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# Agriculture and nutrition in India: mapping evidence to pathways

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**In India, progress against undernutrition has been slow. Given its importance for income generation, improving diets, care practices, and maternal health, the agriculture sector is widely regarded as playing an important role in accelerating the reduction in undernutrition. This paper comprehensively maps existing evidence along agriculture–nutrition pathways in India and assesses both the quality and coverage of the existing literature. We present a conceptual framework delineating six key pathways between agriculture and nutrition. Three pathways pertain to the nutritional impacts of farm production, farm incomes, and food prices. The other three pertain to agriculture–gender linkages. After an extensive search, we found 78 research papers that provided evidence to populate these pathways. The literature suggests that Indian agriculture has a range of important influences on nutrition. Agriculture seems to influence diets even when controlling for income, and relative food prices could partly explain observed dietary changes in recent decades. The evidence on agriculture–gender linkages to nutrition is relatively weak. Sizeable knowledge gaps remain. The root causes of these gaps include an interdisciplinary disconnect between nutrition and economics/agriculture, a related problem of inadequate survey data, and limited policy-driven experimentation. Closing these gaps is essential to strengthening the agriculture sector's contribution to reducing undernutrition.**

**Keywords:** undernutrition; agriculture; food policy; India; framework; mapping

## Introduction

The multiple causes of undernutrition, at the individual, household, and societal levels, are now well recognized. Scientific consensus exists on the effectiveness of a core package of nutrition-specific interventions in addressing the immediate causes of child undernutrition.[1] But wider recognition of the need for nutrition-sensitive development to tackle the underlying and basic determinants of undernutrition—development that draws on diverse sectors, such as agriculture, education, health, water, and sanitation—is also gaining momentum and catalyzing important research.[2,3] Much of this literature has understandably focused on the "Asian enigma," and on India's unusually high rates of undernutrition in particular.[4–7] India alone contains around one-third of the world's undernourished children, and its exceptionally high rates of undernutrition have declined only marginally in the face of rapid economic growth (Table 1).[8] Eradicating undernutrition at the global level will therefore require tackling the immense burden of undernutrition in India, and leveraging the potential of a wide range of nutrition-sensitive sectors.

High on the list of nutrition-relevant sectors in India is agriculture. In theory, the potential for agricultural systems to influence nutrition is sizeable. As we describe in more detail below, agriculture and allied sectors play a crucial role in the provision of food, livelihoods, and income. At the same time, the combination of agricultural production and sociocultural norms can lead to harmful linkages with nutrition, particularly via maternal health and nutrition and suboptimal childcare practices. In relative terms, agriculture might also be less important than other sectors, particularly for nutrition outcomes in the first 1000 days of life when nutritional

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### Box 1. Tackling the agriculture–nutrition disconnect in India: the TANDI initiative

Agricultural initiatives alone cannot solve the nutrition crisis in India but they can play a much bigger role toward that end than they have done thus far. This basic belief gave rise to the first phase of the TANDI initiative (2010–2012), facilitated by the International Food Policy Research Institute, with funding from the Bill & Melinda Gates Foundation. The goal of TANDI was to better understand and address the failure of economic and agricultural growth to make significant inroads into reducing malnutrition in India. The initiative brought together economists, nutritionists, and other stakeholders to (1) build consensus on the key pathways between agriculture and nutrition in India and (2) address key knowledge gaps and drive a change in India's policy and program processes to tackle undernutrition.

knowledge and care practices, as well as health and sanitation, are typically of paramount importance. But what is certain is that agriculture has historically been an essential source of poverty reduction in India,[9,10] and remains a surprisingly large sector in livelihood terms. Nearly 58% of the Indian workforce lists agriculture as their primary source of employment (over 80% for the rural female labor force) and agriculture still generates more than half of total rural income. Moreover, these ratios will be significantly higher for more undernourished rural populations, suggesting that agriculture still has significant potential for driving improvements in nutrition (Box 1).

In light of these complex linkages between agriculture and nutrition, the goal of this review is to systematically assess the available evidence in the Indian context. We first focus on six well-recognized pathways between agriculture and nutrition in India (illustrated in Fig. 1 and described in Box 2). Pathways 1 and 2 focus on what economists term the *separability hypothesis*.[11] Like other productive sectors, agriculture is a source of household income and expenditure on nutrition-enhancing goods and services (pathway 2), although agriculture is generally a more important source of income for the poor and undernourished, both directly, and through so-called multiplier effects on other sectors.[12] However, in the context of various market failures, farmers may make production decisions with the objective of directly shaping their diets through consumption of their own farm produce (pathway 1). Since nonfarm activities do not possess this linkage to nutrition, pathway 1 potentially makes agriculture a special sector, but also opens up complex dynamic policy trade-offs.[13] Pathway 3, which posits that agricultural production conditions can determine the relative prices of food in general as well as specific foods, potentially also makes agriculture a special sector because it influences the composition of diets through macroeconomic linkages. Both champions and critics of the Green Revolution in India have long emphasized that technology-based improvements in wheat and rice production have reduced the relative prices of cereals while increasing the relative prices of other nutritious foods, such as fish and pulses.[14]

The next three pathways focus on linkages between child undernutrition and maternal

**Table 1. Undernutrition in India**

| | India | |
|---|---|---|
| Nutrition indicators | 1998–1999 | 2005–2006 |
| Stunting (children <3) | 51% | 45% |
| Wasting (children <3) | 20% | 23% |
| Underweight (children <3) | 43% | 40% |
| Anemia (<11.0g/dL; children 6–35 months) | 74% | 79% |
| Women with body mass index (BMI) <18.5 | 36% | 33% |
| Men with BMI <18.5 | NA | 28% |
| Women with anemia (<12.0g/dL) | 52% | 56% |
| Men with anemia (<13.0g/dL) | NA | 24% |

Source: National Family Health Survey (NFHS) rounds 2 (1998–1999) and 3 (2005–2006). http://www.rchiips.org/nfhs/about.shtml

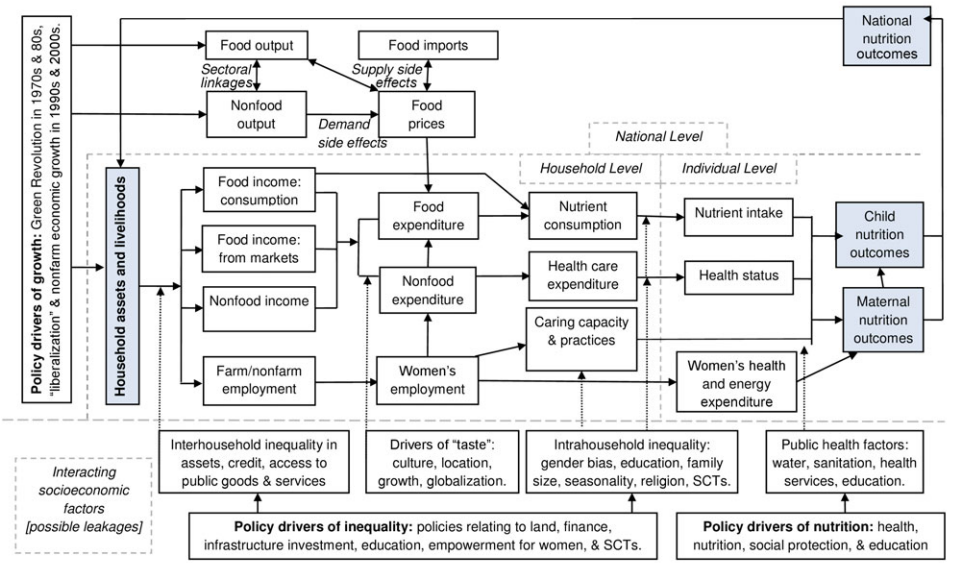


**Figure 1.** Mapping the agriculture–nutrition pathways in India.

socioeconomic and nutritional status. Pathway 4 acknowledges that agricultural production conditions can influence the empowerment of women and household decision-making outcomes for nutrition-relevant resources, particularly food and health care.[15] Pathway 5 focuses more specifically on whether large female workloads in Indian agriculture influence childcare outcomes through inadequate childcare practices. Pathway 6 addresses the possibility that the often arduous and hazardous conditions of agricultural labor in India pose substantial risks for maternal nutritional status and an intergenerational transmission of undernutrition.

The aim of this comprehensive literature review is to map existing evidence along agriculture–nutrition pathways in India, and assess both the quality and coverage of the existing literature. Following this assessment of the state of evidence, the concluding section of the paper discusses where this type of research should be moving, and how to overcome data limitations that currently hamper progress.

## Methods

To populate the evidence along these six agriculture–nutrition pathways we undertook a comprehensive review of the evidence based on three steps. First, we followed the practice of the medical literature in undertaking a systematic literature search with the specific goal of populating the evidence base as comprehensively as possible. Second, we qualitatively categorized studies into low-, medium-, and high-quality studies according to the methodology developed by the UK's Department for International Development (DFID),[16] and mapped these studies to the six agriculture–nutrition pathways described above. The objective of this step is to provide a basic overview of the state of the literature in terms of scope and quality. Third, since the literature on this subject tests multiple pathways—and hence a variety of different hypotheses—we undertook a more informal review of this literature, looking in particular at the findings of higher quality studies, where different studies agree or disagree, and significant evidence gaps. This study is therefore more of a social science–type literature review rather than a conventional systematic review, albeit with the more systematic search approaches common in the medical and nutrition literatures.

For the first of these steps, we searched 12 scientific databases, the websites of relevant institutions, and references from bibliographies (Fig. 2). To cover a range of disciplines, we included a combination of search terms related to food, nutrition, and agriculture. All references were entered into Endnote and duplicates removed. Details of the search, which was concluded in June 2013, are provided in Figure 2 (the

### Box 2. Agriculture–nutrition pathways in India

1. **Agriculture as a source of food:** Farmers produce for own consumption.
2. **Agriculture as a source of income for food and nonfood expenditures:** As a major direct and indirect source of rural income, agriculture influences diets and other nutrition-relevant expenditures.
3. **Agricultural policy and food prices:** Agricultural conditions can change the relative prices and affordability of specific foods and foods in general.
4. **Women in agriculture and intrahousehold decision making and resource allocation** may be influenced by agricultural activities and assets, which in turn influences intrahousehold allocations of food, health, and care.
5. **Maternal employment in agriculture and child care and feeding**: A mother's ability to manage child care may be influenced by her engagement in agriculture.
6. **Women in agriculture and maternal nutrition and health status:** Maternal nutritional status may be compromised by the often arduous and hazardous conditions of agricultural labor, which may in turn influence child nutrition outcomes.

keywords and strategy used for the searches can be provided upon request).

We included all articles that corresponded to the following criteria: full-text publications in published, grey, or unpublished literature linking nutrition outcomes to elements of agriculture in India.

We excluded opinion pieces or conceptual papers; research that did not measure nutrition outcomes (defined below) or did not relate elements of agriculture to nutrition outcomes; research where India-specific results could not be deciphered upon reading the full text; and research that could not be retrieved after employing various strategies, including physical searches of major libraries in Delhi.

We defined *agriculture* broadly to encompass agrifood systems and policies as depicted in Figure 1. Nutrition outcomes included: anthropometry; total calorie intake; diet quality; nutrient consumption; nutrient deficiencies; consumption of specific food commodities; nutrition knowledge; and nutrition-related practices.

As a second step, we categorized studies based on the DFID approach[16] of assessing the study design and general scientific quality (based on conceptual framing, openness and transparency, appropriateness and rigor, internal and external validity, reliability, and cogency of the paper). We then qualitatively graded each study as high, moderate, or low quality and mapped each study to one or more of the agriculture–nutrition pathways described above. We did not exclude low-quality studies from the analysis, but have taken the quality grade and the study design into account in our interpretation of the findings. Our review emphasizes the high- and moderate-quality studies, or notes caveats where appropriate.

Finally, the more analytical and critical discussion of the literature aims to draw policy-relevant conclusions where feasible, identify areas of disagreement or uncertainty, and establish where knowledge gaps or methodological shortcomings are most prevalent.

## Findings

The initial search yielded 7,002 citations, 247 of which were deemed potentially relevant and screened for their relevance to the pathways. After reading the full text and applying the selection strategy described above, 78 articles were found to be relevant (Fig. 2) and included in this evidence review. Table 2 shows the results of the search by pathway and study design. We did not find any randomized controlled research studies and found one lower quality quasi-experimental study.[17] We found 22 observational studies using analytical methods and 49 studies using only quantitative descriptive statistics. In the text below, we focus on summarizing and interpreting the 22 observational studies (14 rated as high quality and 5 as medium quality) that at least shed new evidence on these issues. We draw on high-quality descriptive studies only where we deem them to be particularly useful.

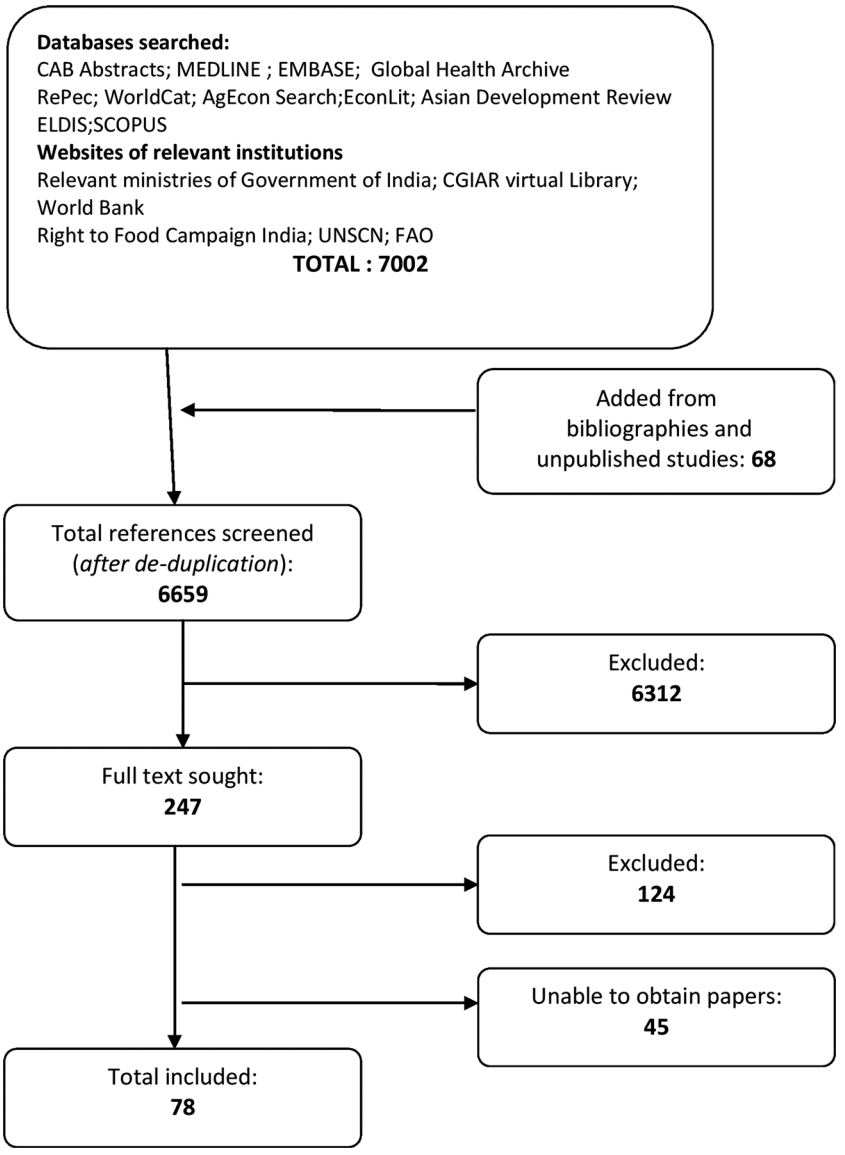


**Figure 2.** Literature search and study selection.

## Pathway 1: Agriculture as a source of food

Twenty-two papers addressed the contribution of some form of farming or home food production to nutrition.[7,17–38] We found just five high- and moderate-quality observational studies using multivariate/econometric modeling methods with multiple nutrition outcomes.[7,18,20,23,39] All of these studies test the idea, with varying degrees of explicitness, that farming assets or activities have direct effects on nutrition outcomes, even after controlling for household income, expenditure, or wealth.

Overall, three large observational studies[7,20,23] suggest that this pathway is important, generating several important findings. First, crop diversification seems to show a positive association with dietary diversification in two large observational studies[20,23] and several high- and moderate-quality descriptive studies.[25,31,33] In Andhra Pradesh,[23] children from households with a more diverse food basket and those growing

**Table 2. Number of studies included in the evidence review by agriculture–nutrition pathways and study design**

| | Number of studies |
|---|---|
| Pathway | |
| 1: Agriculture as a source of food | 22 |
| 2: Agriculture as a source of income for food and nonfood expenditures | 28 |
| 3: Agricultural policy and food prices affecting food consumption | 29 |
| 4: Women in agriculture and intrahousehold decision making and resource allocation | 7 |
| 5: Maternal employment in agriculture and child care and feeding | 9 |
| 6: Women in agriculture and maternal nutrition and health status | 11 |
| Study design | |
| Randomized controlled trials | 0 |
| Quasi-experimental studies | 1 |
| Observational studies using analytical methods such as multivariate regressions and econometric modeling | 22 |
| Observational descriptive studies | 49 |
| Qualitative studies | 3 |
| Others, including reviews with descriptive data and studies that do not clearly identify a design | 14 |

nonfood as well as food crops were more likely to recover from growth faltering. For all rural India, Bhagowalia *et al.*[20] find that irrigation and farm size are important determinants of crop diversification (controlling for household income), with irrigation compensating for smaller farm sizes. However, dietary quality could not rigorously be linked to child nutrition outcomes since dietary quality was only measured at the household rather than individual level. In contrast to these studies, Sharma[39] tests (again, with nationally representative data) whether employment in agriculture influences household nutrient availability, controlling for expenditure. She finds no evidence that farm-owning households have different diets than rural nonfarm households, although this is a weak and very specific test of the separability hypothesis.

Second, livestock assets appear to be a very important determinant of animal-sourced foods.[7,20,33] In the nationally representative study by Bhagowalia *et al.*,[20] cow and buffalo ownership was strongly associated with household milk consumption, which is consistent with emerging results from the African context.[40,41] An older study on Operation Flood found a positive association between joining dairy cooperatives and increased milk production, sales, and consumption.[18]

Finally, several studies look at the inability of farm households to meet their nutrient requirements and allude to the importance of diversification of livelihood and food sources, especially with increasing land fragmentation and landlessness.[22,30,36] However, the lack of rigorous evidence on livelihood diversification and nutrition make policy-relevant inferences difficult.

## Pathway 2: Agriculture as a source of income for food and nonfood expenditures

Although the importance of agriculture for poverty reduction is well established, less research has focused on how agriculture's contribution to the incomes of poor people influences nutrition outcomes. Twenty-eight papers attempt to investigate the link between income or expenditure (sources and shocks) and expenditure patterns, or individual nutrition status,[7,18,20–24,26,29,31,33,38,39,42–56] but only nine are high- and moderate-quality observational studies using multivariate analytical approaches[7,18,20,23,39,43,44,46,55] and very few studies contain anthropometric outcomes as a dependent variable. Instead, a relatively large literature has focused on understanding patterns and trends in household calorie availability in India, mostly with a view to assessing the apparent decline in calorie availability in recent decades.[29,49,51,52] Appropriate measurement of income, expenditure, and calorie availability is also a nontrivial task hindering this literature.

Studies examining the gradient between income and calorie intake have found it to be relatively steep, suggesting that increased income would significantly increase calorie intake.[7,44,57] Despite this, household survey data for India suggest a surprising decline in calorie consumption in recent decades that has been linked to not only declining calorie

requirements,[49] but also to measurement error in national surveys.[58] Rising incomes should also increase dietary diversity. In the nationally representative study by Headey *et al.*, the authors find that increased household wealth is a very significant determinant of the dietary diversity of children.[7] In a study assessing expenditure switching in response to external shocks, such as economic crises, no switching was seen between food and nonfood items, with expenditures rising or falling proportionally with income.[43] Also using nationally representative data, Bhagowalia *et al.*[20] report a strong positive gradient between household income and household dietary diversity, although the income gradients for child nutrition outcomes are relatively weak.

These studies therefore raise something of a paradox: income and expenditure are important determinants of dietary quality, yet nutritional outcomes have improved very slowly in a period of rapid economy-wide growth in India. Several explanations for this paradox have been proposed and investigated in the literature[7,49]—slow income growth among more undernourished populations, slow improvement with regard to micronutrient-rich food consumption and/or nonincome factors (nutrition education, infrastructure, water, sanitation, and health services), and intergenerational inertia—but with little conclusive evidence on the matter. However, the literature is sparse on the question of whether agricultural growth is more pronutrition than nonagricultural growth.

## Pathway 3: Agricultural policy and food prices affecting food consumption

Agricultural developments on either the supply or demand side clearly have substantial scope to influence the price of food relative to nonfood prices (including wages), as well as the relative price of specific foods of particular nutritional importance. Thirty papers attempt to examine supply and demand factors on household food security, and to a lesser extent on nutrition.[7,21,24,25,46,51,53,56,57,59–79] Only 12 observational studies use analytical multivariate regressions or econometric modeling, 11 of which received high and moderate ratings. Most of these studies investigate the role of agricultural growth, policies, tastes, and price changes on consumption patterns.

An earlier literature is mixed on the question of whether India's rural poor are predominantly net producers or consumers of food[9,61,67,75]—a decisive factor in determining the short-run costs or benefits of higher food prices.[51,53,73] The results of a recent high-quality and nationally representative study shows that Indian districts with higher food prices in the period 2004–2009 also saw larger rural wage growth, to the extent that all rural households benefited from higher prices to some extent.[80]

The remaining literature looks at the relative prices of specific foods or food groups. A literature on South Asia's Green Revolution first established the possibility that cheaper prices for staple grains might raise the relative price of more micronutrient-rich foods. Economic theory is ambiguous on the matter because higher relative prices would reduce the consumption of micronutrient-rich foods, but cheaper prices for staple foods also raises real income, which in turn raises demand for micronutrient-rich foods. In the 1998 Asian financial crisis, for example, higher rice prices in Indonesia led to no change in rice consumption but to large decreases in the consumption of more expensive micronutrient-rich foods, particularly eggs.[81] Thus, the real income effect dominated the relative price effect.

In India, relatively few studies rigorously inform this question. The analysis by Gaiha *et al.*[57] is one exception since the study analyzes the demand for different nutrients in a dynamic context over the period 1993–2004. They find that an increase in rice or wheat prices would increase protein consumption, though higher prices for animal-sourced foods have varying (positive and negative) effects on protein consumption. In general, their results suggest that income effects largely dominate relative price effects, at least for protein consumption. Consistent with this result, an analysis of national survey data did not show an adverse effect on child anthropometry (weight-for-age) of a sudden rise in the price of rice supplied by the Public Distribution System (PDS), which largely subsidizes rice and wheat consumption.[60]

This, in turn, touches on the question of whether governments should attempt to alter consumption patterns through the PDS or other programs or policies. While the PDS has shown a positive impact on poverty outcomes,[65] there are many more papers critiquing the inefficiency and ineffectiveness of the system.[78,82,83] A study in Rajasthan that employed a dual pricing model to account for demand-side

and supply-side constraints[84] found low access to PDS and—even among those with access—low utilization. There is no evidence as yet as to whether the PDS has any sizeable impact, positive or negative, on dietary patterns and nutrition outcomes, and this should surely be an area for future research.

Despite the tendency toward finding that the real income effects of cheaper grains outweigh or compensate relative price effects, other studies suggest that relative price changes may explain consumption trends for specific food groups (rather than nutrients as a whole). A quantitative but more descriptive analysis by Headey *et al.*[7] concludes that the steep rise in coarse grain prices relative to other foods (particularly rice and wheat) explains the widely noted decline in coarse grain consumption. The same study also finds a strong correlation between changes in prices over 1983–2000 and changes in the consumption of major food groups: large increases in the prices of pulses seem to predict the absence of consumption growth in pulses, while large declines in the relative price of fruits would appear to explain rapid growth in fruit consumption. However, the authors only offer a speculative analysis of what might explain these relative price changes in the first place.

Two studies investigate the impact of trade on food consumption. In a simulation study, Atkin reports that trade liberalization causes price increases for a number of nutrition-relevant goods.[72] Another study that incorporated both relative price and income effects found that trade liberalization could potentially reduce protein and calorie intake for the poorest 30% in both urban and rural areas of India, despite real income gains.[79] In contrast, the aforementioned paper by Jacoby casts doubt on this idea, finding statistical evidence that higher food prices reduce poverty through positive rural wage effects.[80]

## Pathway 4: Women in agriculture and intrahousehold decision making and resource allocation

Seven studies examined factors linking indicators of female empowerment, intrahousehold decision making, and resource allocation for improved health or nutrition outcomes,[20,39,85–90] five of which are observational studies using multivariate analytical methods. However, two high-quality studies[85,88] do not explicitly relate indicators of women's empowerment to nutrition outcomes per se. Berman *et al.* report that additional female wages were not sufficient to alter the overall spending pattern and, in fact, reduced spending on health, possibly due to women having insufficient time to devote to child health (pathway 5).[85] Swaminathan *et al.* show that women's asset ownership predicts their power to make decisions about their own health.[88] Bhagowalia *et al.* report a positive association between household dietary diversity and mothers' decision-making power.[20] Sharma reports that children of mothers who exercise autonomy in household decision making had better nutritional status.[39] However, none of these studies are strong on causal attribution.

## Pathway 5: Maternal employment in agriculture and child care and feeding

Nine studies examined the links between female employment, maternal caring capacity or health seeking, and nutrition and health outcomes,[7,86,87,91–96] although only four of these are analytical studies using multivariate analytical models. Of these, one study was ranked as poor-, one as moderate-, and two as high-quality empirical studies. The more descriptive studies were primarily ranked as high to moderate with several of them focusing on maternal expenditure patterns and nutritional outcomes among children.

An earlier literature raises concerns about economic liberalization, income volatility, women's labor supply, and health outcomes.[91] A high-quality paper by Bhalotra shows that economic recessions and income volatility increase female labor force participation, particularly in agriculture, with detrimental effects on healthcare seeking, and child survival,[95] which appears to be related to the opportunity cost of maternal time. The risk of rural infant mortality is 50% higher if the mother works in agriculture and her participation in rural agricultural activity also has consistently adverse effects on indicators of health seeking, such as place of delivery and antenatal care seeking.

Other studies, although weaker on causal attribution, focus more tightly on nutrition-relevant outcomes. For example, one study concludes that children of mothers in agricultural work (compared to children of mothers in nonagricultural work and children of fathers in agricultural or nonagricultural work) are more likely to contract both diarrhea and respiratory disease, and are less likely to be treated

and immunized.[87] Another study finds no *prima facie* evidence that women employed in agriculture spend less time on child care[7]—if anything, other relatively unskilled occupations (such as household, domestic, or service employment) tend to show an even higher incidence of preschoolers being cared for by other children or other adults, with the exception of unskilled manual workers. The authors test for the impact of different caregiver categories on child stunting and wasting in a multivariate analysis. They find no difference between the care impacts of mothers and other adults on mean height-for-age Z-score or stunting, but care provided by other children has an adverse impact on height-for-age Z-score. No significant effects were found for wasting or weight-for-age Z-score, and height-for-age results were not particularly robust to different samples, nor were they large in magnitude. The authors tentatively conclude that poor childcare practices are neither more prevalent nor more important in agricultural households than in nonagricultural households of similar socioeconomic status.

### Pathway 6: Women in agriculture and maternal nutrition and health status

Eleven studies related female employment in agriculture to women's energy expenditure and their nutrition and health outcomes.[7,19,85,92,93,97–102] Papers attempted to classify the energy costs of daily household and farming activities; to assess adaptations to seasonality; to assess the impact of activity and food intake on neonatal size; and to look at differences in thinness according to work behavior and gender. Only four studies are observational studies using multivariate analytical methods, one of which we ranked as poor quality, two as moderate quality, and one as high quality.

Energy expenditure by rural women was estimated in two high-quality descriptive quantitative studies using Food and Agriculture Organization Physical Activity Ratios.[97,100] In both studies, activity levels for most women in most tasks were found to be light to moderate. These studies do not necessarily take into account seasonal variations in energy expenditure or other threats to optimal nutrition outcomes. Seasonality was found to affect both energy expenditure and food intake of women in two studies, with loss in body fat, body weight and exercise capacity among poor women engaged in agricultural activities in the lean season[99] and in increased birth weight with lower maternal activity, especially during the harvest time in late gestation.[93] One other study assessed maternal activity (such as farm work) and neonatal size, finding that excessive maternal activity is associated with smaller fetal size.[92]

Thinness could not be attributed to working behavior in another study, although women were thinner in farming families than in nonfarming families, and women were found to be more likely to work long hours in farming as well as carry the burden of household chores.[98]

## Discussion

In reflecting on the general size and quality of this literature, our understanding of the complex linkages between agricultural development and nutrition outcomes in India is still hampered by a lack of high-quality evidence. The poor evidence base is not unique to India and several reviews confirm the paucity of rigorous evidence on the linkages between agriculture and nutrition globally.[2,103–106] Studies with strong causal identification are almost nonexistent. Of the 22 observational studies that use analytical techniques, only 14 were classified as high quality, while a further five were classified as moderate quality. The gender-related pathways (4–6) are particularly poorly informed, and often lack both internal and external validity. Relevant papers exploring pathways 1–3 have often made the most of available data, but the nature of these data and analytical methods limit the strength of any causal inferences. Measurement of anthropometry or micronutrient status was absent from most studies. As a result, nutrition continues to be commonly equated with calorie intake or food expenditures, with only a handful of papers grappling with dietary diversity indicators (and typically at the household rather than individual level).

Given the nature of the evidence, the review has some limitations. Most studies undertaken before 2010 do not explicitly endeavor to investigate agriculture–nutrition linkages, and thus only a handful are theory driven. The studies included in the review varied in scope and quality, and it was especially challenging to rate the descriptive studies. As noted earlier, we were careful to highlight and interpret only high- and moderate-quality analytical studies using observational data.

The gloomy conclusions on the state of the existing evidence prompt two questions. First, what conclusions, however tentative, can be drawn from a review of the existing evidence? And second, why is the evidence base so weak?

On the first of these questions, there is arguably better evidence on pathways 1–3, which look at the impacts of agriculture as an economic sector, than pathways 4–6, where gender impacts of agricultural systems are hypothesized to influence nutrition. While it is hard to establish causal attribution, there is certainly enough evidence to suggest that agriculture is a special sector insofar as it not only contributes to income generation, but also directly influences diets.

Particularly important in India is the interactive influence of farm sizes and irrigation on the diversification of both crop production and food consumption, as well as the impact of livestock assets on animal-sourced foods, particularly milk. The literature on income linkages is somewhat larger, but substantially focused on explaining a paradox: higher incomes predict increased higher calorie consumption in cross-sectional studies, but calorie consumption has seemingly been declining over time. While various papers seek to explain this apparent paradox, there are few firm conclusions, and some evidence shows that the apparent decline in calorie consumption is simply the result of measurement flaws. Finally, the literature on price impacts is inconclusive on several fronts: whether cheaper prices for cereals help or hinder dietary diversification; whether higher food prices in aggregate help or hinder the rural poor; and whether the country's largest safety net program, the PDS, has any impact on nutrition, given its various design and implementation flaws.

Turning to the second important question, it is at least possible to draw some informed conjectures as to why the evidence base is so weak. First, our literature search revealed a paucity of several specific methods, each of which would appear necessary for satisfactorily closing these knowledge gaps. Our study did not reveal any randomized controlled trials, which are now a gold standard for assessing the impacts of specific types of interventions in nutrition, health, and (more controversially) economics, and agriculture.[107] We also found very few examples of studies that use macroeconomic models to assess the impacts of food policies, which has been a notable weakness of the nutrition literature in general.[108] Finally, we found very little recent research looking at the links among gender, agriculture, and nutrition, particularly the important but rarely measured dimension of women's time use.

Second, under the TANDI project, a comprehensive audit of existing Indian datasets was undertaken to assess the possibility of jointly analyzing agriculture–nutrition linkages. The audit revealed a striking dearth of unit-level data that contained information on both nutrition and agricultural outcomes, which clearly limits the potential for rigorous empirical inquiry.[109]

Third, this data disconnect likely reflects an underlying interdisciplinary disconnect. Notable in the Indian context is the persistent focus in academic and political circles on measuring, analyzing, and maximizing household calorie consumption. In contrast, the international literature in both nutrition and economics has for many years now placed increasing emphasis on micronutrient as well as macronutrient deprivation (and on dietary diversity indicators in particular), and on the important programmatic implications of needing to redress malnutrition in the first 1000 days of life.

## Conclusions

With more than one-third of the world's undernourished children, India's relatively poor progress in reducing malnutrition is an issue of both national and global concern. Accelerating progress on this front will require a range of nutrition-specific and nutrition-sensitive interventions, including agricultural interventions.

In evaluating the existing literature on agriculture and nutrition in India, we find the evidence base is often weak and inconclusive, yet nevertheless suggestive of a potentially important role for more nutrition-sensitive agricultural development. This role appears to be multifaceted. As an economic sector, agriculture contributes to income and expenditure, to the dietary patterns of farm households who substantially consume their own produce, and to the relative prices of food as a whole and specific food items in particular. The literature on the role of women in agriculture is much less complete, but has uncovered sufficient evidence of impact to warrant further research, particularly in light of the important role of maternal health and child care in the first 1000 days of a child's life.

Clearly, there is scope for agricultural policies to influence nutrition through any of these pathways, although the existing literature falls well short of providing rigorous evidence-based recommendations. Given the substantial number of observational studies using standard household surveys, it is likely that the frontier in agriculture–nutrition research will need to be broadened through: (1) more explicit experimental designs when such designs are suitable; (2) specialized household surveys that bridge the traditional disconnect between nutrition and economic modules, and which do a better job of understanding gender and intrahousehold dynamics through rigorous modeling methods; and (3) more nutrition-sensitive macroeconomic simulation models that can rigorously gauge the nutritional impacts of large-scale policies and programs. These advances will require political will to bring about greater nutritional change, as well as a more open and dynamic forum for interdisciplinary academic collaborations.

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## Conflicts of interest

The authors declare no conflicts of interest.

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