Global Food Security 17 (2018) 128–153

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Nutrition-sensitive agriculture: What have we learned so far?

Marie T. Ruel[a,*], Agnes R. Quisumbing[a], Mysbah Balagamwala[b]

[a] International Food Policy Research Institute (IFPRI), USA
[b] Oxford Policy Management, Oxford, UK

ARTICLE INFO

Keywords:
Agriculture
Diets
Impact evaluation
Nutrition
Nutrition-sensitive programs
Women's empowerment

ABSTRACT

A growing number of governments, donor agencies, and development organizations are committed to supporting nutrition-sensitive agriculture (NSA) to achieve their development goals. While consensus exists on pathways through which agriculture may influence nutrition-related outcomes, empirical evidence on agriculture's contribution to nutrition and how it can be enhanced is still weak. This paper reviews recent empirical evidence (since 2014), including findings from impact evaluations of a variety of NSA programs using experimental designs as well as observational studies that document linkages between agriculture, women's empowerment, and nutrition linkages. The paper summarizes existing knowledge regarding impacts, but also pathways, mechanisms, and contextual factors that affect where and how agriculture may improve nutrition outcomes. The paper concludes with reflections on implications for agricultural programs, policies, and investments, and highlights future research priorities.

1. Introduction

A growing number of governments, donor agencies, and development organizations are committed to supporting nutrition-sensitive agriculture to achieve their development goals. Nevertheless, nutrition-specific interventions alone, even if implemented at scale, will not meet global targets for improving nutrition (Bhutta et al., 2013; WHO, 2014). Other sectors need to contribute as well, and agriculture has strong potential due to the many ways in which it can influence the underlying determinants of nutrition outcomes (Black et al., 2013), including through improving global food availability and access and through enhancing household food security, dietary quality, income, and women's empowerment. Globally, the need for agriculture to support better nutrition and health has been recognized and was reflected in the discussions leading up to the United Nations' 2030 Agenda for Sustainable Development (United Nations, 2017), and regionally, it is reflected in the growing number of initiatives to support countries in integrating nutrition interventions into their agricultural investment plans, as illustrated by the Comprehensive Africa Agriculture Development Programme investment plans (Rampa and van Seters, 2013). Countries like Nigeria and Ethiopia, for example, have recently developed nutrition-sensitive agricultural plans, a clear manifestation of the greater political priority being given to improving the nutritional impact of investments in the agricultural sector.

Making agriculture more nutrition-sensitive (See Box 1 for definitions of nutrition-specific and nutrition-sensitive interventions or programs), however, requires a new way of thinking, planning, implementing, and partnering, as well as the active engagement of a variety of stakeholders from multiple sectors. It also requires identifying critical entry points where nutrition goals can be incorporated into agro-food systems (Jaenicke and Virchow, 2013). Some of the initial steps undertaken to bring the relevant stakeholders and sectors together include designing and agreeing on conceptual frameworks that identify the multiple pathways by which agriculture can impact nutrition. This topic has been the subject of an extensive body of work including the development of several conceptual frameworks that highlight the dynamic and multifaceted linkages between agriculture, health, and nutrition (Headey et al., 2012; Herforth and Harris, 2014; IFPRI, 2011; Jaenicke and Virchow, 2013; Kadiyala et al., 2014; Pinstrup-Andersen, 2012; World Bank, 2007). Ruel and Alderman (2013) identified six pathways through which agricultural interventions can impact nutrition: (1) *food access* from own-production; (2) *income* from the sale of commodities produced; (3) *food prices* from changes in supply and demand; (4) *women's social status and empowerment* through increased access to and control over resources; (5) *women's time* through participation in agriculture, which can be either positive or negative for their own nutrition and that of their children; and (6) *women's health and nutrition* through engagement in agriculture, which also can have either positive or negative impacts, depending on exposure to toxic agents and the balance between energy intake and expenditure. The characterization of the pathways by which agriculture and nutrition are linked and of the unequivocal mediating role of

* Correspondence to: Poverty, Health and Nutrition Division, International Food Policy Research Institute (IFPRI), 1201 I Street, NW, Washington, DC 20005, USA.
E-mail address: m.ruel@cgiar.org (M.T. Ruel).

https://doi.org/10.1016/j.gfs.2018.01.002
Received 21 September 2017; Received in revised form 2 January 2018; Accepted 3 January 2018

Box 1
Definitions of nutrition-specific and nutrition-sensitive interventions or programs.

Nutrition-specific interventions or programs are those that address the *immediate determinants* of fetal and child nutrition and development—adequate food and nutrient intake, feeding, caregiving and parenting practices, and low burden of infectious diseases.
Nutrition-sensitive interventions or programs are those that address the *underlying determinants* of fetal and child nutrition and development— food security; adequate caregiving resources at the maternal, household and community levels; and access to health services and a safe and hygienic environment—and incorporate specific nutrition goals and actions
Source: Ruel and Alderman (2013).

women's status and empowerment in these linkages has been instrumental in stimulating the development of new initiatives and investments to leverage agriculture to improve nutrition.

Although conceptual frameworks and hypothesized impact pathways are a critically important first step, efforts to support agriculture so that it delivers on nutrition need to be grounded in evidence. A number of reviews of evidence have been published in the past two decades (see, for example, Berti et al., 2004; DFID, 2014; Fiorella et al., 2016; Leroy et al., 2008; Masset et al., 2012; Pandey et al., 2016; Randolph et al., 2007; Ruel, 2001; Webb-Girard et al., 2012; Webb and Kennedy, 2014), and all of them agree that evidence on what and how agriculture can contribute to nutrition is extremely scant. The reviews cover a range of agricultural programs including homestead food production systems; home vegetable gardens; biofortified crops; small animals; livestock; fisheries; dairy; and irrigation projects. In spite of differences in the sets of studies reviewed and the methods and nutrition indicators used in the original studies, the findings from these reviews are surprisingly consistent. Overall, they find evidence that agricultural development programs that promote production diversity, micronutrient-rich crops (including biofortified crops), dairy, or small animal rearing can improve the production and consumption of targeted commodities, and some evidence that such improvements lead to increases in dietary diversity at the household and sometimes the maternal and child level. The reviews report a few cases, especially with biofortified vitamin A–rich sweet potatoes, in which increased production and consumption led to improvements in vitamin A status and health in young children, but little evidence overall of impacts on child stunting, underweight, or wasting; in addition, very few studies have looked at impacts on maternal nutritional status. The inclusion of a strong behavior change communication (BCC) intervention to promote optimal diets and child feeding practices, and a focus on improving women's status and empowerment through agriculture, are consistently reported as key to enhancing the potential impacts of agriculture on diets and other nutrition outcomes. Another main conclusion of the reviews is that most studies so far have had serious methodological limitations that may hamper their ability to demonstrate impacts, especially on anthropometric outcomes. The most common weaknesses include poor evaluation designs, inadequate sample sizes, short duration, and the wrong age group targeted and analyzed for achieving and demonstrating impacts on child anthropometry (Leroy et al., 2016; Masset et al., 2012; Ruel and Alderman, 2013; Webb-Girard et al., 2012).

The links between agriculture and nutrition have also been explored using data at the farm level from observational studies. Motivated by the agricultural household model (Sing et al., 1986), these studies show that when markets are imperfect, the separability between production and consumption decisions breaks down, and farm production can have a direct effect on consumption, and consequently, nutrition. This literature is reviewed in the editors' introduction to a special issue of the Journal of Development Studies on farm-level linkages between agriculture and nutrition (Carletto et al., 2015).

The proliferation of reviews, reports, and special journal issues (for example, Carletto et al., 2015; Strange et al., 2013a, 2013b) focused on the linkages between agriculture, food systems, and nutrition in recent years testifies to renewed interest in the topic and calls for investments in closing the evidence gap and moving toward more gender- and nutrition-sensitive agriculture and food systems (FAO, 2013; Global Panel on Agriculture and Food Systems for Nutrition, 2016, 2014; Pinstrup-Andersen, 2010). Indeed, a 2012 inventory of agriculture-nutrition research identified 151 planned or ongoing projects being undertaken by 49 institutions throughout the world (Hawkes et al., 2012).

This paper reviews findings from new empirical research published from 2014 onwards that may fill some of the knowledge gaps identified in previous reviews regarding agriculture's contribution to nutrition. It reviews impact results from new studies that were not included in previous reviews and that used experimental or quasi-experimental approaches to evaluate different types of nutrition-sensitive agricultural programs (NSAP), including biofortification, homestead food production systems, livestock transfer programs, value chains for nutritious foods, and irrigation programs. In addition, and by contrast with previous reviews, our review also includes new observational studies that use cross-sectional data to document associations between agricultural practice and nutrition outcomes. These studies do not provide the same level of causal inference as experimental studies, but they are useful in generating hypotheses and helping shed light on key design elements for the success of future NSAP. For both impact evaluations and observational studies, we review information available regarding pathways, mechanisms, and contextual factors that affect where and how agriculture may improve nutrition outcomes. The paper does not review the literature on the topic of food systems and nutrition, which, although critically important, is beyond the scope of this more focused review. Also, the paper addresses issues of maternal and child undernutrition but does not cover the emerging nutrition transition and related problems of overweight, obesity, and noncommunicable diseases. Other excellent reviews and conceptual papers cover these important topics (see, for example FAO, 2013; Gillespie and van den Bold, 2017; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Gómez et al., 2013; IFPRI, 2016; Pinstrup-Andersen, 2011, 2010; Popkin, 2014). The paper concludes with reflections on implications for agricultural programs and investments, and suggests priorities for future research.

2. Methods

This paper updates key reviews of the nutrition impacts of agricultural programs with new empirical evidence published from 2014 onwards, using the definition from Ruel and Alderman (2013), which states that programs and interventions are nutrition-sensitive if they (1) have a clearly stated objective of improving nutrition and (2) incorporate specific nutrition interventions to achieve this goal (See Box 1). We started with the Ruel and Alderman (2013) review, which summarized key findings from reviews of agriculture and nutrition programs published before 2013 (see online Supplementary material, web appendices Table 3 (Ruel and Alderman, 2013)) and consulted new evidence reviews as they became available (DFID, 2014; Domènech, 2015; Fiorella et al., 2016; Pandey et al., 2016; Webb and Kennedy, 2014). These evidence reviews helped formulate the search strategy and identify the types of agricultural programs to include in the review.

Table 1
Search topics and terms used in the review of nutrition-sensitive agricultural programs.

Topic	Search terms
Nutrition	"nutrition* outcome", "nutrition* status" "diet* diversity""diet* diversification" micronutrient* anthropom*
Biofortification	biofortif* OR bio-fortif* OR "harvestplus" OR "harvest plus"
Homestead production	"homestead production" "homestead food production" "home garden" "homestead garden" "home gardening"
Livestock and dairy	"livestock* programs" "livestock* production" "livestock* ownership" "dairy* production""dairy* program"
Agriculture Extension	"agricultur* extension"
Irrigation	Irrigation AND impact
Aquaculture	Aquaculture OR fisheries or fishpond
Value chains	("value chain" OR value-chain) AND (nutrition OR diet)
Nutrition-sensitive agriculture	("nutrition-sensitive" OR "nutrition sensitive") AND agriculture

The programs were classified into the following categories: biofortification, homestead food production systems and home gardening, aquaculture, livestock and dairy programs, agriculture extension, nutrition-sensitive value chains, and irrigation studies. All these programs focused on promoting production diversity and increasing access to nutritious foods such as biofortified staple crops, nutrient-rich vegetables or fruits, and animal source foods. Our search also included all observational studies published from 2014 onwards that looked at associations between agriculture production and nutrition outcomes (with the exception of one study published in 2012 (Bhagowalia et al., 2012) that we included because it provides unique information on the linkages between income, agricultural production conditions and nutrition outcomes).

Table 1 lists the search terms used to identify articles for the review. We used a search term for nutrition AND a term for each type of program as listed above. The search term "OR" was used for those words that have multiple stylizations (for example, biofortification OR bio-fortification). A search was also carried out for the terms "nutrition-sensitive" AND "agriculture".

The following databases and online repositories were used for our search which was carried out in January 2017: Scopus, Web of Knowledge, PubMed, and IFPRI Ebrary. The search was restricted to articles published in English since the Ruel and Alderman (2013) review. The number of articles identified in the first stage are reported in Table 2, by topic and database (duplicates are included).

The total number of articles found in this round of search was **8166** (see Fig. 1). Using a reference management software (EndNote), **1502** duplicates were removed and the remaining **6664** articles were screened via their titles and abstracts using the inclusion/exclusion criteria listed in Table 3. This resulted in **38** articles. Using collective knowledge from the team, and after contacting key agriculture, nutrition, and health experts, we added **12** articles. A total of **50** articles were screened using the full-text of the article; **6** were removed in this round of screening because, after reading carefully, we found that they did not meet the eligibility criteria (for example, they were either descriptive, conceptual or review studies, impact evaluations without a baseline survey and/or a valid control or comparison group, or feasibility studies); and **44** were included in the review (see Fig. 1). Our review was limited to peer-reviewed journal articles, published abstracts, and working papers available on line.

While we followed a systematic search process for this review, the review is not a systematic review because we did not strictly follow standard guidelines such as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009).

3. Results

Table 4 and 5 present the list and key characteristics of the studies included in this review, by type of agricultural intervention. The first set of studies (n = 16) includes impact evaluations that used mostly experimental or quasi-experimental designs to document the impacts of agricultural interventions on nutrition outcomes and, where available, information on impact pathways and mechanisms through which impact was achieved (see Table 4 for the main characteristics of studies in this set). The second set of studies includes 28 papers that aimed to document associations between different types of agricultural systems or practices and nutrition outcomes (see Table 5 for the characteristics of studies in this set). Although we could have included studies covering agricultural investments in a broader range of activities related to technological or institutional innovation, either on-farm or postharvest, or those related to input or output markets, we did not find any evaluations of such investments that looked at their impacts on nutrition or described attempts to make them nutrition-sensitive.

3.1. Evidence from impact evaluations

This section reviews new evidence from impact evaluations focused on NSAP. Our search identified three papers on biofortification, 8 on homestead food production and home gardening programs, three on livestock programs, one on a nutrition-sensitive (dairy) value chain, and one on an irrigation program. All programs included approaches to promote production diversity and increase access to— and consumption of — nutrient-rich foods such as vitamin A-rich orange flesh sweet potato, fruit and vegetables, eggs, and dairy.

3.1.1. Biofortification

Biofortification, the breeding of staple crops that are richer in essential micronutrients than traditional varieties, has been shown to be a feasible and cost-effective approach to addressing deficiencies in vitamin A, iron, and zinc (Bouis and Saltzman, 2017).

Table 2
Number of articles identified, by type of agricultural program and database.

Data base	Types of agricultural programs							
	Biofortification	Homestead Food Production System (HFP)	Irrigation	Agricultural extension	Livestock and dairy	Aquaculture	Value chain	Nutrition-sensitive agriculture
Scopus	1624	189	1284	84	678	2437	206	223
Pubmed	216	7	11	21	34	274	13	26
Web of Knowledge	353	27	129	11	101	71	36	47
IFPRI Ebrary[a]	15	10	5	3	6	2	2	21

[a] IFPRI Ebrary is a repository of IFPRI publications.

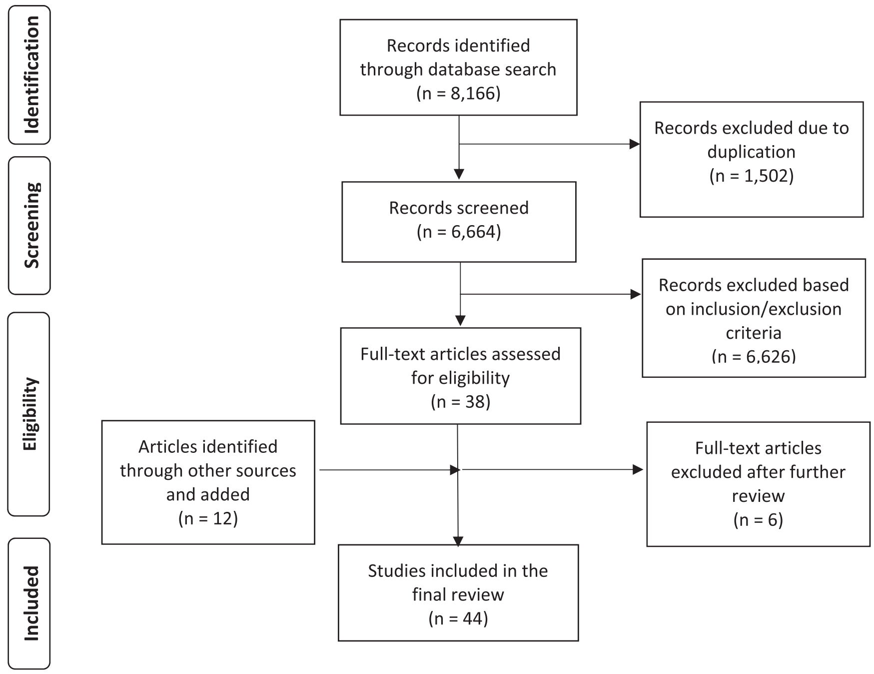

Fig. 1. Search strategy flow diagram (adapted from Moher et al., 2009).

Evidence of the effectiveness of biofortification has been documented for orange-fleshed sweet potato (OSP) in Mozambique and Uganda, showing impacts on vitamin A intake among mothers and young children in both countries and on child vitamin A status in Uganda (Hotz et al., 2012a, 2012b). Three new papers on this two-country study were published since 2014, adding specificity to previous results. The first paper showed that the magnitude of impacts on children's vitamin A intake and dietary diversity increased with the level of farmers' participation in the program (de Brauw et al., 2015a). A second paper used causal mediation analysis and showed that maternal knowledge of the nutrition messages communicated by the program had a small effect on adoption of biofortified OSP in both Mozambique and Uganda, and on vitamin A intake in Uganda (de Brauw et al., 2015b). Additional analyses also documented that the program had large impacts on reducing the prevalence and duration of diarrhea in children younger than five years, with reductions of 11.4% points (ppts) among children younger than five years and 18.9 ppts among children younger than three years (Jones and de Brauw, 2015). These results support the well-known role of vitamin A in protecting immunity. Effectiveness studies of other biofortified crops with other micronutrients are underway, including iron-biofortified beans in Guatemala, iron-biofortified pearl millet in India, and zinc-biofortified wheat in Pakistan (HarvestPlus, 2017).

3.1.2. Homestead food production types of programs

We reviewed 8 papers reporting on findings from impact evaluations of homestead food production programs (See Table 4 for a summary of the studies). Results from the first cluster-randomized

Table 3
Inclusion and exclusion criteria used for review of nutrition-sensitive agriculture programs.

Criterion	Include	Exclude
Publication type	Peer reviewed articles, published working papers and abstracts, and online reports	Unpublished abstracts, reports, and briefs
Publication years	2014–	
Language	English	
Study type	Any quantitative, qualitative, or mixed-methods design	• Literature reviews • Feasibility studies
Agriculture	• Biofortification • Homestead production / home gardening • Irrigation • Value chains • Livestock • Agricultural extension	• Food systems • Food safety
Nutrition	• Anthropometry (WHZ, HAZ, WAZ, stunting, wasting, underweight, MUAC, weight, height, birth weight) • Infant and young child feeding knowledge and practices (breastfeeding; complementary feeding, including minimum meal frequency, minimum dietary diversity, and minimum adequate diet) • Anemia/hemoglobin • Diet / dietary diversity • Macronutrient intake (protein, fats, carbohydrates) • Micronutrient intake (vitamin A, iodine, iron, zinc, folic acid) • Micronutrient status (vitamin A, iron, zinc, folic acid)	• Health outcomes not directly related to nutrition (such as delivery complications) • Nutrition information/awareness • Food security
Location	Low- and middle-income countries	High-income countries
Other		Animal/plant outcomes

Abbreviations: HAZ = height-for-age z-score; MUAC = mid-upper arm circumference; WAZ = weight-for-age z-score; WHZ = weight-for-height z-score.

Table 4
Summary of impact evaluation studies on nutrition-sensitive agriculture programs reviewed.

Author(s), year, study location[a]	Evaluation design	Intervention	Outcomes measured	Findings	Conclusions
Biofortification					
de Brauw, Eozenou, and Moursi 2015a, **Mozambique**	• Longitudinal CRCT • Sample of 36 village-level farmer groups randomly assigned to control and 2 treatment arms, the latter receiving nutrition and extension training for 1 year and 3 years, respectively	*Nutrition:* Trainings on vitamin A and OSP *Agriculture:* Distribution and sale of vines with optional participation in extension meetings (differing intensities of participation) *Marketing:* Actions to increase visibility of and demand for OSP among traders	Children 0–3 years old at baseline: • Vitamin A intake • MMDA • DD measured using 24-hour recall	• Significant impact of program on child vitamin A intake, MMDA, and DD • Effect on vitamin A and DD significantly higher for HHs receiving extension services and participating in nutrition training, compared with those receiving only vines	More intense participation in an integrated biofortification program led to larger impacts on child vitamin A intake and DD.
de Brauw et al. 2015b, **Mozambique and Uganda**	• Longitudinal RCT • Mozambique sample: as above • Uganda sample: 84 farmer groups randomly assigned to a control and 2 treatment arms, the latter receiving nutrition and extension training for 1 year and 2 years, respectively	As above	*Mozambique:* • Vitamin A intake of children 0–3 years old at baseline • Adoption of OSP (keeping vines for following season) *Uganda:* • Children's vitamin A intake and serum retinol • household adoption of OSP (growing OSP at endline) *Both:* • Maternal knowledge of vitamin A and OSP • share of OSP in cultivation	• Impacts in both countries on knowledge of vitamin A, adoption of OSP, and vitamin A intake in treatment HHs; no significant difference between treatment groups with different intensities (duration) of treatment • Average treatment effect larger in Uganda than in Mozambique • Causal mediation analysis shows maternal nutrition knowledge had a small effect on adoption and on vitamin A intake in Uganda only	Integrated biofortification program had an impact on OSP adoption rates and Vitamin A intake in both countries; less intense programs worked just as well as the more intense program.
Jones and de Brauw 2015, **Mozambique**	As above (Mozambique)	As above	• Incidence and duration of diarrhea and other health conditions in last 14 days for children less than 5 years old	• Prevalence of diarrhea reduced in treatment villages • Duration of diarrhea less in children eating OSP • Effect higher for children with educated mothers	Providing OSP reduced the incidence and duration of diarrhea among children.
Homestead food production and other integrated agriculture and nutrition programs					
Olney et al. 2015, **Burkina Faso**	• CRCT • 55 villages randomly assigned to a control and 2 treatment groups, the latter receiving EHFP interventions plus BCC (1) delivered by OWL, (2) delivered by HCM • Children 3–12 months old at baseline (control: $n = 577$; group 1: $n = 443$; group 2: $n = 432$) • Surveys 2 years apart	*Nutrition:* BCC training on ENAs by either an OWL or an HCM *Agriculture:* distribution of inputs (seeds, saplings, chicks, small gardening tools) and training *Gender:* Direct transfer of agricultural inputs to women; formation of women-led VMFs and women's groups	Children's • Anthropometry (weight, height/length) • Hb/anemia • Diarrhea prevalence • HDD • Maternal IYCF knowledge and practices	• Significant impact in group receiving BCC from HCM on • diarrhea • wasting, anemia, Hb (marginally significant) • No impacts on stunting or underweight • Plausibility supported by greater improvements in women's agricultural production and maternal IYCF knowledge and practices in both study arms	HKI's EHFP and BCC program significantly reduced child wasting, diarrhea, and anemia, and increased Hb over two years. The impacts were achieved through improvements in women's agricultural production and improved maternal IYCF knowledge and practices.
Olney, Bliznashka, et al. 2016, **Burkina Faso**	• As above • Women (control: $n = 510$; intervention: $n = 787$) • OWL and HCM groups were combined	As above	• Mother's dietary intake and DD • Mother's BMI, prevalence of underweight • Women's empowerment	• Significant increase in fruit intake and marginal increase in meat intake and DD • Significant reduction in underweight prevalence; no impact on BMI • Improvements in empowerment score	In addition to improving child nutrition outcomes, HKI's two-year EHFP and BCC program significantly improved maternal diets, nutritional status, and empowerment.
van den Bold et al. 2015, **Burkina Faso**	• As above • Complemented by two rounds of qualitative research	As above	• Intra-HH asset distribution • Women's bargaining power	• Increase in number and relative value of women-owned agricultural assets • No impact on women's control of assets	HKI's two-year EHFP and BCC program increased women's control over and ownership of assets, and changed gender

(continued on next page)

Table 4 (*continued*)

Author(s), year, study location[a]	Evaluation design	Intervention	Outcomes measured	Findings	Conclusions
				• Larger impact on small ruminant ownership for men and no impact on large livestock ownership • Changes in communities' perceptions about women's ownership and control of assets	norms around these issues in rural Burkina Faso.
Osei et al. 2017, **Nepal**	• RCT with 8 clusters pair-matched and randomly assigned to control or EHFP (the latter with BCC and gender activities) • Cross-sectional surveys at baseline and endline (2.5 years later) with sample of 1,051–1,307 mother/children pairs/groups (children 12–48 months old)	• *Nutrition:* BCC training on ENAs • *Agriculture:* distribution of inputs (seeds, saplings, • chicks, small gardening tools) and training • *Gender:* Women trained to host VMFs and train other women	Measured in mothers and children: • Weight, height/length • Hb and anemia	• Impact on anemia reduction in children (OR: 0.76) and mothers (OR: 0.62) • Reductions in maternal underweight (OR: 0.61) • No impacts on child anthropometry	The EHFP program had positive impacts on maternal and child anemia and maternal underweight. The program also improved several outcomes along the impact pathways, including production of nutrient-rich foods (eggs, vegetables), improved HH food security and IYCF, and other ENA practices.
Osei et al. 2015, **Nepal**	• RCT with 41 clusters randomly assigned to (1) EHFP (as above), (2) EHFP + MNP supplement, (3) control • Each group contained approximately 110 children 6–9 months old at baseline • Measured at baseline and 11 months later	• *EHFP intervention:* As above • *MNP intervention:* 60 MNP sachets containing 15 micronutrients distributed at baseline and 6 months later for a total of 11 months of supplementation	• Child Hb and anemia • Child anthropometry (weight, height/length)	• Hb increased significantly in all groups between baseline and endline, with no differential increases in EHFP groups • Marginally significant impacts on anemia in both EHFP and EHFP + MNP groups • No impacts on child growth	• Adding MNP component to EHFP had a marginal effect on anemia but no effect on child growth. • Study confirmed feasibility of using EHFP platform to deliver MNPs for young children.
Kumar et al. 2017, **Zambia**	• CRCT with a control and two treatment groups: (1) agriculture intervention only, (2) integrated agricultural and nutrition interventions • Approximately 1,000 HHs per arm • 2 cross-sectional surveys 4 years apart (2011 and 2015)	*Nutrition:* IYCF BCC through women's groups, community health volunteers, and social marketing *Agriculture:* Home gardening; inputs included nutrient-rich vegetable, legume, and tuber seeds; tools and training; and goats and chickens and related training *Gender:* Promotion of gender equality and women's empowerment	Children 0–59 months old: • Anthropometry (weight, height/length) Mothers: • IYCF knowledge and practices • Empowerment	• Decline in stunting in all groups (larger in control group), so treatment had no impacts on stunting • Positive impacts on child WHZ and reduced morbidity (cold/cough, diarrhea) • Low participation in program • Impacts on social capital, access to and control over assets, financial and agricultural decision-making empowerment • Impacts on maternal knowledge of some breastfeeding practices and timing of introduction of complementary foods • Negative impact on women's time spent on childcare, domestic activities, leisure	• Project had impacts on several outcomes along the agriculture-nutrition pathways, such as agricultural production, women's empowerment and nutrition knowledge, and child WHZ and infections, but no impact on stunting. • Low participation and general improvements in child stunting and feeding practices in the country during the study may be responsible for the lack of impact on stunting. • Agriculture programs should include measures to protect women's time.
Schreinemachers et al. 2016, **Bangladesh**	• Quasi-experimental design with control and treatment groups • Baseline in 2013 (control: 252 HHs; treatment: 425 HHs); endline in 2014 (control: 238 HHs; treatment: 408 HHs) • cost-effective component • *Note that study did not use randomization or matching of comparison and intervention groups, but did discuss selection bias*	*Nutrition:* Training on nutrition focusing on vegetables *Agriculture:* Women's training in home gardening and distribution of inputs to grow nutrient-rich vegetables	Per capita production and consumption (quantity and diversity) of vegetables	Comparison between treatment and control groups showed • no differences in area under production • greater production and consumption of vegetables in treatment group	• Training women in home gardening was associated[b] with greater HH supply and consumption of vegetables. • Authors reported that cost calculations showed the approach to be cost-effective in addressing micronutrient deficiencies.

(*continued on next page*)

Table 4 (*continued*)

Author(s), year, study location[a]	Evaluation design	Intervention	Outcomes measured	Findings	Conclusions
Schreinemachers et al. 2014, **Bangladesh**	• Cross-sectional data from 2013 (103 in intervention group since 2012; 479 in control to get intervention in 2013 after survey) • *Note that study did not have baseline information and did not use randomization or matching of comparison and intervention groups*	As above	As above	Intervention, compared with control group, had • greater area of home garden, production of leafy vegetables, and overall per capita vegetable production • greater diversity of vegetable consumption	Training women in home gardening was associated[b] with nutrition security through the supply and consumption of diverse vegetables in rural HHs.
Murty, Rao, and Bamji 2016, **India**	• Before-and-after design (baseline and 3 years later) with no comparison group • Sample: All pregnant women and all mothers with children 6–24 months old registered at 11 ICDS centers (total sample size not specified) • Substudy on KAP: 142 mothers with 6- to 24-month-old children	*Nutrition:* Health and nutrition education, cooking demonstrations, and videos, focused on vegetables *Agriculture:* Homestead gardens (focused on vegetables) and backyard poultry with high-egg-yielding birds	• KAP on child feeding • Vegetable garden area • Vegetable and egg consumption	• greater women's control over the home garden and income-generating activities • Intervention was associated[b] with increases in adoption of vegetable gardens and consumption of green leafy vegetables and eggs. • Intervention was associated with reductions in underweight children (although this outcome cannot be attributed to the program because of the data source).	Comparisons between baseline and endline showed • increases in area cultivated and percentage of HHs with vegetable gardens (from 30 percent to 70 percent) • increases in weekly mean frequency of green leafy vegetables cooked, from 1.9 to 2.4, and in percentage of HHs cooking them, from 21 percent to 45 percent • increases in weekly frequency of egg consumption; more than doubling of quantity of eggs consumed • marked increases in knowledge of components of a balanced diet, including animal-source foods • decline in number of children with low WAZs (according to ICDS centers' records)
Livestock-oriented programs					
Miller et al. 2014, **Nepal**	• Longitudinal pair-matched RCT • Communities randomly assigned to receive intervention at baseline or after 1 year (staggered) • Sample of about 200 families per group (total of 607 children 6–59 months old)	*Agriculture, community development, women's empowerment:* Training on community development, empowerment, and livestock management activities through women's self-help groups; transfer of goats at the end of first year	• Anthropometry of children 6–59 months old (weight, height/length) • Children's morbidity (diarrhea, fever, cough/cold)	• Positive effects (only in Terai [lowland] area) on child weight, height, and number of days sick • Increased income and ownership of animals (also only in Terai)	• Heifer International's interventions improved HH income and ownership of animals and child anthropometry (only in Terai). • In all districts, longer participation in the program led to greater improvements in HAZ.
Darrouzet-Nardi et al. 2016, **Nepal**	Two-year analysis of same intervention and sample as above	As above	Child DD (overall score, animal-source food consumption, minimum DD)	Children living in the hills (poorer, more remote, but more suitable for livestock production) exposed for two years (compared with those exposed for one year) were more likely to have consumed one more food group, to have consumed food from animal sources, and to have achieved minimum DD	• Heifer International's interventions improved DD and consumption of animal-source foods in children 6–59 months old. • The authors concluded that community-level development programs should be carefully tailored to the unique contextual and seasonal constraints faced in different agroecological zones.

(*continued on next page*)

Table 4 (*continued*)

Author(s), year, study location[a]	Evaluation design	Intervention	Outcomes measured	Findings	Conclusions
Rawlins et al. 2014, **Rwanda**	• Cross-sectional survey of 406 HHs divided into "qualifieds" (beneficiary or prospective beneficiary HHs) and "nevers" (HHs not eligible to receive intervention) • Econometric modeling used to test associations	*Agriculture:* Donation of either dairy cows (to eligible HHs with landownership but no ownership of high-producing dairy cows) or meat goats to poor HHs	• HH and individual dietary intake and DD • Children's anthropometry (weight, height/length)	"Qualified" HHs, compared with "nevers," had • greater individual DD (through greater dairy consumption by beneficiaries receiving dairy cows) • Higher HH dairy (for cow beneficiaries) and meat (for goat beneficiaries) consumption • Marginally significantly greater child WAZs (for cow beneficiaries) and WHZs (for goat beneficiaries)	Livestock donations were positively associated[b] with HH dairy and/or meat consumption and marginally associated with children's weight indicators.
Nutrition-sensitive value chains					
Le Port et al. 2017, **Senegal**	• RCT with groups of dairy farmers assigned to receive (1) MNFY + BCC (n = 204 children) or (2) only BCC (n = 245 children) • Children were 24–59 months old at baseline • Baseline and endline were 1 year apart • All dairy farmers who supplied milk to the local company also received payment for the milk	*Agriculture:* Producers established contracts with firm that paid for milk supplied. *MNFY:* Farmers in group 1 who met contract requirements received 1 sachet of MNFY per day for each child 24–59 months old for 7 days. *BCC:* Messages on ENAs (group sessions, home visits, community meetings, radio spots)	• Child Hb and anemia	• Anemia prevalence dropped from 80 percent to 60 percent during 1-year study (no difference between groups) • Statistically significantly greater increase in Hb (+0.55 g/dL) in MNFY + BCC versus BCC-only group; larger in boys (+0.72) than in girls (+0.38, not significant)	• First RCT to show proof of concept that a nutrition-sensitive value chain can improve child nutrition outcomes • Large impacts on Hb in remote area of northern Senegal, where anemia is excessively high
Irrigation studies					
Alaofè et al. 2016, **Benin**	Two treatment villages receiving solar-powered drip irrigation for one year were pair-matched with two control villages	*Agriculture:* Treatment villages received solar market gardens; control group grew vegetables in hand-watered plotsv.Project targeted women's groups.	• Production of fruits and vegetables • Consumption of fruits and vegetables • DD • Income	• Increases in the variety of fruits and vegetables produced and consumed • Increases in income from sale of produce • Increases in DD from purchase of other nutrient-rich foods	Introduction of solar-powered drip irrigation technology improved diets through direct consumption and increased income.

Source: Authors.

Note: BCC = behavior change communication; BMI = body mass index; CRCT = cluster-randomized controlled trial; DD = dietary diversity; EHFP = enhanced homestead food production; ENA = essential nutrition action; HAZ = height-for-age *z*-score; Hb = hemoglobin; HCM = health committee member; HDD = household dietary diversity; HH = household; HKI = Helen Keller International; ICDS = Integrated Child Development Services (India); IYCF = infant and young child feeding; KAP = knowledge, attitudes, and practices; MMDA = mean micronutrient density adequacy; MNFY = micronutrient-fortified yogurt; MNP = micronutrient powder; OR = odds ratio; OSP = orange-fleshed sweet potato; OWL = older woman leader; RCT = randomized controlled trial; VMF = village model farm; WAZ = weight-for-age *z*-score; WHZ = weight-for-height *z*-score.

[a] Studies are ordered by their appearance in the text.

[b] Authors claimed impact, but study design does not allow us to infer causality of the associations found; we therefore use the term *association* instead of *impact* in this review.

controlled trial (CRCT) that assessed the impact of a carefully designed enhanced homestead food production (EHFP) program with a strong gender component on child nutrition outcomes in Burkina Faso were published in 2015 (Olney et al., 2015). The program was implemented by Helen Keller International (HKI), a nongovernmental organization with 25 years of experience designing and implementing homestead food production programs aimed at improving nutrition outcomes (Haselow et al., 2016). The EHFP model implemented in Burkina Faso targeted households with women and children in the first 1000 days of life (pregnant women and children up to 2 years of age) through integrated agriculture production interventions with a strong nutrition and health BCC strategy plus women's empowerment activities, with the explicit goal of improving children's nutrition outcomes. Implemented in Gourma Province in Burkina Faso, the program worked with mothers to establish homestead gardens, providing inputs and trainings in gardening, irrigation, and small livestock rearing. Beneficiary women were also trained in essential nutrition actions focused on women and young children (including optimal IYCF practices) through home visits twice a month provided by either an older woman leader or a health committee member. The evaluation found that, compared with a control (no intervention) group, the group that received the two-year integrated program with BCC delivered by a health committee member significantly improved in several child outcomes, including increases in hemoglobin (Hb) (+0.7 g/dL) and reductions in anemia (−14.6 ppts) in children 3.0–5.9 months of age at baseline; and reductions in diarrhea (−16.0 ppts) and wasting (−8.8 ppts, marginally significant [$p = 0.8$]), but not stunting, among children 3.0–12.9 months at baseline. Positive impacts were also found on several maternal outcomes, including increased intake of nutritious foods (fruit, meat, and poultry), greater dietary diversity, improvements in several dimensions of women's empowerment, and reductions in maternal underweight (−8.7 ppts) (Olney et al., 2016a). Supporting these positive maternal and child impacts, the study documented statistically significant improvements on several outcomes along the impact pathway, including increases in agricultural production, household access to and consumption of nutrient-rich foods, and dietary diversity.

The program also increased the value of agricultural assets of women in intervention compared with control villages (van den Bold et al., 2015), whereas the value of men's agricultural assets in intervention villages decreased. Although the project had no impact on the area of land cultivated by either men or women, qualitative work indicated that gender norms became more favorable toward women's landownership in treatment compared with control areas. In addition to distributing inputs and providing training to women beneficiaries, the project negotiated with the community for land on which women could establish a village model farm. Departing from the practice in past HKI projects in other countries, where village model farms were often run by male farmer leaders, this project worked with communal farms run by women. Some of those who reported changing their opinion about women's owning land attributed the change to the project and to what they had observed in the village model farms (van den Bold et al., 2015).

Preliminary findings from a second phase of the Burkina Faso study carried out between 2012 and 2014 suggested similar positive impacts of the EHFP program on child anemia, but larger impacts when a water, sanitation, and hygiene (WASH) intervention was added to the program's package of interventions, and even larger impacts when both WASH and a small-quantity lipid-based nutrient supplement for young children were integrated into the program (Olney et al., 2017). These results confirm that improving nutrition requires more than just increasing household access to food. It requires multisectoral approaches that simultaneously address the multiple determinants of undernutrition, including improving access to health and WASH services and providing specially formulated nutrient-rich foods or products to fill the nutrient gap in mothers and children during the first 1000 days.

In Nepal, an evaluation of the same HKI EHFP model with a poultry component documented impacts similar to those in Burkina Faso on child anemia and maternal underweight (Osei et al., 2017). Using a CRCT with two repeated cross-sectional surveys (baseline and endline), the study showed impacts on anemia in EHFP program beneficiaries compared with a control group. The program mitigated the rise in both maternal and child anemia that was observed in the study areas over the course of the project (2.5 years). No impacts on child anthropometry were observed, however. Although the age range of children in the Nepal and Burkina Faso studies was different (and therefore anemia levels were not entirely comparable), overall, childhood anemia was much higher (almost universal) in Burkina Faso, with more than 77% of children 24–40 months of age being anemic at endline, compared with one-third of children 12–48 months of age in the Nepal sample (31% in the treatment compared with 42% in the control group) at endline. Regardless of these differences, EHFP was effective at reducing anemia in both contexts. Also, as was found in Burkina Faso, the Nepal evaluation showed significant impacts on various household and maternal intermediary outcomes along the hypothesized program impact pathway, strengthening the plausibility of the results. More specifically, the EHFP program in Nepal significantly improved household food security and production of eggs and vegetables; several maternal breastfeeding, complementary feeding, and hygiene practices; and the use of preventive health services during pregnancy and the first few years of the child's life.

Also in Nepal, HKI tested the addition of a micronutrient powder (MNP) to its EHFP and poultry program using a CRCT with three comparison groups: (1) EHFP + MNP, (2) EHFP, and (3) control (Osei et al., 2015). The EHFP platform was used to deliver the MNP (60 sachets containing 10 micronutrients) to children ages 6–9 months at baseline and 6 months later. Anemia decreased in all three groups (and Hb increased) over the one-year duration of the project (as expected as children age), but the change was only marginally larger in the two EHFP groups combined, and no differences were found between the two intervention groups (EHFP + MNP compared with EHFP only). As the authors noted, one of the potential reasons for the lack of statistical significance between intervention and control groups in spite of the large anemia reductions achieved (−12 ppts and −9 ppts in EHFP + MNP and EHFP, respectively) may have been the study's low statistical power due to its small sample size (about 100 children per group). Small sample sizes and short study duration may also explain the lack of impacts on child anthropometry. Overall, however, the experiment showed that EHFP could be a useful platform to deliver MNP and related BCC to reduce anemia, given the very high delivery rate (91%) and compliance (97%) achieved.

A similar homestead food production project implemented by Concern Worldwide, the RAIN (Realigning Agriculture to Improve Nutrition) project in Zambia, also targeted children younger than two years with an integrated package of agriculture, nutrition, and community-based gender sensitization interventions (Kumar et al., 2017). A CRCT design was used to compare three groups that received (1) agriculture, gender, and women's empowerment interventions; (2) the same package of interventions plus nutrition BCC; and (3) the standard government services. The agriculture component, which aimed to increase year-round availability of and access to nutrient-rich foods, included the same types of inputs as those in the HKI projects (distribution of seeds, chickens and goats, agricultural tools, and training). In areas that received a nutrition and health intervention, the project staff trained existing community health volunteers to lead nutrition BCC sessions with beneficiary women. In addition, some communitywide gender sensitization and information activities were undertaken in both intervention arms. The RAIN project had positive impacts on several outcomes along the pathways from agriculture to nutrition, including agricultural production, several aspects of women's empowerment (social capital, access to and control over assets, and financial and agricultural decision-making power), and maternal knowledge of breastfeeding practices and optimal timing of introduction of nutritious foods in a child's diet. The project also had a small impact on children's weight-for-height z-scores (WHZs) and on reducing the prevalence of infections (cold/cough and diarrhea) in children younger than five years. The project, however, did not have any impacts on IYCF practices or on child stunting. The lack of impact on stunting appears to be due, at least in part, to the strong positive trends in stunting reduction already occurring in the country, which resulted in all three comparison groups experiencing dramatic stunting reductions between baseline and endline (as high as 13–18 ppts, with the largest reductions in the control group). Positive trends in maternal IYCF knowledge and practices were also observed in all three groups over the study period, possibly contributing to reductions in stunting. There was some evidence, however, that engagement in the project's agriculture intervention constrained women's time—women in the RAIN areas spent more time on agricultural work and less time on childcare, domestic activities, and leisure than women in the control group. Overall, the project benefited women in some aspects of empowerment and in improving their access to nutritious foods and their nutrition knowledge, but as cautioned by many (Johnston et al., 2015), agricultural projects should more explicitly include measures to protect women's time in order to prevent unintended negative effects.

A study conducted in Bangladesh examined the impact and cost-effectiveness of training poor rural women in home gardening and nutrition (Schreinemachers et al., 2016). The study used a difference-in-differences estimation approach (comparing changes between baseline and endline between intervention and control households), but the intervention was not randomized and no attempts were made to match the comparison and control groups on key observable characteristics (weakening the strength of inference that can be derived from the comparison between groups). The study found that the intervention was associated with greater vegetable production, diversity, and consumption, and with a higher household supply of micronutrients from the garden. The estimated average increase in household vegetable supply was relatively small, however: 31 kg per year (or 16.5 g per capita per day), contributing 8.2% of the recommended daily intake of vegetables.

A study in Andhra Pradesh, India, also assessed the effects of introducing a homestead garden and backyard poultry intervention linked to the Integrated Child Development Services (ICDS) program in eight villages (Murty et al., 2016). The goal was to improve maternal and child micronutrient intake during pregnancy and the first 24 months of the child's life by increasing access through agricultural production and using BCC to improve knowledge and practices. The study assessed program effects using a three-year before-and-after design without comparison groups and showed positive changes in a variety of outcomes, including high rates of adoption of a homestead garden (an increase from 30% at baseline to 70% after three years); better knowledge, attitudes, and practices regarding food taboos during pregnancy and IYCF practice; regular preparation and intake of green leafy vegetables; and increased frequency and quantity of egg consumption. The authors also reported a gradual decline in the percentage of children 6–24 months of age who suffered from moderate to severe malnutrition (using weight-for-age information; cut-off not defined), but these results were generated from the growth charts maintained at the ICDS centers for all children and therefore changes cannot be attributed to the program.

3.1.3. Livestock-oriented programs

Livestock-oriented programs, many of which involve livestock transfers, have been implemented primarily as interventions to reduce poverty and improve livelihoods, and secondarily to increase farm households' production and consumption of animal-source foods. Because of their primary focus on poverty reduction, they traditionally have not included specific nutrition interventions even though they may have had nutrition goals, such as increasing consumption of animal-source foods or improving household dietary diversity and, in some cases, child nutritional status. Three recent impact evaluations of Heifer International's livestock transfer programs reported on such studies (See Table 4 for a summary of the studies).

Miller et al. (2014) conducted a 2-year longitudinal evaluation of a community development program in 6 communities in the Terai and hill regions of Nepal, pair-matched and randomly assigned to receive Heifer community development activities at baseline (intervention) or 1 year later (control) (Miller et al., 2014). The participatory community development activities included the distribution of livestock and training to rural women, working through women's groups, with a focus on income generation, women's empowerment, social mobilization, group savings and microlending, and enterprise development. A pair of goats was given to each beneficiary family after 1 year of participation in the program. Child anthropometric outcomes were assessed at baseline and every 6 months over the course of the 2-year study, although program activities did not focus specifically on child nutrition or health. Findings from the 12-month evaluation (prior to livestock distribution), showed that in the Terai areas, where program implementation was stronger, the intervention group had increased income and ownership of animals and land, improved sanitation practices, better child anthropometric outcomes (weight and height), and reduced reported sick days, compared with control. In all districts, longer participation in Heifer activities was associated with larger improvements in child height-for-age z-scores (HAZs).

A follow-up analysis of child dietary diversity using data from the same study, but with measurements after 2 years of program exposure, showed that benefits associated with the program differed depending on agroecological region and season (Darrouzet-Nardi et al., 2016). Children living in the hills (poorer, but more suitable region for livestock production) who had been exposed to the program for 2 years were 2.20 times more likely to have consumed food from an additional food group in the day prior to the interview, 1.38 times more likely to have consumed animal-source foods, and 1.27 times more likely to have achieved minimum dietary diversity, compared with those who had been exposed to the program for 1 year. Similarly, greater effects were achieved during the hungry season compared with the harvest season. These dose-response effects were not observed in lowland areas (the Terai, an agroecology more appropriate for crop cultivation) or during the harvest season. The authors concluded that to deliver expected impacts, community-level development programs should be carefully tailored to address the unique contextual and seasonal constraints faced in the targeted agroecological zones.

The nutrition impacts of dairy cow and meat goat transfer programs were also assessed in Rwanda (Rawlins et al., 2014). The study was based on a cross-sectional survey conducted in 2011 in two regions and relied on Heifer's selection criteria for its livestock recipients to classify the sample into "beneficiaries" (those who had already received livestock), "potentials" (qualified applicants who had not yet received livestock), and "nevers" (applicants who were rejected by program staff). Regression models and matching methods were used for the analysis, and although they do not allow us to infer causality, they showed an association between beneficiary status and milk consumption for cow beneficiaries and a marginally statistically significant association with meat consumption for goat beneficiaries. The study documented some associations with child anthropometry, but these results were only marginally significant, possibly due in part to small sample sizes.

3.1.4. Nutrition-sensitive value chain interventions

Although several initiatives in recent years have focused on developing conceptual models, tools, and approaches to making value chains more nutrition sensitive, only one study so far has published results from a CRCT impact evaluation. The study, conducted among pastoralists in a remote area of northern Senegal, assessed the impact of a nutrition-sensitive dairy value chain on child nutrition (Le Port et al., 2017). The purpose of the study was to test whether a dairy value chain could be leveraged to distribute a micronutrient-fortified yogurt produced using the milk supplied by the dairy farmers to improve Hb and reduce anemia among preschool children from participating dairy farmer households. The micronutrient-fortified yogurt was produced by a local dairy firm that established a contractual arrangement with dairy farmers and used the micronutrient-fortified yogurt as an incentive to increase milk supply from farmers, especially during the dry season. Farmers who supplied a predetermined minimum amount of milk 5 days per week were eligible to receive the micronutrient-fortified yogurt and were instructed to give it to their 24- to 59-month-old children to address the severe problem of anemia in the region. The project targeted women and therefore distributed the micronutrient-fortified yogurt at the milk collection points, where women usually took care of the transactions. The project also included a BCC strategy focused on the promotion of optimal IYCF practices, including use of micronutrient-fortified foods or products for young children. Compared with a control group that received only BCC, children exposed to the BCC + micronutrient-fortified yogurt intervention had statistically significantly greater increases in Hb over the 1-year study period (+0.55 g/dL), with larger impacts in boys (+0.72 g/dL) than in girls (+0.38 g/dL; not statistically significant). Anemia prevalence was extremely high in this population (80% at baseline) and dropped to close to 60% over 1 year, but differences between the groups were not statistically significant. To our knowledge, the study is the first proof-of-concept study that has used an experimental evaluation design to document the effectiveness of a nutrition-sensitive dairy value chain at improving nutrition among preschool children living in a remote pastoralist population. Examples of other ongoing experimental studies testing the nutrition impact of nutrition-sensitive value chains include a study of chicken value chains including a nutrition and WASH intervention in Burkina Faso and a study of dairy value chains in Kenya.

3.1.5. Irrigation studies

Irrigation interventions have the potential to impact nutrition and health through several pathways. A review of the linkages between irrigation, food security, and nutrition described five pathways (some positive and other negative) through which irrigation can affect nutrition (Domènech, 2015). The review concludes that, although there is evidence that irrigation contributes to improving food security, there is no evidence of impacts on nutrition because of the lack of studies that have actually sought to document nutrition impacts.

One study examined the impact of solar-powered drip irrigation using solar market gardens on crop production diversity and dietary diversity in Benin (Alaofè et al., 2016). The intervention specifically aimed to enhance food and nutrition security by installing solar market gardens in two villages, working in conjunction with women's agricultural groups engaged in horticulture. The two treatment villages were pair-matched with control villages based on location, administrative status, and size. Women's agricultural groups in control villages grew vegetables on hand-watered plots, as did those in treatment villages prior to the solar market gardens intervention. The intervention led to increases in the variety of fruits and vegetables produced and consumed between baseline and endline (one year later) in treatment compared with control villages. The majority of women's group households receiving solar market gardens also reported using the additional income from the sale of produce to purchase food items that further improved the diversity of family diets, including beans and fish. The study showed that introduction of the solar-powered drip irrigation technology could improve diets through direct consumption and increased income. As the authors noted, greater impacts on micronutrient intakes (a critical nutrition problem in the country) could probably be achieved by incorporating a BCC intervention into the program or by coordinating with other approaches to improve micronutrient status.

3.2. Evidence from observational studies

Observational studies have been used extensively to examine associations between different agricultural practices and nutrition outcomes. Such studies do not allow researchers to derive the same level of causal inference as do well-designed and -implemented experimental trials, but they are useful in unveiling or confirming linkages and associations between hypothesized drivers and outcomes, and for generating new hypotheses about potential impact pathways. For example, early evidence regarding the role of women's empowerment in childcare practices and nutrition outcomes was generated from studies that documented associations between women's social status and indicators of child feeding and care practices or nutritional status (for example, Smith et al., 2003). Similarly, the mediating role of women's empowerment in linkages between agriculture and nutrition was uncovered mostly by observational studies (Malapit et al., 2015; Sraboni et al., 2014). For these reasons, we include in this review a summary of key findings from papers published since 2014 that help build evidence on the linkages between agriculture and nutrition using observational (association) studies.

Table 5 presents a summary of the 29 observational studies identified in the search process. Of these, 2 papers used nationally representative datasets to examine relationships between agricultural livelihoods, diet, and child nutrition; 11 focused on the relationship between crop production diversity and nutrition outcomes; 10 looked at livestock keeping, sanitation, and nutrition and health outcomes; and 2 looked at associations between climatic variability and nutrition outcomes. Finally, 5 studies (including 1 that also contributed to the work on production diversity) looked at how women's empowerment in agriculture mediates and in some cases mitigates agriculture-nutrition linkages.

3.2.1. Income growth, agricultural livelihoods, diets, and child nutrition outcomes

Two papers looked, respectively, at the contributions of household income, livelihoods, and sociodemographic factors in explaining child nutrition outcomes in India (Bhagowalia et al., 2012) and at the drivers of nutrition changes over time in Ethiopia (Headey, 2014). Both studies used publicly available, nationally representative datasets and focused on child anthropometry and dietary diversity as their main outcomes. In India, income growth alone was only modestly associated with child anthropometry, whereas stronger associations were found for female secondary education, access to safe water and sanitation facilities, and use of antenatal and child preventive health services (Bhagowalia et al., 2012). The authors concluded that income growth alone would likely have modest impacts on child nutrition unless accompanied by improved education and access to health services. In contrast, the study in Ethiopia identified income growth and improved food security as the main forces driving nutrition change between 2000 and 2011 (Headey, 2014). The contrasting results are likely due to vast structural and economic differences between India and Ethiopia, but also the nature of the analyses conducted—in India, the analysis was cross-sectional and looked at determinants of nutrition at one point in time; in Ethiopia, the analysis was prospective and modeled drivers of changes in nutrition outcomes over time. Relative to dietary diversity, both studies identified agriculture as playing an important role. In India, the authors identified irrigation, crop diversification, and livestock ownership as possible entry points for diversifying household diets; in Ethiopia, cow ownership, along with several other factors including household assets, parental education, antenatal care exposure, and maternal age were correlated with children's dietary diversity. Although the dietary diversity measures differed, these studies came to similar conclusions regarding the role of livestock ownership and agricultural production conditions as correlates of dietary diversity. They also both made the point that income growth or agriculture alone is not sufficient to improve dietary diversity or child anthropometry.

Table 5
Summary of observational studies on linkages between agriculture, women's empowerment, and nutrition reviewed.

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
Income growth, household livelihoods, diets, and child nutrition outcomes						
Bhagowalia, Headey, and Kadiyala 2012, **India**	Test association between (1) HH income and child anthropometry (2) HH agricultural production and DD	2004/2005 India Human Development Survey, a nationally representative, multi-topic survey of 41,554 HHs in 1,503 villages and 971 urban neighborhoods across India	OLS regressions	● HAZ, WHZ ● HDD (unweighted sum of number of foods) ● share of expenditure on cereals and noncereals	● Income quintiles weakly associated with child anthropometry ● Factors associated with child anthropometry: female secondary education, access to safe water and sanitation facilities, antenatal checkups, and child immunization ● Agricultural production conditions (such as irrigation, livestock ownership) associated with HDD	● Income growth alone is likely to have modest impacts on child nutrition unless accompanied by improved health and education. ● Important entry points for improving nutrition through agriculture include irrigation, crop diversification, and livestock ownership.
Headey 2014, **Ethiopia**	Examine patterns and trends in, and identify main predictors of child nutrition outcomes and IYCF practices	2000 and 2011 Ethiopia DHS (children 0–60 months old)	Nonparametric methods, OLS, linear probability regressions, Poisson models, Blinder-Oaxaca decompositions of changes in stunting over time	● HAZ, stunting, self-reported low birth weight ● Child DD (24-hour recall, WHO 7 food groups), child dairy consumption (24-hour recall)	● Predictors of child undernutrition: HH assets, parental education, antenatal care, and birth interval ● Predictors of child DD: HH assets, parental education, cow ownership, antenatal care exposure, maternal age	Income growth and improved food security are likely to have been the main forces driving nutritional change in Ethiopia in recent decades.
Crop production diversity, market access, dietary diversity, and child nutrition						
Abay and Hirvonen 2016, **Ethiopia**	Test association between market access, seasonality, and child anthropometry	● 7 rounds of HH panel data over 24 months (2012–2014) in East Tigray, Ethiopia ● 1,656–1,837 children (0–60 months old) in 2,387 HHs	Linear regression with and without village fixed effects	● WAZ, WHZ ● HH-level child DD score (7-day recall, 15 food items)	● Lean season associated with lower WHZs and WAZs ● No effect of market access on relationship between seasonality and child anthropometry ● Better market access associated with greater DD in all seasons	● Seasonality is associated with fluctuations in WHZs and WAZs. ● Market access improves DD but does not mitigate seasonal fluctuations in WAZs and WHZs.
Carletto, Corral, and Guelfi 2016, **Malawi, Tanzania, and Uganda**	Test association between agricultural commercialization (measured by CCI) and child anthropometry, and effect modification of gender and crop mix on this association	Nationally representative panel data of farming HHs from LSMS-ISA: ● Malawi: 2,222 HHs ● Tanzania: 1,744 HHs ● Uganda: 1,788 HHs	Pooled sample with different specifications for commercialization using individual-fixed-effects linear model on *z*-scores and random effects logit model on probability of being malnourished	● HAZ, WAZ, WHZ, stunting, wasting, underweight ● HH per capita food expenditure ● HH per capita calorie consumption	● No association between CCI or HH expenditure and child anthropometry ● Significant and negative effect of commercialization by women on child wasting ● Increase in expenditure negatively associated with probability of being stunted and underweight	There is little evidence of a relationship between increased commercialization and improved nutritional status.
Hirvonen and Hoddinott 2014, **Ethiopia**	Test association between HH production diversity and child DD	Cross-sectional survey (2013) in 5 regions of Ethiopia: Amhara, Oromia, SNNPR, Somali, and Tigray (7,011 HHs in 252 villages in 84 *woredas*, including 4,214 children 6–71 months old)	GMM IV model for OLS; nonlinear IV technique for Poisson model based on GMM framework	Child DD: Number of food groups consumed (24-hour recall, 7 food groups)	● Increasing HH production increases child DD by 0.57–0.73 (controlling for confounding factors) ● Significant interaction between production diversity and market access: market proximity mitigates negative effect of low production diversity on child DD	HH production choices are strongly associated with children's diets where HHs have limited access to food markets; this relationship does not hold for HHs with good access to markets to buy and sell food.

(*continued on next page*)

Table 5 (*continued*)

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
Jones 2014, **Bolivia**	Test association between (1) agriculture and IYCF practices, and (2) IYCF practices, child HAZs, and adequacy of child diets	Cross-sectional survey (2009) of 251 HHs with children 6–23 months old in Bolivian highlands	Multiple regression	• IYCF practices, summarized into an index, the ICFI • HAZ • Energy intake, MMDA score (24-hour recall)	• Amount of land cultivated negatively associated with ICFI • Mother's education, livestock ownership, crop diversity positively associated with ICFI • Stronger associations between crop diversity and ICFI at higher elevations • ICFI positively associated with child HAZ, energy intake, and MMDA	Nutrition-sensitive investments in agriculture that aim to diversify subsistence agricultural production could plausibly benefit the adequacy of child diets.
Jones, Shrinivas, and Bezner-Kerr 2014, **Malawi**	Test association between production diversity and HDD	2010/2011 Malawi IHS3, nationally representative (6,623 agricultural HHs)	Multiple linear regression	• Modified HDD score (7-day recall, 12 food groups) • FCS (7-day recall) • Number of foods consumed and food group frequency (days consumed in past 7 days)	• Production diversity positively associated with HDD; FCS; and consumption of legumes, vegetables, and fruits • Effect of production diversity significantly greater in women-headed and wealthier HHs	More diverse production systems may contribute to more diverse HH diets, but the relationship is influenced by gender, wealth, control of HH decisions, markets, and the specific nature of farm diversity.
Jones 2017, **Malawi**	Test association between agricultural biodiversity (measured as CSR) and HDD / diet quality	2013 Malawi IHPS and 2010/ 2011 Malawi IHS3 (nationally representative longitudinal data for 3,000 HHs)	GEE analysis modeling	• HDD score • Daily intake of energy and protein, iron, vitamin A, and zinc per adult equivalent (7-day recall)	• CSR significantly and positively associated with HDD and daily intake of energy, protein, iron, vitamin A, and zinc • No effect of proportion of harvest sold or distance to nearest population center on relationship between CSR and diets	Promoting on-farm CSR may support enhanced diet quality and diversity, and create opportunities for smallholder farmers to engage with markets in subsistence agriculture contexts.
Koppmair, Kassie, and Qaim 2017, **Malawi**	Test association between production diversity, market access, agricultural technology, and DD	Cross-sectional survey (2014) of 16 districts and 165 villages in central and southern Malawi (408 farm HHs with children 0–60 months old)	Poisson regression models	• HDD score (24-hour recall, 12 food groups) • Mother and child DD score (24-hour recall, 12 food groups)	• Farm production diversity positively and significantly associated with HDD and individual DD (small coefficients) • Stronger association of access to markets and use of chemical fertilizer with DD	• Improving market access is more promising for improving diets than is production diversification. • Diversification should not obstruct market integration and commercialization.
Kumar, Harris, and Rawat 2015, **Zambia**	Test association between production diversity and DD (children 6–23 months old) and anthropometry (children 6–59 months old)	Baseline survey data from RAIN project in Central Province, Zambia (3,340 HHs with children 24–59 months old)	• Ordered logit models (with DD as ordered variable) • Marginal probit (for DD and anthropometry as indicator variables) • OLS regressions (for anthropometry as continuous variable)	• HDD score (24-hour recall, 12 food groups) • Child DD: DD score (24-hour recall, 7 food groups); minimum DD (24-hour recall; ≥ 4 food groups) • HAZ, WHZ, stunting, and wasting	• Positive association between production diversity and DD (children 6–23 months old) • Production diversity also associated with higher HAZ and lower stunting (children 24–59 months old)	Production diversity can have a significant impact on DD in young children in subsistence HHs and subsequently on nutritional status as these children age.
Malapit et al. 2015, **Nepal**	Test association between production diversity and nutrition outcomes, and whether this association is modified by women's empowerment in agriculture (measured by WEAI)	Baseline cross-sectional survey (2012) from the Suaahara project (3,332 rural HHs with children 0–60 months old in 3 agroecological zones)	OLS regressions	• WAZ, HAZ, WHZ, and adult BMI • Child DD (24-hour recall, 7 food groups) and maternal DD (24-hour recall, 9 food groups)	• Production diversity positively associated with child DD (small coefficient) and WHZ • Women's empowerment mediates association • Group membership, control over income, reduced workload, and	• Positive associations of production diversity with maternal and child DD and anthropometry suggest that policies to promote diversification can improve nutrition.

(*continued on next page*)

Table 5 (*continued*)

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
					WEAI score positively associated with maternal BMI ● Control over income positively associated with HAZ ● Lower gender parity gap associated with child DD and HAZ	● Women's empowerment mitigates the negative effect of low production diversity on maternal and child DD and HAZ.
Shively and Sununtnasuk 2015, **Nepal**	Test association between production diversity, market participation, and child anthropometry	2010/2011 NLSS, a nationally representative survey (1,769 children 0–59 months old in 1,289 farm HHs)	Multiple linear regressions for HAZ and binary logistic regression for probability of stunting	HAZ, stunting (younger children: < 24 months old; older children: ≥ 24 months old)	● Increases in yield associated (small coefficients) with HAZs and lower stunting in older children ● Own-consumption significantly associated with lower HAZs and higher stunting in older children ● Small but significant positive association between agricultural commercialization and HAZs for younger children ● No significant association between production diversity and child nutrition	● Efforts to strengthen agricultural diversification and overall performance could benefit child nutrition. ● Increased income from agricultural sales more than offsets possible adverse impacts associated with less food available for own-consumption.
Sibhatu, Krishna, and Qaim 2015, **Indonesia, Kenya, Ethiopia, and Malawi**	Test association between production diversity and DD	Cross-sectional HH surveys: (1) 2010/2011 Ethiopia Socioeconomic Survey (nationally representative, 2,045 HHs) (2) 2010/2011 Malawi IHS3 (nationally representative, 5,114 HHs) (3) 2012 survey of 674 HHs in Jambi Province, Indonesia (4) 2012 survey of 397 HHs in Kiambu County, central Kenya	Multiple regression models estimated separately for each country and with pooled data from all four countries	HDD score (7-day recall, 12 food groups)	● Significant and positive association between production diversity and HDD (small coefficients) in pooled sample ● No association between production diversity and HDD in Kenya and Ethiopia ● Negative association (small coefficient) between distance to market and HDD in pooled sample and Malawi model only	● When production diversity is not beyond optimal levels, it is positively associated with DD. ● Increasing on-farm diversity is not always the most effective way to improve HDD in smallholder HHs because greater market access tends to reduce the role of farm diversity for HH nutrition.
Livestock, animal-source food consumption, and nutrition and health linkages						
Bageant, Liu, and Diao 2016, **Nepal**	Test the association between livestock ownership, milk consumption, and child anthropometry in the context of conflict	● 3 rounds of nationally representative panel HH data (NLSS) (959 HHs from 1996 and 2003; 2,800 children 0–60 months old from 2011; HH variables from all rounds) ● Conflict data from other datasets	● Linear regression for child anthropometry ● Fixed-effects and correlated random-effects Tobit model for panel data	● Child HAZ and WAZ ● HH milk consumption	● Livestock ownership positively associated with HH milk consumption ● HH milk consumption positively associated with HAZ but not WAZ ● Conflict had greater negative association with HH milk consumption in HHs with fewer livestock	● Livestock ownership positively affects HH milk consumption, which in turn is associated with greater child HAZ. ● Conflict affects the dairy production-consumption linkage, and the effects are felt more strongly among HHs with fewer cattle.
Flores-Martinez et al. 2016, **Afghanistan**	Test association between agricultural asset ownership and HH mutton consumption and anemia in women	Cross-sectional HH data, nationally representative: ● 2010/2011 Afghanistan Multiple Indicator Cluster Survey, 9,199 adult women ● 2011/2012 National Risk and Vulnerability Assessment, 20,828 HHs	● Logistic regression and quantile regressions on anemia status ● Logit models and Poisson count models for mutton consumption	● Mutton consumption: days in a week and quantity per capita ● Anemia (women 15–49 years old)	● Sheep ownership associated with likelihood and quantity of mutton consumption ● Sheep ownership associated with lower prevalence of anemia in women ● Other agricultural assets had weak or no association with anemia	Linkage between sheep ownership and anemia in women is at least partly due to mutton consumption arising from own-production in the presence of market incompleteness.

(*continued on next page*)

Table 5 (*continued*)

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
Hoddinott, Headey, and Dereje 2015, **Ethiopia**	Test association between cow ownership and child dietary intake and anthropometry	Baseline data for evaluation of the government of Ethiopia's Agricultural Growth Program; 7,930 HHs in Amhara, Oromia, SNNP, and Tigray regions	● Probit and OLS regressions	● Child (6–59 months old) anthropometry: HAZ, WHZ, stunting ● Dairy intake (7-day recall in children 6–24 months old)	● Cow ownership associated with greater dairy intake, higher HAZ, and lower stunting (children 12–18 months old), but not with WHZ ● No association between cow ownership and HAZ in villages with functioning markets	Although cow ownership improves child milk intake and nutritional status, it is less important where there is market access, suggesting that market development can substitute for HH cow ownership.
Iannotti and Lesarogol 2014, **Kenya**	Test determinants of micronutrient intake in pastoralist communities undergoing livelihood transitions	3 rounds of panel HH data (2000, 2005, 2010) with 200 HHs from 2 communities in Samburu County, Kenya	OLS regressions in each round and panel regression by generalized least squares with random effects for longitudinal modeling	● Individual DD (24-hour recall, 9 food groups) ● Probability of adequate intake of vitamins A, B_{12}, and C; folate; zinc; and iron (24-hour recall)	● Livestock ownership associated with nutrient adequacy for vitamin A, vitamin B_{12}, and zinc ● DD associated with livestock and poultry ownership and other HH factors (income, HH head's education), as well as bean and rice consumption	● Micronutrient inadequacies in vitamins A, B_{12}, and C were found among pastoralist communities. ● Policies promoting livestock production with an appropriate mix of cropping and off-farm poverty alleviation strategies are needed.
Kabunga 2014, **Uganda**	Assess association between adoption of improved dairy cows, milk consumption, and child anthropometry	Cross-sectional, 2009/2010 Uganda National Panel Survey (907 HHs that own cows, with 715 children 0–60 months old)	Propensity score matching	● HAZ, WHZ, WAZ ● Per capita annual milk consumption	● Improved dairy cow adoption associated with milk consumption and HAZ but not with WAZ and WHZ ● Stratified sample shows association with HAZ only for large farms	● Large farmers, instead of smallholders, will more likely achieve higher child nutritional benefits from adopting improved dairy cows.
Kidoido and Korir 2015, **Tanzania**	Test association between improved dairy production, HH income, and child anthropometry	Panel HH data, 2008/2009 and 2010/2011 Tanzania LSMS-ISA	2SLS	HAZ, WAZ, WHZ (children 0–60 months old)	● Dairy income associated with food expenditure among low-income HHs ● Dairy consumption positively associated with HAZ, WAZ, and WHZ in low-income HHs ● In high-income HHs, dairy consumption associated with WHZ for boys only	● Dairy is an important pathway to improving nutrition in low-income HHs . ● Pro-poor dairy interventions should be integrated with increasing market access and use of gender-aware strategies to deliver equitable intra-HH benefits.
Headey and Hirvonen 2016, **Ethiopia**	Test association between poultry ownership, exposure of children to poultry, and child anthropometry	Cross-sectional HH survey (2015) in rural areas of 5 regions (Amhara, Oromia, Somali, SNNP, and Tigray), including 2,704 HHs and 3,494 children 0–60 months old	Various regression model specifications	HAZ	● Poultry ownership positively associated with HAZ ● Corralling of poultry in HH dwelling overnight negatively associated with HAZ ● Corralling of other livestock not associated with HAZ	Although poultry ownership can improve HAZ, overly close exposure to poultry poses a concurrent risk factor for undernutrition, most likely because of increased risk of infection.
Headey et al. 2016, **Bangladesh, Ethiopia, and Viet Nam**	Test association between presence of animal feces in compound and child anthropometry	Baseline (2010) and endline (2014) data from Alive & Thrive project (2,214, 1,750, and 2,104 mother-child [6–23 months old] dyads in Bangladesh, Viet Nam, and Ethiopia, respectively)	Multivariate logit models with individual and pooled datasets	HAZ and WHZ	Presence of animal feces significantly and negatively associated with HAZ in the pooled sample and in Ethiopia and Bangladesh, but not in Viet Nam	Although open defecation remains a major health concern, exposure to animal feces is probably more common, and potentially hazardous for child nutrition.
Mosites et al. 2015, **Ethiopia, Kenya, and Uganda**	Test association between livestock ownership and child stunting	Cross-sectional DHS, rural children (0–60 months old): ● Ethiopia (2011), $n = 8{,}079$ ● Kenya (2008/2009), $n=$ 3,903 ● Uganda (2010), $n = 1{,}645$	GEE	Stunting	● Livestock ownership significantly associated (small coefficient) with lower stunting in Ethiopia and Uganda but not Kenya ● Effect did not vary by wealth, diarrheal disease, or animal-source food intake	● A small association exists between livestock ownership and child stunting. ● The small effect size is likely due to data limitations or the complex relationship between nutrition and livestock, including exposure to animal feces,

(*continued on next page*)

Table 5 (continued)

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
					• Weak association when weighted measure of livestock ownership used	livestock health, and productivity.
Mosites et al. 2016, **Kenya**	Test association of livestock ownership, livestock disease, or both with child anthropometry	Cohort data on HHs with children < 5 years old (925 children in 755 HHs in 10 villages): • Livestock ownership data collected quarterly (2013/2014) • Child anthropometry data collected monthly (2014/2015) • Livestock disease data collected throughout study	Cohort study using linear mixed regressions	HAZ, WHZ, annualized child growth rate (cm/year), and mean monthly growth rate	• Livestock ownership not associated with HAZ, WHZ, or growth rates • Livestock disease associated with growth rates only in some months (June–November) and among children 0–23 months old	The study did not find an association between livestock ownership and child growth, but it did find that livestock disease episodes may be related to a lower child growth rate in some groups.
Environmental and climatic factors affecting agriculture						
Mulmi et al. 2016, **Nepal**	Test association of agroclimatic conditions at different periods of gestation, birth, and infancy with child anthropometry, and test whether market access and sanitation mediate this association	• Nepal DHS 2006 (5,327 children 0–60 months old) and 2011 (2,335 children 0–60 months old) • NASA satellite observations of variation in NDVI	Two-stage difference-in-differences design, which exploits random exposure to varying agroclimatic factors in relation to birth month	HAZ (children 12–59 months old)	• Agroclimatic conditions associated with HAZ; for boys, the effect is greatest in second trimester of pregnancy; for girls, in first three months after birth • Toilets in HHs and greater market access reduce negative effect of agroclimatic conditions on HAZ (large coefficient)	• Findings are consistent with biomedical studies of sex-specific fetal development and socioeconomic studies of gender bias in childcare. • Both kinds of vulnerability are eliminated in HHs with toilets and greatly reduced in districts that have more active use of food markets.
Shively, Sununtnasuk, and Brown 2015, **Nepal**	Measure the relationship between environmental variability and child anthropometry	• 2011 Nepal DHS (2,335 children < 5 years old) • NDVI data from NASA satellites (2002/2012)	Probit models	Stunting (children 24–60 months old); wasting (children 0-–60 months old)	• Increases in NDVI in child's first year associated with stunting (small coefficient) • Effect on HAZ smaller in Terai than in mountains • NDVI (in month of survey) weakly associated with wasting	Stunting and wasting are correlated with fluctuations in environmental conditions that affect agricultural production, but the relationship is heterogeneous across the landscape in Nepal.
Women's empowerment in agriculture						
Cunningham et al. 2015, **Nepal**	Examine association between women's empowerment (measured by WEAI) and child anthropometry	Baseline cross-sectional survey (2012) of Suaahara nutrition program, including 1,787 rural HHs with children 0–23 months old in 3 agroecological zones	Multivariate OLS regressions	HAZ and WHZ (children 0–23 months old)	Women's empowerment (specifically leisure, access to credit, and autonomy in production) associated with HAZ but not with WHZ	• The study highlights the potential role of women's empowerment in improving child nutrition in Nepal. • More evidence is needed on whether interventions to improve women's empowerment improve nutrition.
Malapit and Quisumbing 2015, **Ghana**	Test association between women's empowerment in agriculture (using WEAI) and	2012 baseline survey of agricultural HHs representative of Feed the Future's zone of influence in northern Ghana	OLS regressions	• HAZ, WHZ, WAZ, maternal BMI • IYCF practices (24-hour recall), including child	• Strong associations between women's empowerment and IYCF practices for girls, but not for boys	The study suggests that the specific domains of women's empowerment that affect nutrition outcomes

(continued on next page)

Table 5 (*continued*)

Author(s), year, location[a]	Study objectives	Sampling design, characteristics, size	Data analysis methods	Outcomes measured	Key findings	Conclusions
	child and maternal anthropometry and diets	(2,027 women of reproductive age with 1,437 children 0–60 months old)		DD (7 food groups), minimum DD (≥ 4 food groups) ● Women's DD (24-hour recall, 9 food groups)	● Women's empowerment weakly associated with child anthropometry ● WEAI positively associated with women's DD but not with BMI	differ among mothers, boys, and girls.
Malapit et al. 2015, **Nepal**	See section on crop diversity, market access, dietary diversity, and child nutrition above					
Sraboni et al. 2014, **Bangladesh**	Test association between women's empowerment in agriculture (measured by WEAI) and energy (calorie) availability, DD, and adult anthropometry	Cross-sectional survey data from Bangladesh Integrated Household Survey 2011/2012, nationally representative (3,213 farm HHs where both women and men were interviewed)	2SLS with empowerment variables instrumented	● Per capita calorie availability, HDD score (7-day recall, 12 food groups) ● Adult BMI	● Increases in WEAI and narrowing of empowerment gap between men and women positively associated with HH energy availability and DD ● Negative relationship of group membership and credit with male BMI	● Although increases in empowerment are positively associated with HDD and energy availability, other factors such as HH wealth are more important determinants of adult BMI. ● Negative impacts of some domains of empowerment on male BMI suggest the existence of intra-HH trade-offs.

Source: Authors.

Note: 2SLS = two-stage least squares; BMI = body mass index; CCI = crop commercialization index; CSR = crop species richness; DD = dietary diversity; DHS = Demographic and Health Surveys; FCS = food consumption score; GEE = generalized estimating equations; GMM = generalized method of moments; HAZ = height-for-age *z*-score; HDD = household dietary diversity; HH = household; ICFI = infant and child feeding index; IHPS = Integrated Household Panel Survey; IHS3 = Third Integrated Household Survey (Malawi); IV = instrumental variables; IYCF = infant and young child feeding; NDVI = normalized difference vegetation index; LSMS-ISA = Living Standards Measurement Study–Integrated Surveys on Agriculture; MMDA = mean micronutrient density adequacy; NASA = US National Aeronautics and Space Administration; NLSS: Nepal Living Standards Survey; OLS = ordinary least squares; RAIN = Realigning Agriculture for Improved Nutrition; SNNPR = Southern Nations, Nationalities, and Peoples' Region; WAZ = weight-for-age *z*-score; WEAI = Women's Empowerment in Agriculture Index; WHO = World Health Organization; WHZ = weight-for-height *z*-score.

[a] Studies are ordered by alphabetical order, within each category.

3.2.2. Crop production diversity, market access, dietary diversity, and child nutrition outcomes

The number of papers published on the topic of production diversity (n = 11) since 2014 illustrates increased interest in exploring whether production diversity (defined in different ways) is indeed an important driver of better diets and nutrition (See Table 5 for summary of studies). Several of the studies explicitly considered the role of markets in the linkages between production and consumption diversity, whether using a measure of the distance to markets or of the degree of commercialization. The key findings of this body of research are that there is generally a positive association between crop production diversity (or crop species richness, as in Jones, 2017) and dietary diversity, but that the extent to which on-farm production diversity matters differs according to context and is more important in more physically isolated locations (Jones, 2014) or those with imperfect market infrastructure (Zambia in Kumar et al., 2015; and Nepal in Shively and Sununtnasuk, 2015), compared with those located closer to well-functioning markets. Indeed, studies from settings as diverse as Ethiopia (Hirvonen and Hoddinott, 2014; Sibhatu et al., 2015); Indonesia, Kenya, and Malawi (Sibhatu et al., 2015); and Nepal (Malapit et al., 2015) have suggested a positive association of farm production with dietary diversity in some, but not all, contexts. In contexts where farm production diversity is already high, the dietary diversity relationship may not be significant or may even turn negative, owing to the forgone income resulting from farm diversification beyond optimal levels (Sibhatu et al., 2015).

Market access, typically measured as distance to the nearest market and availability of off-farm income sources, comes up in many studies as a key factor that modifies the relationship between production and dietary diversity. In Ethiopia (Abay and Hirvonen, 2016; Hirvonen and Hoddinott, 2014) and Malawi (Koppmair et al., 2017), for example, market access was found to mitigate the potentially negative effect of low crop production diversity on dietary diversity. In Malawi, access to markets for buying food and chemical fertilizers and selling produce was found to be more important for dietary diversity than diversity in farm production (Koppmair et al., 2017). Similarly, a pooled analysis of data from Ethiopia, Malawi, Kenya, and Indonesia showed that market access had stronger effects on dietary diversity than did production diversity (Sibhatu et al., 2015). The study documented that reducing distance to market by 10 km had the same effect as increasing farm productivity by 1 additional crop or livestock species; producing 1 added crop, on the other hand, resulted in a small 0.9% increase in the number of food groups consumed, although effect sizes varied by country. Overall, market participation in the four countries studied had a greater effect than production diversity, and it reduced the role of production diversity on dietary diversity (Sibhatu et al., 2015). Women's empowerment was also identified as an effect modifier of the association between production and consumption diversity in Nepal (Malapit et al., 2015). In that study, higher women's empowerment helped mitigate the negative effects of low production diversity on maternal and child dietary diversity. Similarly, in Malawi, the association between production diversity and household dietary diversity was modified by gender, wealth, control of household decisions, market access, and the specific nature of farm diversity (Jones et al., 2014).

Although the relationship between crop diversity and dietary quality appears robust, linkages between crop diversity and nutritional status are generally weaker, and some studies have found that it varies by child age. In Zambia, Kumar et al. (2015) found strong associations between production diversity and dietary diversity among younger children, ages 6–23 months, but significant associations between production diversity and HAZs and stunting only among older children, ages 24–59 months. This finding is not entirely surprising, given that stunting is a cumulative process that reflects chronic undernutrition over time. A lagged effect between improvements in dietary diversity (say, when children are 6–23 months of age) and their effect on children's linear growth (detectable at an older age) is entirely plausible. In Ethiopia, Abay and Hirvonen (2016) found that children living closer to markets had more diverse diets and higher mean WHZs and weight-for-age *z*-scores (WAZs). They also showed, however, that market access did not mitigate seasonal fluctuations in children's weights. In Nepal, Shively and Sununtnasuk (2015) found higher shares of roots and production of animal products, as well as increased market orientation, to be associated with reductions in the probability of stunting and improvement in HAZ.

Commercialization is different from market access and is usually measured using the proportion of crop production that is sold (although some studies use a binary dummy variable for whether *any* part of the produce is sold). A three-country analysis of nationally representative panel surveys from Malawi, Tanzania, and Uganda found little evidence of a relationship between increased commercialization and child nutritional status (Carletto et al., 2017). In fact, the study found a weak negative relationship between nutrition indicators and women's share of the portion of household output that is sold, possibly indicating negative effects of greater female market participation on time allocated to childcare and domestic responsibilities.

3.2.3. Livestock, animal-source food consumption, and nutrition and health outcomes

Livestock ownership provides households with a rich source of high-quality protein and bioavailable micronutrients, a potential source of income (through sales of livestock products), and productive assets. Since 2014, 10 published papers have examined livestock production-consumption (and in some cases, nutrition) linkages, of which 4 specifically focused on dairy cows and milk consumption, and 3 on the potential health and sanitation implications of exposure to livestock feces (2 papers) and diseases (1 paper) (See Table 5 for summary of studies).

Milk has long been recognized as an important food for young children, especially for its stimulating effect on linear growth (De Beer, 2012), thought to be due to its rich content of high-quality proteins, minerals, and insulin-like growth factor-I (Mølgaard et al., 2011). Four of the studies reviewed focused on dairy cows and confirmed dairy production's association with increased milk consumption and lower prevalence of childhood stunting (or higher HAZs) in Ethiopia (Hoddinott et al., 2015), Uganda (Kabunga, 2014), Tanzania (where milk consumption was also associated with higher WAZs and WHZs) (Kidoido and Korir, 2015), and Nepal (Bageant et al., 2016). The magnitude of these associations varied by context; in Ethiopia, the association between cow ownership and linear growth was found only among households that had limited access to markets (Hoddinott et al., 2015); in Uganda, it was found only among households with large farms (Kabunga, 2014); and in Tanzania, it held only among poorer households (Kidoido and Korir, 2015). In Nepal, the association was affected by conflict, with reductions in milk consumption during conflict felt more strongly among households with fewer cattle (Bageant et al., 2016).

A three-country analysis of Demographic and Health Survey (DHS) data looked at the association between livestock ownership and stunting, but without documenting the potential intermediary effect of livestock on milk consumption. The results showed that a tenfold increase in livestock ownership was associated with a small reduction in the prevalence of child stunting in Ethiopia and Uganda, but not in Kenya (Mosites et al., 2015). The authors attributed the relatively small effect to the complex relationships between livestock ownership and the potential health risks associated with increased exposure to animal feces, as well as livestock health and productivity constraints. A study in Afghanistan documented an association between sheep ownership, mutton consumption, and decreased anemia among women of reproductive age, with the authors noting that the results were driven by own-consumption in a situation with imperfect market access (Flores-Martinez et al., 2016). A study of pastoralist households in Kenya (Iannotti and Lesorogol, 2014) found cattle and chicken ownership to be a positive determinant of dietary diversity, and livestock ownership in general a predictor of the adequacy of key vitamins and minerals including vitamin A, vitamin B_{12}, and zinc.

Benefits from owning livestock must be weighed against the possibly negative effects animals may have on human health. Recent studies have looked at livestock ownership and child nutrition and health outcomes taking into consideration the risk of increased exposure to animal feces. Headey and Hirvonen (2016) found that although poultry ownership was positively associated with child HAZs in Ethiopia, the practice of corralling poultry (but not other livestock species) in the household dwelling overnight was negatively associated with HAZs, probably because it increased children's exposure to chicken feces (Headey and Hirvonen, 2016). An analysis of data from Bangladesh, Ethiopia, and Viet Nam also found the presence of animal feces in the compound to be significantly and negatively correlated with child HAZs in Bangladesh and Ethiopia, but not in Viet Nam, where baseline nutritional status was better and handwashing with soap was commonly practiced (Headey et al., 2016). Mosites et al. (2016), tracking a cohort of young children in western Kenya, found no association between livestock ownership and child growth, and attributed this finding to the potentially high disease burden among children in these households (Mosites et al., 2016). Whether this burden is due to actual transmission of disease between livestock and humans or because livestock diseases result in lower household wealth cannot be convincingly disentangled in this study.

3.2.4. Environmental and climatic factors affecting agriculture and child nutrition outcomes

Two studies examined the influence of environmental and climatic factors affecting agriculture and child nutrition (See Table 5 for summary of studies). Shively et al. (2015) estimated the probability that a child was stunted or wasted using data from the 2011 Nepal DHS as a function of the Normalized Digitized Vegetation Index (NDVI), a proxy for growing conditions and food supply, as well as geographic indicators to control for topographic and climate variation and household, mother, and child characteristics (Shively et al., 2015). They found stunting and wasting to be correlated with fluctuations in environmental conditions, with HAZ effects less strong in the Terai, however, owing to better agricultural, market, and health infrastructure than in the hills and mountains. Interestingly, positive deviations from the NDVI when the child was in utero or during the first year of life were associated with a higher probability of stunting, possibly owing to higher agricultural workloads for women in years of higher agricultural output. In contrast, positive deviations in the NDVI in the same period of the child's life were associated with a lower probability of wasting, suggesting that better growing conditions were associated with better access to food in the short term, which in turn helped prevent or reduce wasting.

Also in Nepal, Mulmi et al. (2016) correlated data on child anthropometry from the 2006 and 2011 Nepal DHS with satellite observations of variations in the NDVI (Mulmi et al., 2016). They found that boys were more vulnerable to variations in the NDVI during their second trimester of gestation and girls in their first three months after birth. Both kinds of vulnerability were eliminated in households with toilets and greatly reduced in districts that had more active food markets, consistent with the studies on market access. In other words, the authors found that climate affected child growth only in districts where households' food consumption was primarily from own-production.

3.2.5. Women's empowerment in agriculture and diet and nutrition outcomes

The recent availability of a standardized measure of women's empowerment in agriculture, the Women's Empowerment in Agriculture Index (WEAI) (Alkire et al., 2013), has greatly increased the use of women's empowerment measures in surveys and in the analytical work looking at the mediating or mitigating role of women's empowerment in agriculture for nutrition outcomes at the household and individual levels. Four studies on this topic were published since 2014 (See Table 5 for summary of studies).

Sraboni et al. (2014), using nationally representative data from Bangladesh, found increases in women's empowerment in agriculture to be positively associated with energy availability and dietary diversity at the household level. In Nepal, a study found that women's overall empowerment in agriculture and in 3 specific domains of empowerment—satisfaction with leisure time, access to and decisions regarding credit, and autonomy in production—was positively associated with length-for-age *z*-scores among children less than 2 years of age (Cunningham et al., 2015). Using a different sample that included all children 0–5 years of age and only women who participated in agriculture, Malapit et al. (2015) found that the domains of women's empowerment in agriculture associated with maternal versus child nutrition outcomes did not always overlap. In their sample from Nepal, overall empowerment, women's group membership, control over income, and reduced workload were positively associated with greater maternal dietary diversity and body mass index (BMI), whereas control over income was associated with higher child HAZs, and a lower gender parity gap was associated with both higher HAZs and greater dietary diversity in children younger than 5 (Malapit et al., 2015).

Associations between nutrition and women's empowerment in agriculture also vary across cultures due to the context specificity of gender norms and differences in levels of empowerment, both overall and by domain. In northern Ghana, women's empowerment was found to be strongly associated with the quality of IYCF practices but only weakly associated with child nutritional status, and associations of empowerment indicators with child outcomes varied by the sex of the child. Similar to the findings in Nepal, domains of empowerment that were associated with women's nutrition outcomes were different from those associated with children's diet and nutrition outcomes (Malapit and Quisumbing, 2015).

Agriculture may also affect nutrition through changes in women's time allocation. Several studies in our review highlighted that agricultural programs and interventions put constraints on women's time, which in turn may have negative consequences on nutrition and health by reducing time for childcare, healthcare seeking, food preparation, and leisure (Carletto et al., 2017; Cunningham et al., 2015; Jones et al., 2012; Kumar et al., 2017; Shively and Sununtnasuk, 2015).

4. Discussion

Our review of recent evidence on NSAP unveiled a rich set of studies published over a short three-year time span (since 2014). The body of evidence on how agriculture can contribute to nutrition has rapidly expanded, with the publication of 16 peer-reviewed papers analyzing impact evaluations of different types of NSAP, livestock, value chain, and irrigation programs, and 28 papers using survey data to explore the linkages between agriculture, women's empowerment, diets, and nutrition. We focus our discussion on what we have learned from this new body of evidence, the remaining research gaps in knowledge, and priorities for research.

4.1. What have we learned?

4.1.1. Impact evaluation studies

The most consistent finding from our review of NSAP, in which all programs aimed to increase household access to nutrient-rich foods, is their impact on household and child dietary diversity (where studied) and on the consumption of animal-source foods or fruits and vegetables (when targeted). Impacts on micronutrient intakes were also found in studies that measured dietary intake though a 24-h recall (de Brauw et al., 2015b). These results were achieved in diverse settings and through a variety of program models including biofortified vitamin A–rich OSP, gender-sensitive EHFP, livestock and dairy value chain programs, and a fruit and vegetable solar market gardens irrigation program. Overall, these programs were highly successful at meeting their production and consumption goals and, more specifically, at achieving their main objective of improving household and individual access to nutrient-rich foods.

The studies reviewed in this paper also generated evidence of the impacts of EHFP (with chickens) on child Hb and anemia in Burkina Faso (Olney et al., 2015) and Nepal (Osei et al., 2017), where it was assessed. These studies add to previous evidence of impacts on micronutrient status (vitamin A) provided by the evaluation of biofortified vitamin A–rich OSP in Uganda (Hotz et al., 2012b). The studies that used an EHFP or a dairy value chain platform to distribute micronutrient-fortified sprinkles or yogurt targeted to young children also documented impacts on anemia (Osei et al., 2015) and Hb (Le Port et al., 2017), concluding that agricultural programs could be effective platforms to deliver micronutrient-fortified products targeted to young children. Of the six studies that measured child anthropometry, however, none found an impact on stunting (with the exception of a livestock study that found impacts in one of the two geographic areas studied (Miller et al., 2014)) and impacts on WHZ or wasting were small or only marginally significant (Olney et al., 2015; Kumar et al., 2017; Miller et al., 2014 in one region only; Rawlins et al., 2014). Three studies documented reductions in diarrhea prevalence or days sick in young children (Jones and de Brauw, 2015; Olney et al., 2015; Miller et al., 2014), and two showed reductions in the prevalence of maternal anemia and underweight (Olney et al., 2016a; Osei et al., 2017).

Overall, the studies published since 2014 have expanded the breadth of agricultural programs studied (from traditional home gardens to EHFP systems with small animals, livestock programs, dairy value chains, and irrigation) and the set of nutrition outcomes measured in children (from anthropometry and diets to micronutrient status and morbidity). New studies also started to document some of the untapped potential of agriculture to improve women's nutritional status, especially in countries such as Burkina Faso, Nepal, and Zambia, where maternal undernutrition is a critical nutrition problem. The studies also used more consistent indicators of household, women's, or children's dietary diversity, allowing for comparability across contexts. The range of effects on production and consumption varied between studies, but in general, impacts on maternal and child dietary diversity, food intake, micronutrient status, and weight-specific nutritional status indicators were modest. For stunting, the lack of impacts may be explained at least in part by the relatively short duration of most programs (1.0–2.5 years) and the wide age range targeted by many, often well beyond the first 2 years of life, when the greatest benefits on child growth from nutrition interventions can be expected (Black et al., 2013; Leroy et al., 2016). As documented before, studies also may have been underpowered to detect effects on stunting (Herforth and Ballard, 2016). Finally, several new studies specifically documented impacts along the project-specific hypothesized pathways, strengthening the plausibility of impacts on maternal and child diets and nutritional status outcomes. For example, results from the evaluation of EHFP in Burkina Faso and Zambia showed impacts on specific dimensions of women's empowerment such as social capital, ownership of and control over assets, and decision making in selected domains, and a number of studies documented impacts on maternal IYCF knowledge, practices, or both (Kumar et al., 2017; Miller et al., 2014; Murty et al., 2016; van den Bold et al., 2015). These findings confirm the hypothesized mediating (and in some case modifying) role of women's empowerment and improved knowledge and practices in fostering nutrition impacts from agriculture (SPRING, 2014).

Our review also found marked improvements in recent studies both in program design and in the quality and rigor of impact evaluations. In contrast with the studies included in previous reviews, most of the agriculture and nutrition programs reviewed here were truly nutrition sensitive (except for some of the livestock studies and the irrigation study) in that they had both explicit nutrition goals and carefully designed nutrition interventions. Nutrition, health, and hygiene BCC were the most common nutrition-related interventions provided, but a few studies also delivered micronutrient-fortified products, recognizing that in some contexts, increasing household access to nutritious foods may not be sufficient to meet the high micronutrient requirements of children in their first two years of life. Several of the programs also had a strong focus on gender equity and women's empowerment, which included not only targeting women but also engaging women, men, and communities through trainings and social mobilization and carefully designed promotional activities. The purpose of these gender-focused activities was not only to improve the quality and productivity of women's lives but also to ensure that resources would be used more efficiently to support children's nutrition, health, and well-being. Only two studies specifically documented impacts on women's empowerment outcomes, however.

In addition to having improved program designs, the new studies have tended to pay more attention than before to implementation quality, and a few of them documented working with researchers to design a program impact pathway framework (Rawat et al., 2013) and to measure, through process evaluations, implementation fidelity, quality of service delivery, use of the program, and the perceptions of program implementers and users (Olney et al., 2015, 2016a, 2016b; Osei et al., 2017). Finally, the quality of impact evaluation designs and analyses also improved in the newly published studies, with some using CRCTs or quasi-experimental approaches. More studies than before used baseline and endline surveys and valid comparison groups (through either randomization or matching) to document impacts, although weaknesses remained in some studies, including the lack of a valid control group or of baseline information.

In sum, the set of studies reviewed in this paper generally had stronger and more nutrition-sensitive program designs, clearer and better-tailored target groups for the nutrition objectives they had set, more rigorous evaluation designs and better-defined sample size calculations, more appropriate data analysis approaches (for example, use of double differences, control for potentially confounding factors, and so on), and more standardized nutrition outcomes. Some evaluations also included careful analysis of hypothesized program impact pathways. Additionally, most new programs evaluated were genuinely designed to be nutrition sensitive, and in several cases also gender sensitive. The emerging evidence from these higher-quality nutrition- and gender-sensitive program designs, which pay careful attention to both implementation quality and pathways of impact, and use careful and rigorous evaluation methods, is generally positive, although effect sizes are modest for maternal and child diet and weight-specific anthropometric indicators and, so far, no impacts have been documented on stunting.

4.2. Observational studies

An exceptionally large number of observational studies on the linkages between agriculture and nutrition have been published in the past three years, many focusing on the importance of production diversity for household, maternal, and child diets. The main takeaway from this literature is that production diversity and livestock ownership are consistently associated with household and dietary diversity and, when measured, with increased intake of essential micronutrients. Livestock ownership is also specifically associated with greater animal-source food intake (especially milk in young children). Evidence of associations with health and nutritional status outcomes is still limited, but milk intake (in households that own livestock) is positively associated with child linear growth, confirming the well-documented contribution of milk to linear growth (De Beer, 2012). A second key takeaway from this literature is that although production-consumption diversity linkages were found in all studies, the associations were modified by contextual factors, the most important one being market access. Indeed, studies that included some measure of market access highlighted its strong role as an effect modifier of the association between production diversity or livestock ownership and household or child dietary diversity, and in some cases between production diversity or livestock ownership and child nutritional status (Hoddinott et al., 2015; Mulmi et al., 2016). Other contextual, socioeconomic, and food environment factors were also identified as important effect modifiers of the associations between production, consumption, and nutritional status.

As found for the evaluation literature, the quality of the observational studies varied but was generally better than that of earlier studies, with greater attention paid to using appropriate statistical modeling tools, controlling for potentially confounding factors, using robustness checks as needed, and focusing on appropriate age groups for nutritional status indicators. The choice of indicators of consumption diversity and child nutritional status was generally consistent, but significant variation arose in the selection of production diversity and market access indicators, making comparison between studies difficult.

With the availability of a new indicator to measure women's empowerment in agriculture (the WEAI), overall and for different dimensions of empowerment, some of the new studies confirmed the hypothesized association between women's empowerment, food security, and women's and children's nutrition outcomes, including child HAZs. The studies also revealed complex relationships between different domains of women's empowerment and how they affect women's and children's (and boys' and girls') outcomes differently, as well as the context sensitivity of these relationships.

Overall, the main conclusions from the association literature are that production diversity or livestock ownership is important to consumption diversity and possibly nutritional status, but mostly for households that live in remote areas and have limited access to markets, which usually are the poorest of the poor. Women's empowerment is also an important mediator and in some cases an effect modifier of these relationships. The main implications of these findings are that increasing production diversity should not be considered a main goal in itself in all contexts (Sibhatu et al., 2015) and that market interventions should be leveraged and combined with women's empowerment and BCC interventions to further improve availability of, access to, affordability of, and demand for nutritious foods.

4.3. What are the remaining gaps in knowledge and priorities for research?

Although encouraging progress has been achieved in documenting agriculture, gender, and nutrition linkages in the context of community-based programs and through analyses of existing data, much remains to be learned about what, how, and at what cost agriculture can contribute to improving nutrition. Evidence will continue to grow over the next 5–10 years, with innovative ongoing studies on nutrition-sensitive value chains (for example, value chains for biofortified staple crops, dairy products, and chickens); experimentation with new platforms such as livelihoods-focused self-help groups, government extension services, and agriculture-targeted financial services for women in South Asia; and research that incorporates targeted WASH interventions to address the potential harm of homestead agriculture involving small animal rearing (Gelli et al., 2017), to name a few (note that the studies listed are only illustrative and by no means an inventory of all on-going studies on the topic). The Innovative Methods and Metrics for Agriculture and Nutrition Actions (IMMANA) portfolio of research on agriculture, nutrition, and health metrics should also generate a set of innovative tools, methods, and indicators for analyzing multisectoral programs and standardizing approaches and measurement in this area. Large knowledge gaps remain, however, on the potential nutrition contributions of traditional community-level agricultural programs and value chains such as those included in the present review, but also on the more holistic national and global agriculture and food systems and their effects on all forms of malnutrition. We focus our discussion on research gaps mostly regarding the former and refer the reader to other recent reviews on agriculture and food systems for the latter (Gillespie and van den Bold, 2017; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Pingali and Sunder, 2017).

To further enhance our understanding of the value and contribution of household- and community-focused agricultural programs to women's empowerment and to maternal, adolescent, and child nutrition, we provide examples of some key research gaps that need to be filled in the short to medium term:

- **Long-term impacts and sustainability:** Given the impacts of nutrition- and gender-sensitive agricultural programs on several outcomes along the impact pathways, and especially impacts on women's empowerment, knowledge, and practices, we can assume that these programs could have long-lasting impacts on women's social, health, and nutritional status, which in turn could have impacts on their families and future children. So far, no information exists on the long-term impacts—or the sustainability of any impacts—of nutrition- and gender-sensitive programs, nor on the sustainability beyond these programs' specific funding cycles of the practices adopted or assets built by participants. A preliminary analysis of the Burkina Faso EHFP suggested some spillover effects of the program on maternal and child weight indicators, but no sustained impacts on household assets, livestock ownership, food security, or dietary diversity (Bliznashka et al., 2016). Research on the long-term impacts and sustainability of nutrition- and gender-sensitive agricultural programs should be prioritized.
- **Scaling up and operating at scale:** The types of NSAP reviewed were implemented at a relatively small scale and often for short periods of time delineated by funding cycles. None of the programs included in this review were implemented at scale, and data, information, and evidence from efforts to scale up NSAP are extremely slim (Gillespie et al., 2015; Linn, 2012). Research is needed on how and where to scale up or implement NSAP programs, the key factors for success, and the cost of scaling up and achieving impacts at scale. Research should also characterize how agricultural development programs can fit within—and complement—the scale-up of larger agricultural and food systems investments.
- **Cost and cost-effectiveness:** The complexity of collecting and interpreting cost data for multisectoral programs has prevented many researchers from doing so. Moreover, cost-effectiveness assessments, which focus on one outcome (for example, stunting), cannot capture the multiple benefits of programs that generate impacts on a series of outcomes (for example, women's empowerment, knowledge, diets, nutritional status) (Bill & Melinda Gates Foundation and DFID UK Department for International Development, 2017). Cost-effectiveness assessments of such programs also cannot factor in the benefits the programs may have on several of the underlying determinants of stunting, which in turn may have long-term cumulative impacts on either the targeted children, their younger siblings, or the next generation. Cross-disciplinary research is urgently needed to develop methodologies to assess cost-effectiveness for programs that are designed to have impacts on a suite of outcomes.
- **Which target groups, which nutrition outcomes?** With the recent focus on the first 1000 days and the call for action on reducing stunting, many agricultural development programs switched from an earlier focus on improving household production, food security, and dietary quality to a goal of reducing childhood stunting. As a result, several programs shifted their targeting mechanism from the community level (based on poverty and food insecurity) to poor households with pregnant women and children in their first 1000 days. This shift was appropriate if the main nutrition goal of the program was to reduce stunting, but current evidence suggests that agriculture may in fact be more beneficial for improving household access to nutritious food and diverse diets than for reducing stunting, and for household members other than young children, who have particularly high nutrient needs. Research should therefore continue to assess which nutrition indicators (for example, diets

or micronutrient intake and status) are most likely to respond to agriculture interventions, and which household members are most likely to benefit. So far, the few studies that have assessed impacts on women's nutritional status have found significant impacts on diets, weight and BMI, and micronutrient status. It is likely that other household members, including adolescent boys and girls, who are also nutritionally vulnerable, may benefit more from agriculture interventions than young children. Research should therefore be undertaken to redefine which nutrition outcomes and which age groups agriculture should aim to support in different contexts. Research should also focus on improving the quality of, while also simplifying, data collection and processing for dietary assessment in different population groups.

- **Using agriculture programs as delivery platforms for tailored nutrition interventions:** An alternative to completely reverting the targeting of community-level agricultural programs to households based on poverty and food insecurity would be to develop and adopt different models, based on household demographic characteristics or other factors. There could, for example, be a model specifically designed to meet the needs of households with pregnant women and children in their first 1000 days. Similarly, some models could be tailored to address the needs of adolescent boys and girls or the elderly, or could explore targeting some resources (including BCC) to specific individuals within the household and others to the household as a whole. Such a strategy would require careful targeting, monitoring, and community tracking to identify households with the preestablished eligibility criteria for the specialized intervention packages and may therefore be operationally too complex, at least in most contexts. Research could assess the operational feasibility and effectiveness of some variations of these approaches. Different implementation modalities could also be assessed, including comparing existing government delivery systems; nongovernmental organizations; and innovative approaches that link government, private, and nongovernmental organization delivery systems.
- **BCC in the context of agricultural programs:** Effective nutrition, health, and hygiene BCC requires carefully designed, locally adapted materials and tools, and well-trained and dedicated staff to deliver it. It is generally resource intensive and requires time and active engagement from both staff and beneficiaries. In the area of breastfeeding, for example, evidence shows that more intensive and better-targeted BCC and the use of multiple approaches including combinations of home visits, community-based or service-based sessions, and mass media tend to deliver greater impacts on knowledge and practices than single approaches (Nguyen et al., 2016; Rollins et al., 2016; Sinha et al., 2015). Process evaluations of agricultural programs have identified BCC as a common bottleneck in implementation (Olney et al., 2016b, 2009), and although most programs have shown some impacts on knowledge and practices, there is room for much more improvement than what is usually achieved. Research is needed to identify best practices in designing and implementing effective yet affordable BCC strategies in the context of agricultural programs and how to make them attractive and useful for beneficiaries without adding too much burden on their time. BCC topics also need to be broadened, from the traditional focus on optimal IYCF practices to the promotion of healthy and nutritious diets, meal planning and budgeting, and hygiene, and health service utilization for all household members. Achieving greater operational efficacy, impact, and cost-effectiveness from BCC strategies is not specific to agriculture, so research in this area should join broader efforts to strengthen BCC in all aspects of development and food systems improvement.
- **Dimensions of women's empowerment that affect maternal and child nutrition:** Although there is some evidence that women's empowerment positively affects maternal and child nutrition, a lack of clarity remains on which specific dimensions of empowerment affect which nutrition outcomes. Existing research using the WEAI suggests that different aspects of empowerment matter for different outcomes, and that these also differ according to social and cultural context. One criticism of the WEAI is that its focus on agriculture may miss out on other aspects of empowerment that may be more directly related to nutrition, such as control of nonagricultural income or decision making on nutrition and health inputs. The Gender, Agriculture, and Assets Project, Phase 2, is developing a measure of women's empowerment that agriculture projects can use to track project impact, with specific attention to which dimensions of empowerment matter for nutrition. An on-going research project under IMMANA is also developing a Women's Empowerment in Nutrition Index. Research will be needed to test the tools in different contexts and generate evidence on which dimensions of women's empowerment need to be strengthened to improve maternal and child nutrition.
- **Context, food environment, and gender roles:** Another takeaway from the review is the importance of broad contextual and food environment factors that shape the agriculture and nutrition equation. There are useful frameworks to characterize—and indicators to measure—food environments (Global Panel on Agriculture and Food Systems for Nutrition, 2016; National Cancer Institute, 2017), and researchers need to use them and if possible create typologies of food environment contexts that would require or could accommodate different types of nutrition-sensitive agricultural interventions. Similarly, gender roles are culture and context specific, making it difficult to generalize the possible impacts of women's empowerment interventions, because they will vary depending on existing gender norms. As more evidence is accumulated from evaluations in different contexts, it may be possible to create typologies of how gender roles interact with nutrition-sensitive agricultural interventions.
- **The role of markets and nutrition-sensitive market interventions:** The association literature showed the consistent and large modifying effect of market access on agriculture's impact on nutrition outcomes, especially access to and consumption of diverse diets. This finding has clear implications for continued work on market development, which in and of itself would likely improve diets among poor households living in remote areas. Another implication is that markets could be leveraged to become more nutrition sensitive and provide a source of information about nutrient-rich foods, healthy diets, and meal planning, further impacting diets and nutrition. This approach, which has been used at a small scale for traditional value chains (Hawkes and Ruel, 2011), would need to identify and involve all market actors and institutions to work toward the common goal of improving access to, affordability of, information about, and demand for nutritious and diverse diets. More research on how different types of markets can support improvements in diets and nutrition is needed. Research is also needed to test effective interventions to support increased production diversity and nutrition knowledge (through targeted BCC) in communities where access to markets continues to be limited.
- **Unintended negative impacts of agriculture programs on nutrition:** The two main types of potentially negative consequences of agriculture documented in the set of studies reviewed include impacts on women's time for child feeding and care, and the health and nutrition risks associated with exposure to livestock and chicken feces, especially for young children. More research is needed to document the importance, nature, and consequences of these risks, and to design and test effective measures to mitigate them. The development of time- and labor-saving tools and machinery to reduce drudgery, particularly for women, has been proposed to address constraints on women's time, but research is needed to assess the extent to which such tools actually benefit women, rather than deprive them of income-earning opportunities in situations in which they are unable to control the use of these tools (Johnson et al.,

2016). A systematic review of time use in agriculture and nutrition concludes that existing studies do not provide clear-cut evidence on the nutrition implications of agricultural interventions, even when these interventions increase time spent in agriculture, because households tend to use adaptive measures to adjust for changes in time allocation (Johnston et al., 2015). These findings are encouraging, but more solid evidence from different contexts is needed to rule out the potentially negative consequences of women's time in agriculture on child care and nutrition.

5. Program and policy recommendations

New evidence from rigorous impact evaluations confirms that NSAP improve a variety of nutrition outcomes in both mothers and children, especially when these programs include nutrition and health BCC and carefully designed interventions to empower women. Greater benefits for child nutrition outcomes (for example, dietary diversity, nutrient intakes, Hb/anemia, diarrhea, and WHZs) are achieved when programs also incorporate actions to improve health and WASH practices and to provide specially formulated fortified products to address children's high nutrient requirements in areas where access to nutrient-rich foods is limited. Impacts on stunting, however, is still very limited, in spite of renewed efforts to strengthen the design, scope, implementation, and evaluation of NSAP. It appears that loading agricultural programs with multiple interventions that address a large number of direct and underlying determinants of child nutrition (for example, income; food availability and access; micronutrient adequacy; gender equity; and nutrition, health, and hygiene knowledge, practices, and use of services) is effective in improving several nutrition outcomes, but is insufficient to achieve stunting impacts in the usual two- to four-year time frame used for impact assessments. We question whether a high quality of operations, implementation, and monitoring can be maintained for such complex, multisectoral programs, and whether successful scale-up is achievable

Given these constraints, we join the emerging consensus on the need for agriculture to focus on supporting access to and consumption of high-quality diets rather than on directly reducing childhood stunting. Improving diets for all household members is a much more logical, reasonable, and achievable goal for agriculture than addressing childhood stunting, and it is equally important for global development (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Herforth and Ballard, 2016). Our review shows that NSAP consistently improve household access to nutritious foods and the quality of mothers' and young children's diets. Although this has not yet been tested, it is likely that NSAP can convey similar benefits to other household members, including the nutritionally vulnerable adolescents and elderly. The main implication of this recommendation for NSAP is that they should continue to be designed carefully, taking into account the specific context in which they are to be implemented and using formative research to identify the main constraints that limit household and individual access to healthy diets, women's empowerment, and optimal nutrition.

Previous reviews have discussed the issues of complexity and potential overload in relation to NSAP and other multisectoral, nutrition-sensitive programs, raising the question of "integration" versus "co-location" of interventions (Ruel and Alderman, 2013). This question relates to whether it is necessary to *integrate* multiple interventions from different sectors into programs, at the risk of making them overly complex and difficult to implement and scale up with quality, or whether the same impacts could be achieved by *co-locating* or targeting sectoral interventions to the same individuals, households, or communities. A recommendation to "think multisectorally, and act sectorally" (World Bank, 2013) suggests stimulating dialogue across sectors at the planning, monitoring, and review stages, while ensuring that each sector uses its unique expertise to implement (sectorally) with quality and efficiency. This approach should be rigorously tested and compared with integrated programs offering the same set of interventions, using implementation and impact research tools to assess efficiency, effectiveness, and cost-effectiveness.

Another main takeaway from the review is the importance of context in determining how, to what extent, and under what conditions agriculture impacts nutrition. The literature looking at associations between agriculture and nutrition outcomes was particularly useful in highlighting how markets modify production-consumption diversity linkages. In general, production diversity was found to be important for dietary diversity mostly, if not only, among households that have limited access to markets. This led Sibhatu et al. (2015) to comment that recommendations to diversify production everywhere are misguided and that supporting commercialization of smallholder farms may be a far more effective strategy to improve nutrition. Several other contextual factors, including women's social status and empowerment; social norms; and socioeconomic, environmental, political, cultural, and food environment factors were identified as key aspects that affect both associations between agriculture and nutrition outcomes and the uptake of, response to, and nutrition impacts of agriculture programs (Fiorella et al., 2016; Herforth and Ballard, 2016). The importance of context makes the tailoring of programs and interventions all the more important but greatly complicates the interpretation and generalizability of findings across studies. This complexity, however, needs to be addressed, and it is possible that some typologies of contexts and related decision-making tools could be designed in the future when results from a larger body of evidence are available.

6. Conclusions

A lot has happened in the area of agriculture and nutrition over the past decade, and the body of evidence—and its quality—have increased exponentially. It will be particularly important in the near future to expand this work to look at issues of sustainability, scale-up, and cost-effectiveness, and to explore how the new body of evidence can help inform broader agriculture policy and investment decisions. With the rich set of ongoing studies, a greater understanding of what agriculture can and cannot do to contribute to nutrition improvements, and a solid commitment to achieving the Sustainable Development Goals, the next 10 years promise to bring new evidence, action, and successes in improving nutrition through agriculture.

Acknowledgements

We are grateful for the significant contributions to the design and focus of the paper from Nancy Johnson, previously Senior Research Fellow at IFPRI, now Senior Agricultural Research Officer for the CGIAR's Independent Science and Partnership Council at the UN Food and Agriculture Organization (FAO) in Rome, Italy.

Conflicts of interest

None.

Funding source

This work was supported by the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH) led by the International Food Policy Research Institute (IFPRI).

References

Abay, K., Hirvonen, K., 2016. Does market access mitigate the impact of seasonality on child growth? Panel data evidence from northern Ethiopia (No. WP-2016-05), Innocenti Working Paper.

Alaofè, H., Burney, J., Naylor, R., Taren, D., 2016. Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in Northern Benin. Food Nutr. Bull. 37, 164–175. http://dx.doi.org/10.1177/0379572116639710.

Alkire, S., Meinzen-Dick, R., Peterman, A., Quisumbing, A., Seymour, G., Vaz, A., 2013. The women's empowerment in agriculture index. World Dev. 52, 71–91. http://dx.doi.org/10.1016/j.worlddev.2013.06.007.
Bageant, E., Liu, Y., Diao, X., 2016. Agriculture-Nutrition Linkages and Child Health in the Presence of Conflict in Nepal (IFPRI Discussion Paper 1515., IFPRI Discussion Paper). International Food Policy Research Institute (IFPRI), Washington DC.
Berti, P.R., Krasevec, J., Fitzgerald, S., 2004. A review of the effectiveness of agriculture interventions in improving nutrition outcomes. Public Health Nutr. 7, 599–609. http://dx.doi.org/10.1079/PHN2003595.
Bhagowalia, P., Headey, D., Kadiyala, S., 2012. Agriculture, Income, and Nutrition Linkages in India Insights from a Nationally Representative Survey (IFPRI Discussion Paper 01195). International Food Policy Research Institute (IFPRI), Washignton, DC.
Bhutta, Z.A., Das, J.K., Rizvi, A., Gaffey, M.F., Walker, N., Horton, S., Webb, P., Lartey, A., Black, R.E., 2013. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet 382, 452–477. http://dx.doi.org/10.1016/S0140-6736(13)60996-4.
Bill & Melinda Gates Foundation and DFID (UK Department for International Development), 2017. Agriculture for Improved Nutrition: A Future Research Agenda (WWW Document). URL ⟨http://anh-academy.org/sites/default/files/Agriculture for Improved Nutrition-A Future Research Agenda.pdf⟩ (accessed 5 July 2017).
Black, R.E., Victora, C.G., Walker, S.P., Bhutta, Z. a., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., The Maternal and Child Nutrition Study Group, 2013. Maternal and child undernutrition and overweight in low-income and middle-income countries. Lancet 382, 427–451. http://dx.doi.org/10.1016/S0140-6736(13)60937-X.
Bliznashka, L., Olney, D.K., Ruel, M.T., Rawat, R., Becquey, E., Birba, O., 2016. An integrated agriculture and nutrition program in Burkina Faso has positive intrahousehold spillover effects on maternal and child nutritional status, but no sustained longterm improvements in household welfare. FASEB J. 30, 274.2.
Bouis, H.E., Saltzman, A., 2017. Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. Glob. Food Secur. 12, 49–58. http://dx.doi.org/10.1016/j.gfs.2017.01.009.
Carletto, C., Corral, P., Guelfi, A., 2017. Agricultural commercialization and nutrition revisited: empirical evidence from three African countries. Food Policy 67, 106–118. http://dx.doi.org/10.1016/j.foodpol.2016.09.020.
Carletto, G., Ruel, M., Winters, P., Zezza, A., 2015. Farm-level pathways to improved nutritional status: introduction to the special issue. J. Dev. Stud. 51, 945–957. http://dx.doi.org/10.1080/00220388.2015.1018908.
Cunningham, K., Ploubidis, G.B., Menon, P., Ruel, M., Kadiyala, S., Uauy, R., Ferguson, E., 2015. Women's empowerment in agriculture and child nutritional status in rural Nepal. Public Health Nutr. 1–12. http://dx.doi.org/10.1017/S1368980015000683.
Darrouzet-Nardi, A.F., Miller, L.C., Joshi, N., Mahato, S., Lohani, M., Rogers, B.L., 2016. Child dietary quality in rural Nepal: effectiveness of a community-level development intervention. Food Policy 61, 185–197. http://dx.doi.org/10.1016/j.foodpol.2016.03.007.
De Beer, H., 2012. Dairy products and physical stature: a systematic review and meta-analysis of controlled trials. Econ. Hum. Biol. 10, 299–309. http://dx.doi.org/10.1016/j.ehb.2011.08.003.
de Brauw, A., Eozenou, P., Moursi, M., 2015a. Programme participation intensity and children's nutritional status: evidence from a randomised control trial in Mozambique. J. Dev. Stud. 51, 996–1015. http://dx.doi.org/10.1080/00220388.2015.1018907.
de Brauw, A., Eozenou, P., Gilligan, D.O., Hotz, C., Kumar, N., Meenakshi, J.V., 2015b. Biofortification, Crop Adoption, and Health Information: Impact Pathways in Mozambique and Uganda. HarvestPlus Working Paper 21. HarvestPlus, Washington, DC.
DFID, 2014. Can Agriculture Interventions Promote Nutrition? Agriculture and Nutrition Evidence Paper. DFID (UK Department for International Development), London UK.
Domènech, L., 2015. Improving irrigation access to combat food insecurity and undernutrition: a review. Glob. Food Secur. 6, 24–33. http://dx.doi.org/10.1016/j.gfs.2015.09.001.
FAO, 2013. The State of Food and Agriculture (SOFA). Food Systems for Better Nutrition. FAO, Rome, Italy.
Fiorella, K.J., Chen, R.L., Milner, E.M., Fernald, L.C.H., 2016. Agricultural interventions for improved nutrition: a review of livelihood and environmental dimensions. Glob. Food Secur. 8, 39–47. http://dx.doi.org/10.1016/j.gfs.2016.03.003.
Flores-Martinez, A., Zanello, G., Shankar, B., Poole, N., 2016. Reducing anemia prevalence in Afghanistan: socioeconomic correlates and the particular role of agricultural assets. PLoS One 11, e0156878. http://dx.doi.org/10.1371/journal.pone.0156878.
Gelli, A., Becquey, E., Ganaba, R., Headey, D., Hidrobo, M., Huybregts, L., Verhoef, H., Kenfack, R., Zongouri, S., Guedenet, H., 2017. Improving diets and nutrition through an integrated poultry value chain and nutrition intervention (SELEVER) in Burkina Faso: study protocol for a randomized trial. Trials 18, 412. http://dx.doi.org/10.1186/s13063-017-2156-4.
Gillespie, S., Menon, P., Kennedy, A.L., 2015. Scaling up impact on nutrition: what will it take? Adv. Nutr. Int. Rev. J. 6, 440–451. http://dx.doi.org/10.3945/an.115.008276.
Gillespie, S., van den Bold, M., 2017. Agriculture, food systems, and nutrition: meeting the challenge. Glob. Chall. 1, 1600002. http://dx.doi.org/10.1002/gch2.201600002.
Global Panel on Agriculture and Food Systems for Nutrition, 2016. Food Systems and Diets: Facing the Challenges of the 21st Century. Global Panel on Agriculture and Food Systems for Nutrition, London, UK.
Global Panel on Agriculture and Food Systems for Nutrition, 2014. How Can Agriculture and Food System Policies Improve Nutrition? Technical Brief. Global Panel on Agriculture and Food Systems for Nutrition, London, UK.
Gómez, M.I., Barrett, C.B., Raney, T., Pinstrup-Andersen, P., Meerman, J., Croppenstedt, A., Carisma, B., Thompson, B., 2013. Post-green revolution food systems and the triple burden of malnutrition. Food Policy 42, 129–138. http://dx.doi.org/10.1016/j.foodpol.2013.06.009.
HarvestPlus, 2017. Biofortification: The nutrition revolution is now. [WWW Document]. URL ⟨http://www.harvestplus.org/biofortification-nutrition-revolution-now⟩ (accessed 15 March 2017).
Haselow, N.J., Stormer, A., Pries, A., 2016. Evidence-based evolution of an integrated nutrition-focused agriculture approach to address the underlying determinants of stunting. Matern. Child Nutr. 12, 155–168. http://dx.doi.org/10.1111/mcn.12260.
Hawkes, C., Ruel, M., 2011. Value Chains for Nutrition. 2020 Conference: Leveraging Agriculture for Improving Nutrition and Health. 2020 Conference Paper #4. International Food Policy Research Institute (IFPRI), Washington, DC.
Hawkes, C., Turner, R., Waage, J., 2012. Current and Planned Research on Agriculture for Improved Nutrition: a Mapping and a Gap analysis. Technical Report. UK Department for INternational Development (DFID), London.
Headey, D., 2014. An Analysis of Trends and Determinants of Child Undernutrition in Ethiopia, 2000/2011. Ethiopia Strategy Support Program (Working Paper # 70). International Food Policy Research Institute (IFPRI), Washington, DC.
Headey, D., Chiu, A., Kadiyala, S., 2012. Agriculture's role in the Indian enigma: help or hindrance to the crisis of undernutrition? Food Secur 4, 87–102. http://dx.doi.org/10.1007/s12571-011-0161-0.
Headey, D., Hirvonen, K., 2016. Is exposure to poultry harmful to child nutrition? An observational analysis for rural Ethiopia. PLoS One 11, e0160590. http://dx.doi.org/10.1371/journal.pone.0160590.
Headey, D., Nguyen, P., Kim, S., Rawat, R., Ruel, M., Menon, P., 2016. Is exposure to animal feces harmful to child nutrition and health outcomes? A multicountry observational analysis. Am. J. Trop. Med. Hyg. http://dx.doi.org/10.4269/ajtmh.16-0270.
Herforth, A., Ballard, T.J., 2016. Nutrition indicators in agriculture projects: current measurement, priorities, and gaps. Glob. Food Secur. 10, 1–10. http://dx.doi.org/10.1016/j.gfs.2016.07.004.
Herforth, A., Harris, J., 2014. Understanding and Applying Primary Pathways and Principles. Brief #1. Improving Nutrition through Agriculture Technical Brief Series. USAID/Strengthening Partnerships, Results, and Innovations in Nutrion (SPRING), Arlington, VA.
Hirvonen, K., Hoddinott, J., 2014. Agricultural production and children’s diets: Evidence from rural Ethiopia (No. 69), Ethiopia Strategy Support Program Working Paper.
Hoddinott, J., Headey, D., Dereje, M., 2015. Cows, missing milk markets, and nutrition in rural Ethiopia. J. Dev. Stud. 51, 958–975. http://dx.doi.org/10.1080/00220388.2015.1018903.
Hotz, C., Loechl, C., de Brauw, A., Eozenou, P., Gilligan, D., Moursi, M., Munhaua, B., van Jaarsveld, P., Carriquiry, A., Meenakshi, J.V., 2012a. A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women. Br. J. Nutr. 108, 163–176. http://dx.doi.org/10.1017/S0007114511005174.
Hotz, C., Loechl, C., Lubowa, A., Tumwine, J.K., Ndeezi, G., Masawi, A.N., Baingana, R., Carriquiry, A., de Brauw, A., Meenakshi, J.V., Gilligan, D.O., 2012b. Introduction of b-carotene – rich orange sweet potato in rural Uganda results in increased vitamin A intakes among children and women and improved vitamin A status among. J. Nutr. 142, 1871–1880. http://dx.doi.org/10.3945/jn.111.151829.The.
Iannotti, L., Lesorogol, C., 2014. Animal milk sustains micronutrient nutrition and child anthropometry among pastoralists in Samburu, Kenya. Am. J. Phys. Anthropol. 155, 66–76. http://dx.doi.org/10.1002/ajpa.22547.
IFPRI, 2016. Global Nutrition Report 2016: From Promise to Impact: Ending Malnutrition by 2030. International Food Policy Research Institute (IFPRI), Washington, DC.
IFPRI, 2011. Leveraging Agriculture for Improving Nutrition and Health: Highlights from an International Conference. International Food Policy Research Institute (IFPRI), Washington, D.C.. http://dx.doi.org/10.2499/9780896296725.
Jaenicke, H., Virchow, D., 2013. Entry points into a nutrition-sensitive agriculture. Food Secur. 5, 679–692. http://dx.doi.org/10.1007/s12571-013-0293-5.
Johnson, N.L., Kovarik, C., Meinzen-Dick, R., Njuki, J., Quisumbing, A., 2016. Gender, assets, and agricultural development: lessons from eight projects. World Dev. 83, 295–311. http://dx.doi.org/10.1016/j.worlddev.2016.01.009.
Johnston, D., Stevano, S., Malapit, H., Hull, E., Kadiyala, S., 2015. Agriculture, Gendered Time Use, and Nutritional Outcomes: A Systematic Review IFPRI Discussion Paper #01456. International Food Policy Research Institute (IFPRI), Washington, DC.
Jones, A.D., 2017. On-farm crop species richness is associated with household diet diversity and quality in subsistence- and market-oriented farming households in Malawi. J. Nutr. 147, 86–96. http://dx.doi.org/10.3945/jn.116.235879.
Jones, A.D., 2014. The production diversity of subsistence farms in the Bolivian Andes is associated with the quality of child feeding practices as measured by a validated summary feeding index. Public Heal. Nutr. 18, 329–342. http://dx.doi.org/10.1017/S1368980014000123.
Jones, A.D., Cruz Agudo, Y., Galway, L., Bentley, J., Pinstrup-Andersen, P., 2012. Heavy agricultural workloads and low crop diversity are strong barriers to improving child feeding practices in the Bolivian Andes. Soc. Sci. Med. 75, 1673–1684. http://dx.doi.org/10.1016/j.socscimed.2012.06.025.
Jones, A.D., Shrinivas, A., Bezner-Kerr, R., 2014. Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data. Food Policy 46, 1–12. http://dx.doi.org/10.1016/j.foodpol.2014.02.001.
Jones, K.M., de Brauw, A., 2015. Using agriculture to improve child health: promoting orange sweet potatoes reduces diarrhea. World Dev. 74, 15–24. http://dx.doi.org/10.1016/j.worlddev.2015.04.007.
Kabunga, N., 2014. Improved Dairy Cows in Uganda: Pathways to Poverty Alleviation and Improved Child Nutrition (IFPRI Discussion Paper 01328). International Food Policy

Research Institute, Washington, DC.
Kadiyala, S., Harris, J., Headey, D., Yself, S., Gillespie, S., 2014. Agriculture and nutrition in India: mapping evidence to pathways. Ann. N. Y. Acad. Sci. 1331, 43–56.
Kidoido, M., Korir, L., 2015. Do low-income households in Tanzania derive income and nutrition benefits from dairy innovation and dairy production? Food Secur. 7, 681–692. http://dx.doi.org/10.1007/s12571-015-0419-z.
Koppmair, S., Kassie, M., Qaim, M., 2017. Farm production, market access and dietary diversity in Malawi. Public Health Nutr. 20, 325–335. http://dx.doi.org/10.1017/S1368980016002135.
Kumar, N., Harris, J., Rawat, R., 2015. If they grow it, will they eat and grow? Evidence from Zambia on agricultural diversity and child undernutrition. J. Dev. Stud. 51, 1060–1077. http://dx.doi.org/10.1080/00220388.2015.1018901.
Kumar, N., Nguyen, P.H., Harris, J., Harvey, D., Rawat, R., Ruel, M.T., 2018. What it takes: evidence from a nutrition and gender sensitive agriculture intervention in rural Zambia. J. Dev. Eff (under review).
Le Port, A., Bernard, T., Hidrobo, M., Birba, O., Rawat, R., Ruel, M.T., 2017. Delivery of iron-fortified yoghurt, through a dairy value chain program, increases hemoglobin concentration among children 24 to 59 months old in Northern Senegal: a cluster-randomized control trial. PLoS One 12, 1–17. http://dx.doi.org/10.1371/journal.pone.0172198.
Leroy, J.L., Olney, D.K., Ruel, M.T., 2016. Evaluating nutrition-sensitive programs: challenges, methods, and opportunities. In: Covic, N., Hendricks, S.L. (Eds.), Achieving a Nutrition Revolution for Africa: The Road to Healthier Diets and Optimal Nutrition. International Food Policy Research Institute, Washington, D.C., pp. 130–146.
Leroy, J.L., Ruel, M., Verhofstadt, E., Olney, D.K., 2008. The micronutrient impact of multisectoral programs focusing on nutrition: examples from conditional cash transfer, microcredit with education, and agricultural programs. In: Micronutrient Forum 2008.
Linn, J.F. (Ed.), 2012. Scaling up in Agriculture, Rural Development, and Nutrition. 2020 Vision Focus 19. International Food Policy Research Institute (IFPRI), Washington DC.
Malapit, H.J.L., Kadiyala, S., Quisumbing, A.R., Cunningham, K., Tyagi, P., 2015. Women's empowerment mitigates the negative effects of low production diversity on maternal and child nutrition in Nepal. J. Dev. Stud. 51, 1097–1123. http://dx.doi.org/10.1080/00220388.2015.1018904.
Malapit, H.J.L., Quisumbing, A.R., 2015. What dimensions of women's empowerment in agriculture matter for nutrition in Ghana? Food Policy 52, 54–63. http://dx.doi.org/10.1016/j.foodpol.2015.02.003.
Masset, E., Haddad, L., Cornelius, A., Isaza-Castro, J., 2012. Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review (d8222–d8222). BMJ 344. http://dx.doi.org/10.1136/bmj.d8222.
Miller, L.C., Joshi, N., Lohani, M., Rogers, B., Loraditch, M., Houser, R., Singh, P., Mahato, S., 2014. Community development and livestock promotion in rural Nepal: effects on child growth and health 35, pp. 312–326.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 6, e1000097. http://dx.doi.org/10.1371/journal.pmed.1000097.
Mølgaard, C., Larnkjær, A., Arnberg, K., Michaelsen, K.F., 2011. Milk and growth in children: effects of whey and casein. In: Milk and Milk Products in Human Nutrition. KARGER, Basel, pp. 67–78. doi: 〈https://dx.doi.org/10.1159/000325576〉.
Mosites, E., Thumbi, S.M., Otiang, E., McElwain, T.F., Njenga, M., Rabinowitz, P.M., Rowhani-Rahbar, A., Neuhouser, M.L., May, S., Palmer, G.H., Walson, J.L., 2016. Relations between household livestock ownership, livestock disease, and young child growth. J. Nutr. 146, 1118–1124. http://dx.doi.org/10.3945/jn.115.225961.
Mosites, E.M., Rabinowitz, P.M., Thumbi, S.M., Montgomery, J.M., Palmer, G.H., May, S., Rowhani-Rahbar, A., Neuhouser, M.L., Walson, J.L., 2015. The relationship between livestock ownership and child stunting in three countries in eastern Africa using National Survey Data. PLoS One 10, e0136686. http://dx.doi.org/10.1371/journal.pone.0136686.
Mulmi, P., Block, S.A., Shively, G.E., Masters, W.A., 2016. Economics and Human Biology Climatic conditions and child height: sex-specific vulnerability and the protective effects of sanitation and food markets in Nepal. Econ. Hum. Biol. 23, 63–75. http://dx.doi.org/10.1016/j.ehb.2016.07.002.
Murty, P.V.V.S., Rao, M.V., Bamji, M.S., 2016. Impact of enriching the diet of women and children through health and nutrition education, introduction of homestead gardens and backyard poultry in rural India. Agric. Res. 5, 210–217. http://dx.doi.org/10.1007/s40003-016-0206-x.
National Cancer Institute, 2017. Categorizing the Food Environment & Defining Measures. [WWW Document]. URL 〈http://epi.grants.cancer.gov/mfe/categorizing-the-food-environment〉 (accessed 7 September 2017).
Nguyen, P.H., Kim, S.S., Nguyen, T.T., Hajeebhoy, N., Tran, L.M., Alayon, S., Ruel, M.T., Rawat, R., Frongillo, E.A., Menon, P., 2016. Exposure to mass media and interpersonal counseling has additive effects on exclusive breastfeeding and its psychosocial determinants among Vietnamese mothers. Matern. Child Nutr. http://dx.doi.org/10.1111/mcn.12330.
Olney, D.K., Bliznashka, L., Becquey, E., Birba, O., Ruel, M.T., 2017. Adding a water, sanitation and hygiene intervention and a lipid-based nutrient supplement to an integrated agriculture and nutrition program improved the nutritional status of young burkinabé children. FASEB J. 31, 455. 〈http://www.fasebj.org/content/31/1_Supplement/455.1.s〉.
Olney, D.K., Bliznashka, L., Pedehombga, A., Dillon, A., Ruel, M.T., Heckert, J., 2016a. A 2-year integrated agriculture and nutrition program targeted to mothers of young children in Burkina Faso reduces underweight among mothers and increases their empowerment: a cluster-randomized controlled trial. J. Nutr. 146, 1109–1117. http://dx.doi.org/10.3945/jn.115.224261.
Olney, D.K., Dillon, A., Ruel, M., Nielseon, J., 2016b. Lessons learned from the evaluation of Helen Keller International's Enhanced Homestead Food Production Program. In: Covic, N., Hendricks, S. (Eds.), Achieving a Nutrition Revolution for Africa: The Road to Healthier Diets and Optimal Nutrition. International Food Policy Research Institute (IFPRI), Washington, DC, pp. 67–81.
Olney, D.K., Pedehombga, A., Ruel, M.T., Dillon, A., 2015. A 2-year integrated agriculture and Nutrition and Health Behavior Change Communication Program targeted to women in Burkina Faso reduces anemia, wasting, and Diarrhea in children 3 – 12.9 months of age at baseline: a cluster-randomized controlled tri. J. Nutr. 1–8. http://dx.doi.org/10.3945/jn.114.203539.1.
Olney, D.K., Talukder, A., Iannotti, L.L., Ruel, M.T., Quinn, V., 2009. Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. Food Nutr. Bull. 30.
Osei, A., Pandey, P., Nielsen, J., Pries, A., Spiro, D., Davis, D., Quinn, V., Haselow, N., 2017. Combining home garden, poultry, and nutrition education program targeted to families with young children improved anemia among children and anemia and underweight among nonpregnant women in Nepal. Food Nutr. Bull. 38, 49–64. http://dx.doi.org/10.1177/0379572116676427.
Osei, A.K., Pandey, P., Spiro, D., Adhikari, D., Haselow, N., De Morais, C., Davis, D., 2015. Adding multiple micronutrient powders to a homestead food production programme yields marginally significant benefit on anaemia reduction among young children in Nepal. Matern. Child Nutr. 11, 188–202. http://dx.doi.org/10.1111/mcn.12173.
Pandey, V.L., Mahendra Dev, S., Jayachandran, U., 2016. Impact of agricultural interventions on the nutritional status in South Asia: a review. Food Policy 62, 28–40. http://dx.doi.org/10.1016/j.foodpol.2016.05.002.
Pingali, P., Sunder, N., 2017. Transitioning toward nutrition-sensitive food systems in developing countries (annurev-resource-100516-053552). Annu. Rev. Resour. Econ. 9. http://dx.doi.org/10.1146/annurev-resource-100516-053552.
Pinstrup-Andersen, P., 2012. Can agriculture meet future nutrition challenges? Eur. J. Dev. Res. 25, 5–12. http://dx.doi.org/10.1057/ejdr.2012.44.
Pinstrup-Andersen, P., 2011. The Food System and Its Interaction with Human Health Nutrition. Leveraging Agriculture for Improved Nutrition and Health (2020 Conference brief #13). International Food Policy Research Institute (IFPRI), Washington, DC.
Pinstrup-Andersen, P. (Ed.), 2010. The African Food System and Its Interactions with Human Health and Nutrition. Cornell University Press, Ithaca, NY.
Popkin, B.M., 2014. Nutrition, agriculture and the global food system in low and middle income countries. Food Policy 47, 91–96. http://dx.doi.org/10.1016/j.foodpol.2014.05.001.
Rampa, F., van Seters, J., 2013. Toward the Development and Implementation of CAADP Regional Compacts and Investment Plans: the State of Play. European Center for Development Policy Management (ECDPM), Maastricht, The Netherlands and Brussels, Belgium.
Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Peden, D., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J., Ruel, M., 2007. Invited review: role of livestock in human nutrition and health for poverty reduction in developing countries. J. Anim. Sci. 85, 2788–2800.
Rawat, R., Nguyen, P.H., Ali, D., Saha, K., Alayon, S., Kim, K., Ruel, M., Menon, P., 2013. Learning how programs achieve their impact: embedding theory-driven process evaluation and other program learning mechanisms in alive & thrive. Food Nutr. Bull. 34, 212–224.
Rawlins, R., Pimkina, S., Barrett, C.B., Pedersen, S., Wydick, B., 2014. Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. Food Policy 44, 202–213. http://dx.doi.org/10.1016/j.foodpol.2013.12.003.
Rollins, N.C., Bhandari, N., Hajeebhoy, N., Horton, S., Lutter, C.K., Martines, J.C., Piwoz, E.G., Richter, L.M., Victora, C.G., on behalf of The Lancet Breastfeeding Group, 2016. Why invest, and what it will take to improve breastfeeding practices? Nemat Why invest, and what it will take to improve breastfeeding practices? Lancet 387, 491–504.
Ruel, M.T., 2001. Can Food-Based Strategies Help Reduce Vitamin A and Iron Deficiencies? A Review of Recent Evidence. Food Policy Review #5. International Food Policy Research Institute (IFPRI), Washington, DC.
Ruel, M.T., Alderman, H., 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet 382, 536–551. http://dx.doi.org/10.1016/S0140-6736(13)60843-0.
Schreinemachers, P., Patalagsa, M.A., Uddin, N., 2016. Impact and cost-effectiveness of women's training in home gardening and nutrition in Bangladesh. J. Dev. Eff. 8, 473–488. http://dx.doi.org/10.1080/19439342.2016.1231704.
Shively, G., Sununtnasuk, C., 2015. Agricultural diversity and child stunting in Nepal. J. Dev. Stud. 51, 1078–1096. http://dx.doi.org/10.1080/00220388.2015.1018900.
Shively, G., Sununtnasuk, C., Brown, M., 2015. Agricultural diversity and child stunting in Nepal. Health Place 35, 37–51. http://dx.doi.org/10.1016/j.healthplace.2015.06.008.
Sibhatu, K.T., Krishna, V.V., Qaim, M., 2015. Production diversity and dietary diversity in smallholder farm households. PNAS. http://dx.doi.org/10.1073/pnas.1510982112.
Singh, I., Squire, L., Strauss, J. (Eds.), 1986. Agricultural Household Models: Extensions, Applications, and Policy. The Johns Hopkins University Press, Baltimore, MD.
Singa, B., Chowdhury, R., Sankar, M.J., Martines, J., Taneja, S., Mazumder, S., Rollins, N., Bahl, R., Bhandari, N., 2015. Interventions to improve breastfeeding outcomes: systematic review and meta analysis (n/a-n/a). Acta Paediatr. http://dx.doi.org/10.1111/apa.13127.
Smith, L., Ramakrishnan, U., Ndiaye, A., Haddad, L., Martorell, R., 2003. The Importance of Women's Status for Child Nutrition in Developing Countries. Research Report #131. International Food Policy Research Institute (IFPRI), Washington, DC.
SPRING, 2014. Understanding the Women' s Empowerment Pathway. Brief #4.

Improving Nutrition Through Agriculture Technical Brief Series. USAID/ Strengthening Partnerships, Resuts, and Innovations in Nutrition Globally (SPRING) Project, Arlington, VA.
Sraboni, E., Malapit, H.J., Quisumbing, A.R., Ahmed, A.U., 2014. Women's empowerment in agriculture: what role for food security in Bangladesh? World Dev. 61, 11–52. http://dx.doi.org/10.1016/j.worlddev.2014.03.025.
Strange, R., Virchow, D., Jaenicke, H., 2013a. In this issue. Food Secur. 5, 749–750. http://dx.doi.org/10.1007/s12571-013-0311-7.
Strange, R., Virchow, D., Jaenicke, H., 2013b. In this issue. Food Secur. 5, 615–616. http://dx.doi.org/10.1007/s12571-013-0296-2.
United Nations, 2017. The Sustainable Development Goals Report 2017. United Nations, New York, NY.
van den Bold, M., Dillon, A., Olney, D., Ouedraogo, M., Pedehombga, A., Quisumbing, A., 2015. Can integrated agriculture-nutrition programmes change gender norms on land and asset ownership? Evidence from Burkina Faso (IFPRI Discussion Paper 51). J. Dev. Stud. 1155–1174. http://dx.doi.org/10.1080/00220388.2015.1036036.
Webb-Girard, A., Self, J.L., McAuliffe, C., Olude, O., 2012. The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review. Paediatr. Perinat. Epidermiol. 26, 205–222. http://dx.doi.org/10.1111/j.1365-3016.2012.01282.x.
Webb, P., Kennedy, E., 2014. Impacts of agriculture on nutrition: nature of the evidence and research gaps. Food Nutr. Bull. 35, 126–132.
WHO, 2014. Global Nutrition Targets 2025: Policy Brief Series (WHO/NMH/NHD/14.2). World Health Organization (WHO), Geneva, Switzerland.
World Bank, 2013. Improving Nutrition through Multisectoral Approaches. World Bank, Washington, DC.
World Bank, 2007. From Agriculture to Nutrition. Pathways, Synergies and Outcomes. The International Bank for Reconstruction and Development/The World Bank, Washington, DC.