamin A status and health. The COVA study also measured biological indicators of anemia and vitamin A status, including hemoglobin and serum retinol binding protein (RBP), respectively.

Table 4 shows the prevalence and proportion of cases averted data for all outcomes included in these analyses. Baseline survey findings were used to estimate the prevalences of stunting, wasting, and child diarrhea [15]. The prevalence of maternal anemia is based on the unadjusted prevalence of anemia in control areas in the COVA study at nine months postpartum [16]. The prevalence of child anemia was not captured at baseline but was reported for Western Kenya by Suchdev et al. in 2012 [17].

Preliminary, unadjusted difference-in-difference results from the BL-EL evaluation for Mama-SASHA are used to estimate the cases averted for stunting (child), wasting (child), and diarrhea (child) [16]. The proportion of cases averted for maternal and child anemia are estimated from the COVA study by comparing intervention and control at nine months postpartum.

In addition to the directly measured outcomes, we use the literature to estimate prevalences and proportion of cases averted for sequelae of vitamin A deficiency that include night blindness (mother and child), corneal scarring (child), blindness (child), measles (child), malaria (child), and mortality (mother and child). Prevalence estimates are based on the published literature, including DHS, WHO and MMWR reports. The prevalence of corneal scarring and blindness are based on WHO-reported ratios between those outcomes and the prevalence of night blindness [18].

The proportion of cases averted for vitamin A functional outcomes is based on a review and meta-analysis for the effectiveness of vitamin A supplementation [19]. The proportion of malaria cases averted is based on a randomized controlled trial which found that vitamin A supplementation lowered malaria morbidity by 30% in children <5 years old [20]. We assume the same efficacy of OFSP as VAS based on comparability of the average daily dose of retinol activity equivalents (RAEs) between the two strategies[†] .

[†] VAS capsule contains 200,000 IU of pre-formed retinol, or 60,000 retinol equivalents (REs), which equates to approximately 333 RE/day over 6 months. OFSP efficacy studies indicates that they provide between 250 to 425 RAE/day, which is equivalent to 500-850 REs per day, a higher daily dose than the average daily REs received through VAS [9, 10].

Economic benefits

Economic benefits captured in this study primarily fall into two categories: value of OFSP production for vine multipliers and beneficiaries, and treatment costs averted.

We estimated vine multiplier income from sale of OFSP vines and OFSP roots. The value of vouchers redeemed for vines was estimated using monitoring data, and private sales of OFSP roots were estimated from SSIs with five of the 14 VMs that participated in the project. We did not estimate the value of OFSP roots produced by VM for personal consumption.

To capture the value of OFSP to beneficiaries, we used monitoring data to estimate the average plot size (hectares). This was multiplied by the average yield (8 tonnes per hectare), average value of OFSP roots (20,000 Kenyan shillings per tonne), and number of women who redeemed vouchers.

We estimated treatment costs averted for two conditions which had data on treatment cost per case available in the literature: diarrhea and malaria. For each condition, the treatment cost per case was multiplied by the number of cases averted, as calculated for our DALY estimates (see below) to obtain a total treatment cost averted per condition. The average treatment cost for diarrhea in the Bungoma region of Western Kenya is USD $1.96 per case [21]. The average treatment cost for uncomplicated malaria in Kenya is USD $8.68 per case [22].

DALYs averted and incremental cost-effectiveness ratio

Cost-effectiveness analyses traditionally assess the costs necessary to achieve a change in one specific outcome of interest [23], such as cases of stunting averted through a child feeding program or cases of disease averted due to vaccination. For many interventions, such as micronutrient supplementation and fortification, this may be appropriate because the interventions are designed with one primary outcome of interest. However, integrated nutrition-sensitive strategies are designed to meet several nutrition and other desired outcomes, and therefore have multiple inter-related outcomes of interest. As such, conducting traditional cost-effectiveness analyses based on a single outcome indicator is likely to underestimate the effects of these interventions.

The DALY is a standard metric that convert morbidity and mortality into a single measure of utility [23]. Any year of life lost due to early death is equivalent to one DALY. Morbidity conditions are ascribed disability weights that represent the severity of the disability, with a higher weight reflecting greater disability. In this way, early death and disease or disability conditions can be accounted for in a single measure. We use a standard 3% discount rate and the following formula to estimate annual DALYs averted for each outcome of interest associated with the Mama-SASHA project [24].

$$-\left[\frac{DCe^{-\beta a}}{(\beta+r)^{2}}\left[e^{-(\beta+r)(L)}\big(1+(\beta+r)(L+a)\big)-\big(1+(\beta+r)a\big)\right]\right]{}^{\ddagger}$$

Because the intervention was hypothesized to have multiple nutrition and health benefits, DALYs were calculated from a whole program perspective. Table 4 contains DALY input information. The assumed population size is 1535, which is the average annual number of women who received vouchers at ANC visits based on Mama-SASHA monitoring data. Age of onset is assumed to be 1 year for children and 19.7 years for pregnant women, which is the average age of first birth in Western Kenya [25].

[‡] D=disability weight; a=age of onset; L= duration of disability; C and B are constants associated with age-weighting; and r=discount rate.

Disability weights are based on those reported in the WHO's Global Burden of Disease 2004 report, or for VAD functional outcomes, those proposed by Harvest Plus [26]. Duration of disability (in years) for VAD functional outcomes is based on those proposed by Harvest Plus [26]. For outcomes that persist throughout the life course, life expectancy is determined using a model life table based on life expectancies in Japan [24]. Other duration of disability estimates are based on the literature, when available. We assume a ten day duration of diarrhea per episodes and three episodes per year, for a total of 30 days per year [27]. For malaria, we assume a 5.1 day average duration per episode and one episode per year [28]. We assume that the effects of stunting and anemia persist throughout the life course [29, 30].

We calculate the incremental cost-effectiveness ratio (ICER) for the Mama-SASHA project by dividing the net incremental economic annual cost by net gain in health benefits, measured as the annual DALYs averted. To determine whether the Mama-SASHA project was cost-effective, we use the WHO threshold s based on GDP per capita [31]. An intervention is considered very cost effective if the cost per DALY averted is less the GDP per capita and cost effective if it is less than three times the GDP per capita. Kenya's GDP per capita was USD $994 in 2013 [32].

Sensitivity analysis

We conducted multiple variable sensitivity and scenario analyses on key parameters using Excel 2013 (Microsoft 2013) and the @risk add-in, version 6 (Palisade Corporation 2014), which uses Monte Carlo simulations to model many possible outcomes and produce a probability distribution function to represent the uncertainty in model estimates. Costs were varied by 25% and 50%. Likewise, the baseline prevalence and the proportion of cases averted were varied by 25% and 50% for each health outcome. These two input variables determine the total number of cases averted for each outcome of interest. We also varied several other factors in the calculations which have an effect on the total DALYs averted and the cost per DALY averted. The discount rate was varied between 1% and 5%. We ran the model using Kenyan, instead of Japanese, life expectancies from 2012 [33]. Likewise, we changed our assumptions about the lifelong effects of stunting and child anemia, assuming that the effects of each condition only persist through age 5.

Results

Economic costs and benefits

The total economic cost of the Mama-SASHA project was USD $572,756. Table 5 summarizes the financial costs, value of shared and volunteer labor (including beneficiaries), and the total economic costs by activity for the full three-year project. The value of shared and volunteer labor accounts for 11.3% of the total economic costs. The value of beneficiary time is included under the activity "improve OFSP knowledge and practices."

The economic benefit captured in this analysis is valued at USD $135,990 for the full three year project (Table 6). The value of OFSP root sales for VMs is USD $12,063, and the value of OFSP roots produced in beneficiary plots was USD $119,287. There was an economic benefit for VM and beneficiary participation because their increased value from consuming or selling the OFSP was greater than the value of their time used to participate in the project and in labor activities for producing OFSP. Total treatment costs averted through Mama-SASHA during the three year implementation were estimated at USD $72 for diarrhea and USD $4,569 for malaria.

Overall, the net economic cost of the intervention was USD $436,766, for an average annual cost of USD $145,589.

DALYs averted and ICER

The Mama-SASHA project averted 72.25 DALYs annually, for a total of 216.75 DALYS over the full three-year project. Table 7 shows the total cases and DALYs averted for each outcome assessed. Stunting and anemia, not VAD outcomes, contribute the most DALYs averted.

Table 8 summarizes the base case average annual net economic costs and ICER for the Mama-SASHA project. The base case cost per DALY averted was USD $2,015 and is considered cost-effective as it is less than three times the GDP per capita for Kenya in 2013.

Multiple variable sensitivity and scenario analyses

Multiple variable sensitivity analysis indicated that the estimates are quite robust to variation, and a summary of findings are available in Table 9. When varying costs, baseline prevalences of each condition, and the proportion of cases averted for each condition by 25%, the highest ICER, or worst-case scenario, is USD $2,562, which is still within the WHO threshold for cost-effectiveness. The lowest ICER, or best-case scenario when varying those factors by 25% is USD $1,297. Varying those factors by 50%, the highest ICER is USD $3,563, which is outside the WHO threshold for cost-effectiveness, and the lowest-cost scenario is USD $811. Varying the discount rate from 1% to 5% leads to an ICER range of USD $1,212 to USD $2,641, all within the WHO threshold for cost-effectiveness. Assuming a Kenyan life expectancy increases the ICER to USD $1,924, and assuming a shorter duration of disability for child anemia and stunting increases the ICER to USD $2,599, both of which are within the WHO threshold.

As demonstrated in the Tornado diagram, variation in discount rate and economic costs have the most influence on ICER, followed by the proportion of anemia averted for pregnant women and the duration of disability for child anemia (Figure 16).

Discussion

This study is one of the first to estimate DALYs averted for an integrated, nutrition-sensitive intervention and one of few studies of its kind to include volunteer and beneficiary time in economic cost estimates. With an ICER of USD $2,015 per DALY averted, the Mama-SASHA project is considered cost-effective according to WHO criteria for cost-effectiveness. Strengths of this study include robust economic data collection, rigorous evaluation design, and reasonable assumptions for DALY estimates. The results are robust to variation with 25% variability in key variables and relaxing key assumptions about life expectancy and duration of disability. In spite of the strengths of this study, and the robustness of the cost per DALY in sensitivity analyses, these estimates should be interpreted with caution due to the numerous assumptions upon which they were based, the use of preliminary, unadjusted estimates for effectiveness of the Mama-SASHA intervention, and the uncertainties around many of the model variables that may over- or underestimate the benefits of the program. For example, the large reduction in stunting may not be entirely attributable to the Mama-SASHA project, and further investigation is underway to explore this finding.

There are many likely benefits of the program that we failed to capture in this analysis due to the difficulty in estimating the full range of benefits for an integrated, nutrition-sensitive intervention. For example, disability weights are estimated for actual morbidity and mortality outcomes, but not for risk factors of disease, such as most nutritional deficiencies. For functional outcomes that are linked with a specific nutrient deficiency, such as xerophthalmia with vitamin A deficiency, we are able to capture the morbidity and mortality averted due to reductions in that deficiency. However, vitamin A deficiency is associated with infections and other conditions that are not fully reflected in the outcomes included in our estimates, and undernutrition is an underlying factor in 45% of all child deaths [34]. As an underlying factor, morbidity and deaths are not attributed directly to nutritional deficiencies and counted in DALY estimates.

One limitation of summing the DALYs averted for multiple outcomes associated with the Mama-SASHA project is that we assume that the outcomes are independent. In reality, the outcomes are interrelated, and this assumption may lead to overestimation of DALYs averted. On the other hand, there are many ways in which DALYs may be underestimated in these analyses. Due to the integrated nature of the intervention and the role of undernutrition as an underlying risk factor for poor health, it is likely that the program led to other health benefits for mothers and children not captured in these analyses. As well, benefits of the Mama-SASHA project are likely to extend beyond the targeted mothers and children due to improved training for health and agriculture professionals and improved health of other household members. In fact, operational research identified additional benefits of the Mama-SASHA project that could not be fully quantified or monetized for the analyses presented here. Additional benefits identified during the operational research are described in Box 1 and include nutrition education, food security, stamina for other household members, and improved services at ANC facilities [13]. Furthermore, future economic benefits are likely to accrue through averting long-term impacts of early stunting and anemia on intellectual capacity, adult work productivity and chronic disease [29, 35-38]. Finally, if the intervention is sustainable or if impacts are long-lasting while costs are primarily upfront, that could shift the perspective on overall cost-effectiveness.

An advantage of measuring DALYs associated with the Mama-SASHA project is that it lends itself to comparability with other nutrition-specific and nutrition-sensitive interventions. These comparisons must be done with caution due to the limitations described above as well as other methodological differences in estimating the cost-effectiveness of other intervention models. The evidence base for effectiveness and cost-effectiveness for many nutrition-specific interventions is developed using carefully controlled and intensively implemented randomized-controlled trials (efficacy studies), so the reported effectiveness and cost-effectiveness may be based on idealistic conditions rather than realistic scaled-up programs [39]. Often, program effectiveness is reduced in the "real world" by problems of implementation, coverage and compliance [40, 41]. For example, fortification of foods with iron and other micronutrients often contributes to significant improvements in micronutrient status and health outcomes, and it can be very cost-effective. However, the availability of fortified foods is limited in many rural areas, and many young children do not consume enough of the fortified foods to receive the full benefit, meaning those who need it most are least likely to benefit [5, 42, 43]. Overall, the evidence for cost-effectiveness of micronutrient interventions varies widely and is influenced by many factors including the country context, delivery system, and costing methodology [44]. When comparing nutrition-sensitive strategies like Mama-SASHA to nutrition-specific strategies, it is important to consider the context and method of estimating cost-effectiveness.

While this research demonstrates that the Mama-SASHA project is cost-effective according to WHO criteria, we cannot claim that the intervention is affordable or the best investment of limited resources based exclusively on these findings. In fact, some argue that using thresholds to determine cost-effectiveness is arbitrary because policy decisions are complex and reflect the values and priorities of policy makers in addition to economic realities [45]. Implementing all interventions that meet the WHO criteria for cost-effectiveness is likely impossible in a resource-constrained environment. Decisions about which interventions will be maintained or scaled up must be informed by careful consideration of societal and funding priorities, who has the capacity to implement the projects, the coverage and cost-effectiveness of alternative strategies, and how the intervention complements or might be integrated with other strategies. Integrated, multi-sectoral, nutrition-sensitive interventions have great potential for improving nutrition and other outcomes, but it is necessary to effectively communicate shared goals, processes and results across sectors to maintain engagement from all stakeholders [46].

Further research should address gaps in the data and expand on this approach to better capture the full scope of benefits from integrated agriculture and nutrition interventions. Additional research on the long-term effects of the intervention may shed light on whether the investments made during the Mama-SASHA project implementation will continue to accrue benefits for the community over time. As well, future research may consider other intervention models to determine whether other nutrition-sensitive strategies will be more effective or cost-effective.

Chapter 5 Tables and Figures

Table 4: DALY input values, source data and assumptions for all project-related outcomes included in DALY estimates.

Outcome	**Target group**	**Prevalence**	**Proportion of cases averted**	**Disability weight**	**Age of onset**	**Duration of disability**
Directly measured prevalence and cases averted						
Stunting	Children <5	25.1 [c]	0.398406[c]	0.002[k]	1	80.5[o]
Wasting	Children <5	5.9 [c]	0.40678 [c]	0.053[k]	N/A	1
Diarrhea	Children <5	24.9[c]	0.032129 [c]	0.105[k]	N/A	0.082191[m]
ID Anemia	Children <5	30[e]	0.072183[c]	0.011[k]	1	80.5[p]
	Pregnant women	12.8[c]	0.552381[c]	0.011[k]	19.7[l]	29.3 [p]
Projected prevalence and cases averted						
Night blindness	Children <5	2[a]	0.68[g]	0.05[j]	N/A	1 [j]
	Pregnant women	10 [a]	0.2244 [g]	0.1 [j]	N/A	0.416667 [j]
Corneal scarring	Children <5	0.1 [a]	0.5 [g]	0.2 [j]	1 [j]	80.5 [j]
Blindness	Children <5	0.02 [a]	0.6 [g]	0.5 [j]	1 [j]	80.5 [j]
Measles	Children <5	0.000059[b]	0.15 [g]	0.35 [j]	N/A	0.027397 [j]
Malaria	Children <5	38.1	0.3[h]	0.211[k]	N/A	0.0139726[n]
Mortality	Children <5	0.052[f]	0.23[g]	1[k]	1	80.5
	Pregnant women	0.00488 [f]	0.05	1[k]	19.7 [l]	63

[a]WHO 2009 and VMNIS 2014, [b]MMWR 2012, [c]Grant 2015, [d]Kenya Malaria indicator survey 2010, [e] Suchdev 2012, [f]Kenya National Bureau of Statistics 2010, [g]Mayo-Wilson 2012, [h] Shankar 1999. [i] [j] Stein 2005, [k]WHO 2004, [l] Kenya DHS 2008-09. [m]IRIN 2010, [n]Snow 2013, [o]Hoddinott 2013, [p] Lozoff 2013.

Table 5: Financial costs, value of labor and total economic costs (and percentage of total cost) by program activity and category of actor for 3-year project (2011-2013), 2013 USD.

Program Activity	**Total Financial Costs (%)**	**Shared and volunteer labor costs (%)**	**Total Economic Costs (2010-2013) (%)**
Planning/Microplanning	$16,881 (3.0)		$16,881 (3.0)
Training	$73,545 (12.8)	$10,376 (1.8)	$83,921 (14.6)
Development of materials	$12,442 (2.2)		$12,442 (2.2)
Awareness raising/sensitization	$2,399 (0.4)	$1,894 (0.3)	$4,293 (0.8)
Establish continuous supply of vines	$44,885 (7.8)	$4,344 (0.8)	$49,230 (8.6)
Improve OFSP knowledge and practices	$30,750 (5.4)	$16,747 (2.9)	$36,080 (8.3)
Adequate and continuous supply of roots	$35,867 (6.3)	$3,928 (0.7)	$39,795 (7.0)
Health implementation	$25,555 (4.5)	$11,698 (2.0)	$37,253 (6.5)
Integration	$136,222 (23.8)	$15,959 (2.8)	$152,181 (26.6)
Capital investment	$12,231 (2.1)		$12,231 (2.1)
Admin and overhead	$117,030 (20.4)		$117,030 (20.4)
Total	**$507,809 (88.7)**	**$64,947 (11.3)**	**$572,756**

The value of beneficiary time is included under the activity "improve OFSP knowledge and practices."

Table 6: Total economic benefits attributed to Mama SAHSA (2011-2013), 2013 USD.

Economic benefit of Mama-SASHA			**Total value**
OFSP production	**Value per person** (2011-2013)	**Number of people**	
Vine multiplier profit from sale of OFSP	$861.6	14	$12,063
Value of OFSP produced by beneficiaries	$26.7	4464	$119,287
Treatment costs averted	**Cost per case**	**Cases averted** (2011-2013)	
Diarrhea	$1.96	36.9	$72
Malaria, uncomplicated	$8.68	526.5	$4,569
Total			**$135,990**

Table 7: Annual cases and DALYs averted for all outcomes included in total DALY estimates.

Outcome	**Target group**	**Cases averted**	**DALYs averted**
ID Anemia	Pregnant women	108.5	32.56
ID Anemia	Children <5	33.2	12.18
Stunting	Children <5	153.5	10.23
Mortality	Children <5	0.2	6.12
Corneal scarring	Children <5	0.8	5.11
Blindness	Children <5	0.2	3.07
Night blindness	Pregnant women	34.4	2.08
Wasting	Children <5	36.8	0.44
Night blindness	Children <5	20.9	0.24
Mortality	Pregnant women	0.0	0.13
Malaria	Children <5	175.5	0.08
Diarrhea	Children <5	12.3	0.02
Measles	Children <5	0.0	0.00
TOTAL			**72.25**

Table 8: Summary of annual effectiveness, annual economic costs and benefits, and cost-effectiveness ratio, 2013 USD.

Effectiveness (annual)	
DALYs averted	72.25
Costs (annual)	
Total economic costs	$190,919
Economic benefits	$45,330
Net cost	$145,589
Incremental Cost-effectiveness ratio (ICER)	
Cost per DALY averted	$2,015
For comparison, *GDP/capita*	*$994*

Box 1. Non-quantified benefits attributed to Mama-SASHA project during qualitative operational research.

Nutrition education

- Increased mothers' confidence in knowing how to care for baby.

Food security

- The time taken for OFSP to mature was half that of common sweetpotatoes.
- Increased availability of nutritious foods for all household members.

Energy for household members

- Mothers and children are more energetic.
- Partners report greater strength to work.

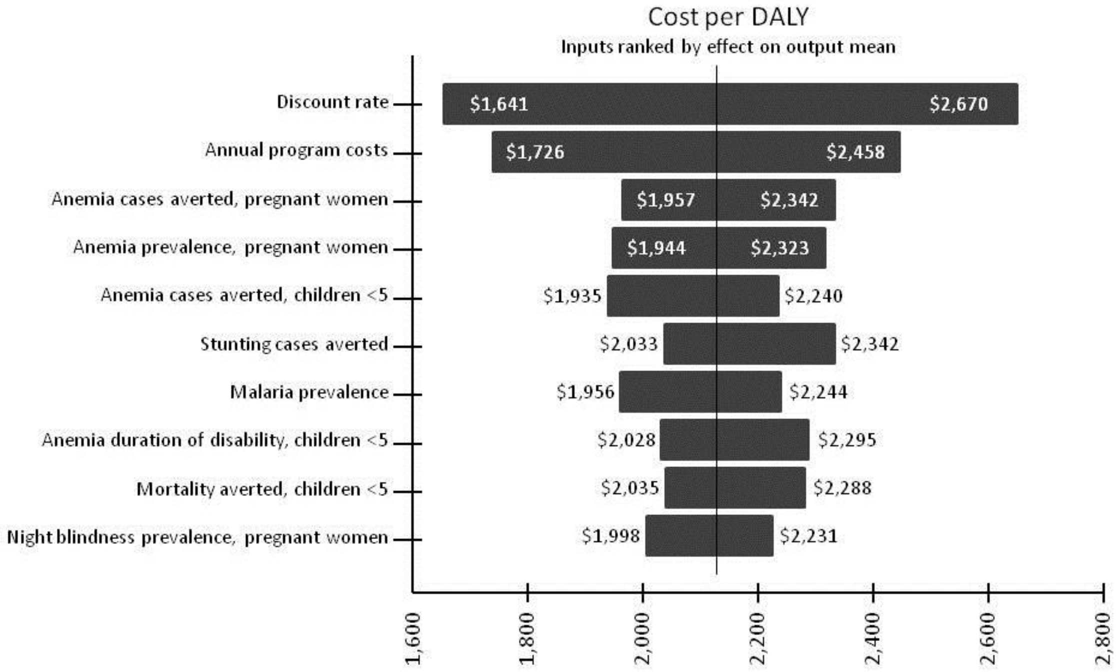
Health facility benefits

- Increased ANC attendance reported by ANC nurses.
- Improved training for health workers.

Table 9: ICER Sensitivity analysis for CEA and DALYs (parameter values – base case, high and low, etc), 2013 USD.

Condition	**ICER**
Base case	$2,015
Multiple input variable sensitivity analyses	
25% variation ↑ costs, ↓ baseline prevalence and ↓ proportion of cases averted	$2,562
25% variation ↓ costs, ↑ baseline prevalence and ↑ proportion of cases averted	$1,297
50% variation ↑ costs, ↓ baseline prevalence and ↓ proportion of cases averted	$3,563
50% variation ↓ costs, ↑ baseline prevalence and ↑ proportion of cases averted	$811
Single variable sensitivity analyses	
Discount rate 1%	$1,212
Discount rate 5%	$2,641
Assuming Kenyan life expectancy	$1,924
Assuming that effects of childhood anemia and stunting only persist through age 5	$2,599

Figure 16: Tornado diagram for ICER sensitivity analyses.



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Chapter 6: Summary and Conclusions

Summary of Findings

The primary objective of this dissertation was to expand the analytical tools available for evaluating integrated, nutrition-sensitive strategies to improve maternal and child nutrition and health. Previous research has shown mixed results regarding the impact of integrated, nutrition-sensitive interventions, and reviews indicate that methodological weaknesses and inadequate evaluation tools have limited the extent to which program evaluations can identify how these complex strategies achieve their effects or capture the full scope of benefits they may achieve [1-4]. Due to differences in project goals and intervention design, the evaluation tools that are established for nutrition-specific interventions do not adequately assess the contributions of integrated, nutrition-sensitive interventions due to their variety and complexity [5].

I focused on two nutrition-sensitive interventions, the AAMA Project in Nepal and the Mama-SASHA Project in Kenya, and applied analytical approaches that are relatively new or underutilized in this field to improve the evidence-base about the role of nutrition-sensitive programs. Using the Program Impact Pathway for the AAMA Project and other theoretical models showing how household food production interventions are believed to achieve their effects, my co-authors and I developed testable path models for several nutrition and health outcomes of interest. We applied path analysis to the endline evaluation data from the AAMA Project to test how well the models fit the data and assess the strength of pathways within the models. We found that simplified versions of the models for child outcomes fit the data well, but the models for maternal outcomes were not a good fit even after we respecified the models. These analyses are among the first to use path analysis to identify the causal pathways of complex, nutrition-sensitive interventions. From these analyses, we were able to assess how well the theoretical model is supported by program evaluation data, identify agricultural inputs and nutrition education as the strongest program components in the effect pathways, and identify several aspects of program implementation and evaluation that may improve model fit for future projects.

In addition to assessing the effect pathways of nutrition-sensitive strategies, I sought to estimate the cost-effectiveness of a nutrition-sensitive intervention. My co-authors and I estimated the net economic cost of the Mama-SASHA program from a societal perspective, which means that we consider the health and well-being of society as a whole, as compared to focusing on a specific sector, such as health, or a single stakeholder, such as the government. We accomplished this by capturing the program financial costs of implementation and opportunity costs of labor including volunteers and beneficiaries as well as the economic benefits including the value of OFSP produced and the treatment costs averted for relevant illnesses. Next, using a combination of evaluation findings and the literature, we estimated the DALYs averted attributable to Mama-SASHA. Finally, we estimated the ICER and concluded that the Mama-SASHA project is cost effective based on WHO criteria comparing the ICER to the Kenyan GDP per capita. This is the first study we know of to assess the cost-effectiveness of a nutrition-sensitive strategy using a range of outcomes to comprehensively reflect the variety of benefits such strategies are designed to achieve.

Together, this research demonstrates new approaches for evaluating nutrition-sensitive programs. These findings suggest that, in addition to improving the rigor of evaluation designs, other assessment tools can be used to contribute new knowledge about integrated, nutrition-sensitive strategies and potentially improve intervention designs.

Improving understanding of the mechanisms of impact and the cost-effectiveness of nutrition-sensitive interventions will help project leadership refine these strategies, give researchers valuable new information to identify the contributions of nutrition-sensitive strategies to improving maternal and child nutrition, and provide policy makers more accurate information on strategy effectiveness for purposes of prioritization and decision-making.

Limitations

The research in this dissertation is not without limitations. First, each type of assessment, path analysis and cost-effectiveness analysis, was only conducted on one program. Due to the wide variety in program design and programmatic context, similar analyses should be completed for other nutrition-sensitive programs before making general conclusions about nutrition-sensitive strategies.

For the path analysis, in spite of a robust evaluation design, we were unable to assess the full PIP for the AAMA Project due to data limitations. For example, gender empowerment and household income generated through selling HFP products. Other concepts in the models may have also been affected by inadequate measurement, as we learned that the types of variables needed for path analysis may be more specific than the type of measurement that is adequate for impact evaluation. In particular, continuous or scale variables with a wide range of variability are preferred in path analysis.

Next, the path analyses did not assess for effect modification or assess how the program input variables may have interacted with each other. The model defined three distinct input variables, but these aspects of the program are not so clearly distinct during program implementation.

A final limitation for the path analysis is that we are unable to clearly attribute issues with model fit to implementation weaknesses, programmatic context, or measurement issues. Additional research is needed to rule out or improve measurement issues, assess intervention fidelity, and understand how the context may impact model fit.

For the cost-effectiveness analysis, the DALY estimates were based on numerous assumptions when measured data were not available, and directly measured outcomes are based on preliminary, unadjusted findings, so there is uncertainty among many model variables that may cause an over- or underestimation of the program benefits. However, inputs for the DALY calculations were carefully researched and based on the best available evidence from the literature, and the estimates were robust to variation in sensitivity analysis.

Finally, due to difficulties in capturing and quantifying all relevant benefits of nutrition-sensitive programs, it is likely that we underestimate the benefits. Some benefits cannot be included in DALY calculations because they are not directly linked with morbidity and mortality outcomes and therefore do not have disability weights associated with them. For example, we know that subclinical vitamin A deficiency is an underlying factor in many health conditions beyond the clinical outcomes captured in our analyses [6-8]. As well, our estimates do not capture additional benefits, such as social benefits or those that may accrue due to improved training for health professionals and or the nutrition education offered for mothers.

Strengths and Innovations

The AAMA Project and the Mama-SASHA Project were both designed for robust evaluation, which was essential for supporting these analytical approaches. These analyses rely on robust evaluation design and high quality data, so strengthening evaluation quality for nutrition-sensitive programs will be necessary to support this type of research.

This research expands on theory-driven program planning and evaluation to assess the extent to which hypothesized models of nutrition-sensitive programs fit with the program evaluation data. We identified many opportunities for improvement related to evaluation and measurement as well as aspects of the intervention that may need additional attention to improve effectiveness and alignment with the program theory.

As well, our research is one of the first to assess the cost-effectiveness of an integrated program designed to affect multiple outcomes and capture a wide range of benefits. By using DALYs to assess cost-effectiveness, our estimates can be compared with other strategies as well as established thresholds to determine whether an intervention is cost-effective [9].

Conclusions and Future Research

These analyses demonstrate how path analysis and economic evaluation can be applied to further our understanding of the potential impact of nutrition-sensitive strategies. My co-authors and I demonstrate that HKI's AAMA Project operates through hypothesized mechanisms to improve child nutrition and that the Mama-SASHA Project is a cost-effective intervention when you capture a range of relevant benefits.

There are several additional opportunities for improving research about nutrition-sensitive programs. First, validation and wider adoption of technologies to improve field measurement of nutrition and health outcomes will improve evaluation capacity. For example, utilizing techniques to accurately and inexpensively measure low levels of vitamin A would allow us to assess the impact pathways for interventions that aim to improve vitamin A status without relying on clinical symptoms like night blindness that primarily appear only in cases of extreme deficiency. Bechir et al. report findings from a nutritional assessment of nomadic pastoralists in Chad using portable retinol and beta-carotene assessment methods, but they indicate that the methodology needs to be validated. Expanding the use of tools that are validated, inexpensive and easy to implement can improve assessment of nutrition-specific and nutrition-sensitive interventions [10].

Assessing the extent to which the effects of nutrition-sensitive programs are sustained after program intervention activities have ended is another important frontier for better understanding the potential contribution of such strategies. As well, improving our understanding of the long-term impacts, which may differ from the immediate effects of the programs, will contribute to a better overall understanding of nutrition-sensitive strategies. The research on sustainability of nutrition-sensitive strategies is limited, largely because funding is infrequently allocated to collect data after program implementation has been completed and endline data has been collected. Bushamuka et al. assessed the sustainability of an HFP program in Bangladesh three years after implementation ended. They found that the prevalence of year-round gardening, among former program participants was 50%, compared with only 15% in a comparison group and 78% among active program participants [11].

Based on this limited evidence, it appears that after direct program support is withdrawn, many households maintain improved gardening practices and continue to produce food year round. Households tend to sell more of their crops after program support has ended, but they use some of that income to purchase other foods for household consumption, including nutritious foods such as fish, pulses and meat. Also, approximately 15% of the income generated as a result of household food production is spent on healthcare, which may complement the improved dietary intakes to improve overall nutritional outcomes [11].

A few other household food production programs that have assessed sustainability suggest long-lasting effects on diet but were unable to document improvements in nutritional status and health during long-term follow-up. Their findings indicate that differences in the program design may affect nutritional and economic outcomes differently, and that the long-term benefits may occur in different outcomes compared to the short-term benefits (economic versus nutritional) [12-14]. Additional research about the long terms impacts of nutrition-sensitive strategies may also enhance path analyses by helping refine the theoretical models and improve economic analyses by identifying long-term benefits that are not included in the analyses presented here.

Another important area of future research is to better assess the impact of modifying factors on nutrition-sensitive programs, such as health status, household socioeconomic status, asses to market, sanitation practices, as well as climate and agronomic factors. In the path analyses described here, we included many relevant confounders, but we did not assess for moderating variables. Household factors such as socioeconomic status and land ownership, and village-level factors such as quality of health or agriculture education and agro-ecological conditions may have an influence on intervention effectiveness by affecting how easily and fully the targeted households can participate. For example, socioeconomic status and land ownership may influence the extent to which households can participate in the intervention because families without access to land or the means to purchase agricultural inputs with have more difficulty maintaining the desired garden.

Many village level factors may also influence program effectiveness. Villages that are very spread out may find it more difficult for women to regularly attend the nutrition and agriculture education meetings. Likewise, even when spacing within a village makes it easy to attend meetings, an ineffective village health worker may influence program effectiveness at the village level. As well, latitude, altitude, rainfall, and terrain all influence growing conditions at a village or regional level.

Nutrition-sensitive strategies may be more context specific compared to nutrition-specific strategies. For example, assuming adequate coverage, vitamin A supplementation is likely to have similar impacts in many settings, especially areas with high prevalence of vitamin A deficiency. However, a nutrition-sensitive strategy that integrates agriculture or health services may need to be more tailored to unique settings in which the impact pathways and cost-effectiveness are likely to vary. Gaining a more thorough understanding of modifying factors for nutrition-sensitive programs could help adapt interventions for optimal impact and is likely to influence how well a program's measured effects correspond with the hypothesized mechanisms of the programs effects. Better identifying and addressing modifying factors for nutrition-sensitive programs may also help refine and target interventions to improve cost-effectiveness.

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