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Seasonal variation in the proximal determinants of undernutrition during the first 1000 days of life in rural South Asia: A comprehensive review

Emily M. Madan[a,*], Jere D. Haas[a], Purnima Menon[b], Stuart Gillespie[c]

[a] Division of Nutritional Sciences, Cornell University, Ithaca, NY, USA
[b] International Food Policy Research Institute (IFPRI), Delhi, India
[c] IFPRI, Brighton, United Kingdom

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ABSTRACT

In this review, the influence of seasonal variation on undernutrition during the first 1000 days of life of life in rural South Asia is conceptualized using a modified framework developed under the “Tackling the Agriculture and Nutrition Disconnect in India” project. Evidence for the existence and extent of seasonality is summarized from 14 studies reporting on six proximal determinants of undernutrition. A limited number of studies examine seasonal variation in risk factors for this age group. All available studies, however, report a compelling finding of significant seasonal variation for at least one determinant of undernutrition. Research to clarify mechanisms for potentially adverse effects of seasonal variation on health and nutritional status during the first 1000 days of life is needed.

1. Introduction

Various measures of nutritional status are widely used to define undernutrition. Anthropometric assessment of body size, however, remains one of the most widely used and accepted methods of assessment, particularly in children from low-resource settings (The World Health Organization, 1995). The definition of undernutrition is based on a negative deviation in child growth, or growth faltering, relative to an age appropriate reference. Child undernutrition remains one of the world's most significant public health challenges. South Asia, where an estimated 34.4% of children less than five years of age are stunted (low height-for-age), has the highest number of undernourished children of any region in the world (United Nations Children's Fund (UNICEF) et al., 2016). Due to the high nutritional requirements for rapid growth and development during early life, the first 1000 days (period from conception through approximately two years of age), is a particularly high risk period for undernutrition (Save the Children, 2012). Children who are undernourished in early life are at potentially life-long increased risk of morbidity and mortality, cognitive deficits, and decreased adult productivity and earnings (Victora et al., 2008; Hoddinott et al., 2008; Martorell, 2017). Understanding and addressing undernutrition in early life in South Asia is therefore of critical public health importance.

Agriculture serves as the primary livelihood for over half the population in South Asia, and thus has important potential to be leveraged for the reduction of child undernutrition (Gillespie et al., 2015). The agricultural cycle in tropical and sub-tropical regions of developing countries is driven by agro-ecological conditions and by annual cycles in the weather. In rural South Asia, different seasons, or periods of the year, are marked by extreme variations in agro-climatic factors (e.g. temperature, rainfall, labor demands, crop cycles, etc.). The climate in South Asia is largely determined by the summer monsoon (southwest monsoon), which runs from approximately June to September. In India, for example, the heavy rainfall associated with the monsoon period typically begins on the western coast at the beginning of June, covers the entire country by mid-July, and withdrawals between September and early October. The monsoon is critical for agriculture and rural livelihoods across South Asia and forms the basis for many of the definitions of seasons employed across the region (Asia Continent: Climate; South Asia: Climate and Vegetation; The World Factbook: South Asia). Many of these definitions, however, remain somewhat arbitrary and are influenced by local and regional climate and agricultural characteristics. To allow for standardization of different seasonal definitions utilized in the literature, we employ a simplified three season framework commonly reported in the South Asian literature: summer/pre-monsoon (March–June; hot and dry), monsoon/rainy (June–September; hot and wet), and winter/post-monsoon (October–March; cool and dry) (Stevens et al., 2017).

Seasonality, or any regularly occurring variation that is correlated with the seasons (e.g. changing agricultural labor demands, food

* Correspondence to: Cornell University, 213 Savage Hall, Ithaca, NY 14850, USA.
E-mail address: emb56@cornell.edu (E.M. Madan).

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supplies, and disease vectors in the environment, etc.), is often associated with negative health and economic consequences for both individuals and populations (Devereux et al., 2012). In rural areas of developing countries, seasonality in infant and young child growth is a fairly well documented phenomenon. In South Asian countries, seasonal differences of greater than 100 g in mean birth weights and 0.5 standard deviations in birth lengths, in favor of the dry, post harvest period have been reported in the published literature (Chodick et al., 2009a, 2009b; Rao et al., 2009; Hort, 1987; Shaheen et al., 2006; Hughes et al., 2014). Seasonal changes in weight and prevalence of wasting (low weight-for-height) have also been observed in children less than two years of age (Brown et al., 1982; Costello, 1989; Panter-Brick, 1997; Gillespie and McNeill, 1994). In Bangladesh, for children 6–60 months of age, the magnitude of these differences was on the order of 3–4 fold, with weight loss occurring during the rainy season (Brown et al., 1982). Seasonal fluctuations in agro-climatic cycles may serve as potentially important indirect determinants of undernutrition and/or a failure to achieve nutritional recovery (Seasonal Dimensions to Rural Povery, 1983).

In South Asia, the majority of undernourished children continue to reside in rural areas where subsistence and semi-subsistence agriculture serve as the primary livelihoods (Kadiyala et al., 2014). The importance of agriculture for livelihoods and nutrition is increasingly recognized, and various publications have described the potential causal pathways linking agriculture and nutrition (Gillespie et al., 2015, 2012; Kadiyala et al., 2014; The World Bank, 2007; Ruel and Alderman, 2013). The potential influence of seasonality, a central feature of agrarian lives, on these pathways, however, is not widely considered, especially for the vulnerable first 1000 days life. Given the large magnitude of the undernutrition problem in South Asia, the importance of agriculture for livelihoods and nutrition, and the potential for seasonality to act as an indirect determinant of undernutrition, a better understanding of the existence and extent of seasonality in agriculture-nutrition pathways during early life in South Asia is needed. The objectives of this paper are three-fold: 1) To conceptualize the potential influence of seasonality on the proximal determinants of early child nutrition in agriculture-nutrition pathways, 2) to explore the PubMed literature for evidence of the existence and extent of seasonality in the proximal determinants of undernutrition during the first 1000 days of life in rural South Asia and, 3) To identify gaps in the existing literature for which hypotheses can be generated for future research on seasonality and young child undernutrition.

2. Conceptual framework

2.1. Approach

The TANDI framework was chosen for the purposes of this review because it was developed for the South Asian context, provides a concise picture of a causal network linking agriculture and nutrition, and is one of the few available frameworks that consider the concept of seasonality (Devereux et al., 2012). This framework (Fig. 1) illustrates seven key pathways though which agricultural livelihoods affect the nutritional status of mothers and children that have been described in detail elsewhere (Headey et al., 2012; Gillespie et al., 2012). In brief, the key pathways are: agriculture as a source of food, agriculture as a source of income, the link between agricultural policy and food prices, income derived from agriculture and how it is actually spent, women's socioeconomic status and ability to influence household decisions, women's ability to manage the care, feeding and health of young children, and women's own nutrition status (Headey et al., 2012; Gillespie et al., 2012). Due to expectations regarding the organization of the literature in PubMed, the TANDI framework was modified to reflect the underlying and immediate causes of undernutrition terminology as originally described in the UNICEF conceptual framework and expanded in various subsequent nutrition frameworks (United nations Children Fund (UNICEF), 1998). The underlying causes of undernutrition in young children include food (food security) health (health status, access and availability of health care and the health environment) and care (child feeding and care practices). The immediate causes of undernutrition include diet (dietary intake) and infection (infectious disease status). Because the nutritional status of pregnant and lactating women is integrally related to the nutritional status of children during the first 1000 days of life, the potential seasonality of these determinants (with the addition of maternal energy expenditure) were also examined in pregnant and lactating women.

3. Pathways: proximal determinants of undernutrition

We examined the pathways illustrated in the TANDI framework to conceptualize the potential mechanisms for adverse effects of seasonality on young child undernutrition. First, underlying agro-climatic conditions and production potential determine the suitability of a farming system. Second, seasonal patterns of temperature and rainfall drive the agricultural cycle, which in turn drives patterns of food production, agricultural income and agricultural labor demands for women and other members of the household. Household (e.g. socio-economic status, non-farm income, etc.) and community factors (e.g. food policies, social protection schemes, etc.) are also likely to exhibit complex seasonal patterns and relationships that will determine the likelihood, extent and ways in which seasonality is experienced by individuals and households. Adverse effects of seasonality on nutrition outcomes may then feed back to further negatively affect household assets and strategies, and thus increase risk for additional detrimental seasonal effects, or other external negative shocks.

Regardless of the pathway examined, the influence of seasonality (including any adverse effects) on young child and maternal undernutrition converges at the levels of the underlying and immediate, or the most proximal determinants, of undernutrition. For example, the time that women spend in agricultural labor is expected to change depending on the season of the year (e.g. higher during sowing and harvest periods) such that women's time for child care and feeding will be more constrained during periods of heavy labor demands. One could thus hypothesize that young infant care and feeding practices would also follow seasonal patterns related to the agricultural cycle (pathway of women's ability to manage the care, feeding and health of young children in the TANDI framework). Based on this conceptualization of the potential impact of season on the proximal undernutrition determinants outlined in the TANDI framework, we conducted a comprehensive search of PubMed in order to identify and assess published literature for the existence and extent of seasonality in the proximal determinants of undernutrition during the first 1000 days of life in rural South Asia.

4. Literature review methodology

4.1. Search strategy

Key concepts for the proximal determinants of undernutrition were extracted from components of the modified TANDI framework, and PubMed was comprehensively searched in January 2017. The following concepts were included in the search: "Immediate determinant of undernutrition" (diet, infection, maternal energy expenditure) OR "Underlying determinant of undernutrition" (food, health, care) OR "Seasonality" OR "South Asia" (Online Supplemental Table 1). Although a systematic search process informed our review, a strict systematic review protocol was not followed, and thus it should be considered as a rigorous literature review rather than a systematic review (Hagan-Zanker and Mallett, 2013).

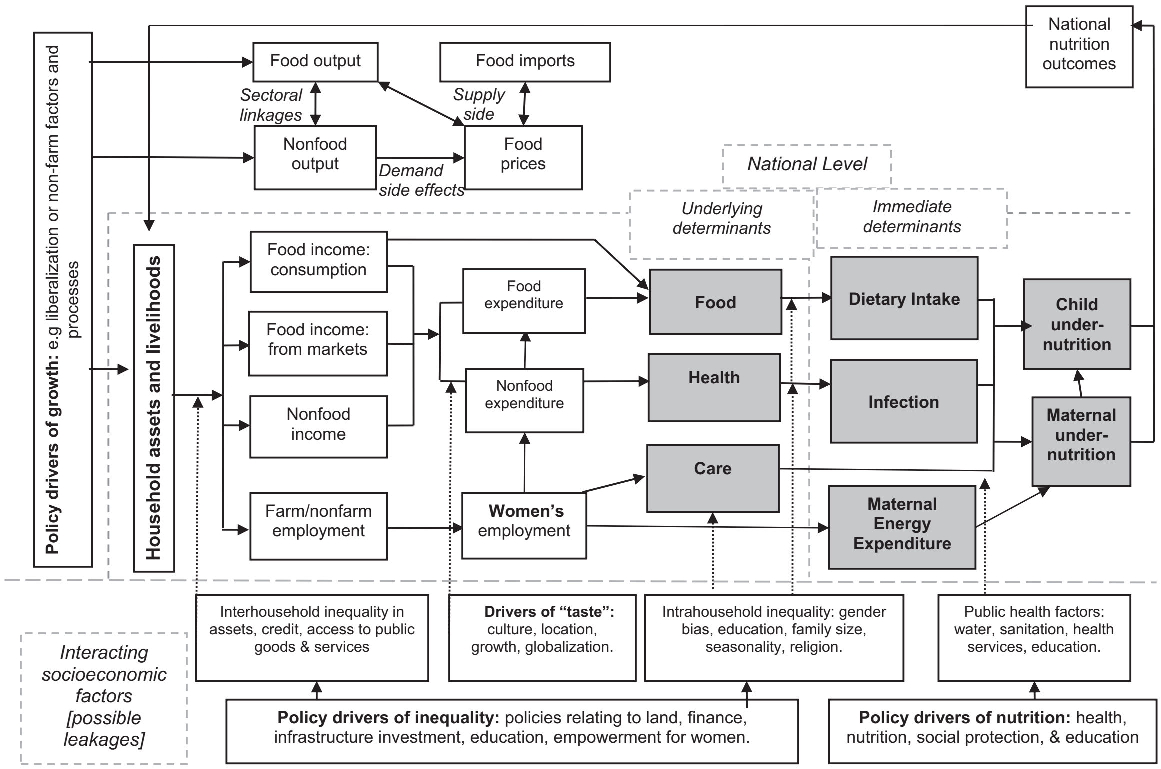

Fig. 1. Modified Tackling Agriculture and Nutrition Disconnect in India (TANDI) framework.

4.2. Eligibility criteria

Our inclusion criteria were as follows: 1) Original peer-reviewed research article with a measure of statistical significance published in English since 1980; 2) Article addressed the seasonality of at least one of the identified determinants of undernutrition during the first 1000 days of life in rural South Asia; 3) Articles on infection were included only if they examined the seasonal variation in either diarrhea or respiratory infection because these are two of the most common nutrition-relevant morbidities affecting infants in this age group, and prevalent across South Asia. Because we were interested in understanding more general seasonal trends, articles were excluded if they examined only the seasonality of specific pathogens; 4) Articles on dietary intake were likewise included only if they examined overall dietary patterns and, excluded those that focused on single nutrients; and 5) Articles for children were included only if the main analyses or sub-analyses were conducted exclusively for children between birth and two years of age.

4.3. Article Screening and data extraction process

All references were uploaded to Endnote reference manager and duplicates were removed. Title/abstract and full texts were then screened for inclusion (Fig. 2). To synthesize data from the included research, we extracted the following information into a matrix format: reference, year, country and context, study design/methods, sample, season exposure metric, type of analyses, nutrition determinant (outcomes measured), summarized main results and covariates included in the models (Table 1**)**. The approximate geographic location of the selected studies is shown in Fig. 3 (South Asia).

5. Overview of selected studies

Our search generated 14 eligible journal articles published over 31 years and spanning five South Asian countries: India (6 articles), Bangladesh (4 articles), Nepal (2 articles), Sri Lanka (1 article) and Bhutan (1 article). Study designs included cross-sectional (2 articles) and prospective (12 articles). A total of 14 main outcomes across four proximal determinants of undernutrition were reported in the included studies (Table 2). Season was most frequently defined according to month/months of the year and all 14 studies reported some significant seasonal variation in at least one undernutrition determinant. Four studies reported findings for pregnant or lactating women and ten studies reported findings for children 0–2 years of age.

6. Seasonality of proximal determinants of undernutrition in children 0–2 years of age

Ten studies from five South Asian countries (India, Bangladesh, Nepal, Sri Lanka and Bhutan) were identified that examined the seasonality of four determinants of nutritional status for children 0–2 years of age (dietary intake, infection and health).

6.1. Diet

One study was identified that examined seasonal variation in the dietary intake of young children. In a prospective study conducted in rural Bangladesh, Brown et al. (1985) examined dietary intake in children 5–18 months of age across seasons (n = 70). Compared with April–May (summer), energy consumption per kg was significantly lower in October–November (early winter) and February–March (early summer) ($p < 0.05$), and not significantly different during either August–September (monsoon) or December–January (late winter). Similar findings were reported for seasonal variation in protein and other nutrients. Overall, the percentage difference in intake between the season of highest and lowest intakes was reported as approximately 33% ($p < 0.001$). The breastmilk intake in October–November (winter) was lower than in April–May (summer), and only approximately 88% of the age expected amount ($p < 0.005$). The authors suggest that this difference likely reflected reduced maternal lactation capacity during certain periods throughout the year (Brown et al., 1985).

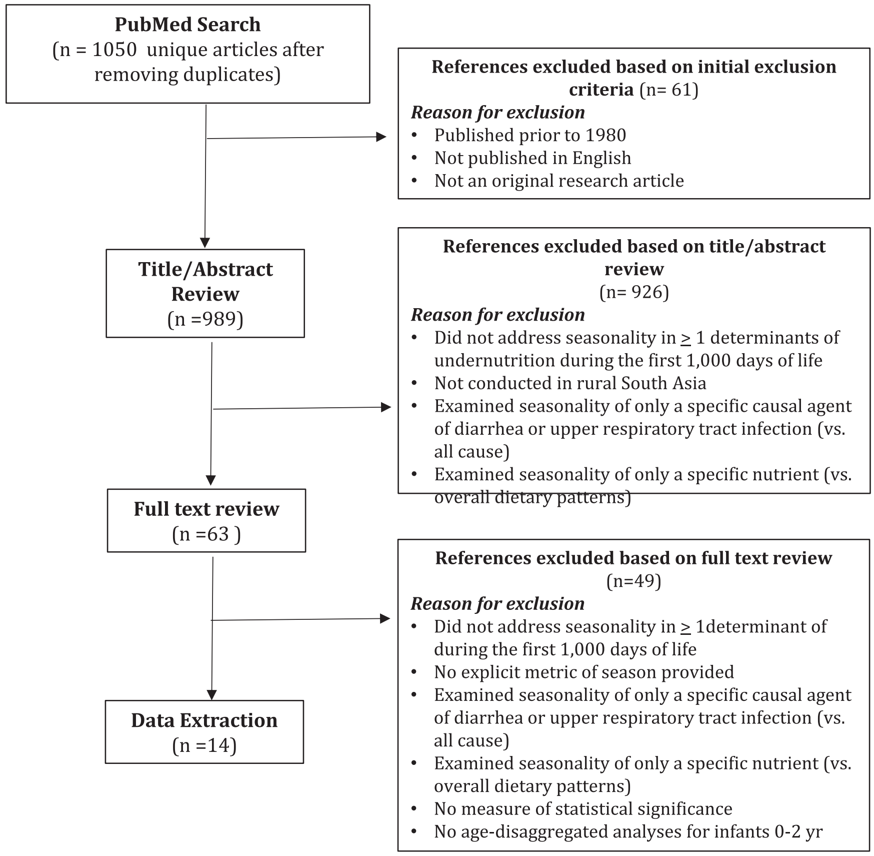

Fig. 2. Study screening and selection process.

6.2. Infection

Six studies examined the seasonality of either all-cause diarrhea or ARI. Three prospective and one cross-sectional study reported only diarrhea outcomes, two prospective studies report on both outcomes, and one prospective study reported only ARI outcomes. Ahmed et al. (2008) conducted a repeated cross-sectional survey in rural Kashmir, India and examined diarrhea prevalence in children less than five years of age across seasons. Analyses were disaggregated by age, and revealed that the prevalence of diarrhea in children 0–5, 6–11 and 12–23 months was significantly higher during the summer season as compared to other seasons ($p < 0.05$). Overall, the highest prevalence of diarrhea was reported in infants 6–11 months of age during the summer season, suggesting that seasonal risk for diarrhea may differ depending on the age of the child (32%) (Ahmed et al., 2008).

Two longitudinal studies conducted in rural Bangladesh reported similar seasonal patterns for diarrhea. Zeitlin et al. (1995) demonstrated that the incidence of diarrhea was 71% in the hottest months of April–May (summer), 35% in the preceding cooler months (winter), and 42% in the relatively less hot months after May (monsoon; $p < 0.001$) among 185 children aged 4–27 months. It was also observed that the incidence of diarrhea increased with age, as reported in other studies. The authors hypothesized that the peak incidence of diarrhea could be explained by household use of fecal contaminated water (Zeitlin et al., 1995). Pathela et al. (2006) also examined diarrhea incidence in infants 0–2 years of age in Bangladesh (n = 252). Similarly, the incidence of diarrhea peaked in March–April (summer) and had a smaller peak again in June and July (summer). In multivariate analyses, both these seasons were associated with an increased risk of diarrhea as compared to the winter season ($p < 0.001$ and $p < 0.05$, respectively) (Pathela et al., 2006).

Two other longitudinal studies conducted in Bhutan and India examined the seasonality of both diarrhea and ARI. In Bhutan, among 113 children aged 13–39 months, the peak incidence of diarrhea occurred in May and June (late summer/early monsoon period). In multivariate analyses, the monsoon period was associated with a significantly increased risk for incidence of diarrhea (OR = 2.47; $p < 0.001$). In sub-analyses, diarrhea had a negative impact on growth only during the monsoon season (7.4 +- 2.8 g/day; $p < 0.0001$), suggesting that the effect of diarrhea may have been exacerbated by other seasonal risk factors (Bohler et al., 1995). The incidence of respiratory tract infection was also significantly higher in the monsoon season as compared to other seasons ($p = 0.0268$) (Bohler et al., 1995).

In India, in a cohort of 1016 neonates (1–28 days of life) from 39 villages in India, Bang et al. (2005) report no significant seasonal difference in the incidence of diarrhea. This lack of seasonal variation may suggest that infants in the first month of life are relatively protected from seasonal effects on diarrhea, perhaps due to protective effects of breastmilk and/or less exposure to environmental contaminants as compared to older infants (Bang et al., 2005). The percent incidence of upper respiratory infection (URI), however, was significantly higher in winter as compared to both the rainy and summer seasons (29.9, 16.1 and 11.3 respectively; $p < 0.001$). Rupa et al. (2012) conducted nasopharyngeal swabbing in a cohort of slightly older Indian infants (n = 201 infants 0–12 months of age) and similarly showed an increase in infection during the winter months. URI was 1.67 times higher in winter compared to summer and 1.2 times higher in winter compared to autumn (early winter) after controlling for various confounding factors ($p < 0.001$) (Rupa et al., 2012).

6.3. Care and feeding

Two studies, one cross-sectional study in India, and one prospective study in Nepal, examined seasonal variation in feeding capacity and

Table 1
Summary of included studies.

Ref.	Country; Study Design; Sample	Study description	Season exposure metric	Type of analysis	Outcomes (Immediate (I) or Underlying (U) determinant)	Summarized main results	Potential confounders considered in analyses
Pregnant and Lactating women							
1. Panter-Brick, 1993	Nepal; Prospective; Non-pregnant non lactating women (NPNL) (n = 19); Pregnant (P) or lactating women aged 16–55 (L) (n = 24)	Women selected from a sample of representative households in one village in rural Nepal (Salme). Data on time allocation (direct observation) and total energy expenditure (TEE) (indirect calorimetry) collected in each of four seasons	Year divided into 4 seasons: Early Winter (Nov–Dec); Late Winter (Jan–Mar); Spring (Apr–Jun); Monsoon (Jul–Sept)	ANOVA and Wilcoxon tests	Time allocation (U); Energy expenditure (I)	• Most total time spent in outdoor activities during monsoon months ($p < 0.05$) with no differences by pregnancy or lactation status • P and L women increased TEE by 660 kJ/d and 1601 kJ/d, respectively from Jan–Mar to Jul–Sept ($p < 0.018$).	pregnancy/lactation status, body mass index (BMI), basal metabolic rate (BMR)
2. Schmid et al., 2007	India; Prospective (control group of RCT); Mothers with children 6–39 months of age (n = 96)	Intervention (mixed cropping system of sorghum, millet, pulses, green leafy vegetables, fruits, vegetables, roots and tubers grown without the use of pesticides and with supplemental gathering of wild fruits and vegetables) conducted in 19 intervention and 18 control villages in Medak district. 24-h recalls collected once in each season. Nutrient values were used from the Indian National Institute of Nutrition.	Year divided into 2 seasons: Summer (April); Monsoon (August)	Paired *t*-test and signed rank test to compare summer and rainy season within control group	Nutrient intakes (energy, protein and other nutrients (I)	• Energy intakes, significantly higher during summer and monsoon ($p < 0.005$)	N/A
3. Rao et al., 2009	India; Prospective; Pregnant women; (n = 633 at 18 weeks and n = 594 at 28 weeks)	Conducted in six villages near Pune (Maharashtra state). Women recruited during pregnancy and followed until delivery. Detailed activity questionnaires and 24-h dietary recalls with meal weights collected at 18 and 28 weeks of gestation.	Month of year; Year divided into 3 seasons: Summer (Feb–May); Monsoon (Jun–Sept); Winter (Oct–Jan)	Non-parametric median tests	Dietary intake (energy and protein) (I); Maternal Activity (I)	• Median energy and protein intakes higher in winter vs. summer and rainy season ($p = 0.001$) • Proportion of women with intakes > 75% of RDA higher in winter (46%) vs. summer and rainy season (32%) • Median energy scores significantly higher in winter vs. summer and rainy seasons ($p < 0.001$)	N/A
4. Stevens et al., 2017	Bangladesh; Cross-sectional; Pregnant women; n = 288	Data collected once per season in 12 villages of Pirganj sub-district, Rangpur district. FANTA Household food insecurity access scale (HFIAS), and dietary diversity score (DDS) computed for use in analyses	Year divided into 6 seasons: Summer (15 April–14 June); Monsoon (15 June–14 August); Autumn (15 August–14 October) Late Autumn (15 October–14 December); Winter (15 December–14 February); Spring (15 February–14 April)	Kruskal-Wallis one way ANOVA by ranks test with post-hoc Mann-Whitney *U* test or chi-squared test	HFIAS (U); DDS (I)	• Median DDS significantly lower in summer vs. late autumn ($p = 0.029$ and $p = 0.027$, respectively) and significantly lower in spring vs. late autumn ($p = 0.038$). Median HFIAS score significantly higher in spring vs.	N/A

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Table 1 (*continued*)

Ref.	Country; Study Design; Sample	Study description	Season exposure metric	Type of analysis	Outcomes (Immediate (I) or Underlying (U) determinant)	Summarized main results	Potential confounders considered in analyses
						monsoon and late autumn ($p = 0.006$ and $p = 0.009$, respectively). ● No significant seasonal differences in mid-upper arm circumference	
Children 0–2 years of age							
5. Brown et al., 1985	Bangladesh; Prospective; Children 5–30 months of age (n = 70)	Conducted in two villages in Matlab, Bangladesh. Food weighings collected once per season on days when children were without illness. Breastmilk consumption was quantified with a test-weighing technique	Month of year divided into six seasons: Apr–May; Jun–Jul; Aug–Sept; Oct–Nov; Dec–Jan; Feb–Mar	Multiple regression analyses	Dietary intake (energy, protein and other nutrients) (I); Breastmilk intake (I)	● No significant seasonal variation in energy consumption in any month vs. reference season (Apr–May) ● In Oct–Nov and Feb–Mar energy consumption significantly lower vs. Apr–May ($p < 0.05$) ● Mean breastmilk intake, fat and vitamin A intake significantly lower in Oct–Nov vs. Apr–May ($p < 0.005$) ● Febrile, non-diarrheal illnesses explained significant proportion of variation in nutrient intake ($p < 0.05$)	age, age*season
6. Panter-Brick, 1991	Nepal; Prospective; Infants age 0.1–38 months of age; n = 10–40	Time allocation study conducted in one village in central Nepal. All Kami women, and a representative sample Tamang women (different ethnic groups) included. Women were observed several times per year and nursing behaviors (duration, interval, total time and frequency)	Year divided into three seasons: Winter, Spring, Monsoon	Multiple regression analyses; Analyses of co-variance with repeated measures	Nursing duration, interval, total nursing time and frequency (U)	● For Tamang women, no significant seasonal variation in feeding behaviors ● For Kami women, nursing interval ($p < 0.05$), total nursing time ($p < 0.001$) and nursing frequency ($p < 0.01$) significantly lower in winter vs. other seasons	age, ethnic group
7. Bohler et al., 1995	Bhutan; Prospective; Children 13–36 months (n = 113)	Conducted in 45 villages in Wamrong subdistrict. Children were followed monthly for 32 months and data on anthropometry, diarrhea and respiratory tract infections were collected. Recall of symptoms by maternal report. Diarrhea defined as ≥ 3 stools per day for > 4 consecutive days. Respiratory tract infection defined as coughing for > 4 consecutive days.	Year divided into 3 seasons: Pre-monsoon (February–May); Monsoon (June–September); Post-monsoon (October–January)	Logistic regression (I)	Diarrhea (incidence) (I); Respiratory tract infection (incidence) (I)	● Monsoon season associated with significant increase in incidence of diarrhea ($p < 0.0001$) ● Negative effect of diarrhea on growth was significant during the monsoon season ($p < 0.0001$), but non-significant for other seasons ($p > 0.1$). ● Incidence of respiratory tract infection significantly higher in the monsoon season vs. other seasons ($p = 0.0268$).	Breastfeeding status, age, dummy variables for individual
8. Zeitlin et al., 1995	Bangladesh; Prospective; Children aged 4–27 months; (n = 185)	Morbidity surveillance conducted from in children recruited from baseline census from 5 villages in Manikganj. Morbidity data	Year divided into 3 seasons: Dry, dusty, temperate (Feb–Mar); Hot, low water (Apr–May); Humid and rapidly rising water (Jun–Jul).	Repeated measures analysis of variance (Hotellings statistic)	Diarrhea (incidence) (I)	● Incidence of diarrhea in April–May (71%) significantly higher vs. Feb–Mar and Apr–May ($p < 0.001$).	N/A

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Table 1 (*continued*)

Ref.	Country; Study Design; Sample	Study description	Season exposure metric	Type of analysis	Outcomes (Immediate (I) or Underlying (U) determinant)	Summarized main results	Potential confounders considered in analyses
		collected by maternal recall during weekly home visits and stool consistency check. Each household was observed on average 27 times. Diarrhea defined by maternal perception.					
9. Bang et al., 2005	India; Prospective; Children 0–28 day(n = 763)	Study conducted in 39 villages nested within field trial of newborn care in rural Gadchiroli. 20 neonatal morbidities were diagnosed by trained village health workers at birth and at 8 additional home visits. Upper respiratory infection (URI) defined as cough or nasal discharge for ≥ 3 days without respiratory distress or increased respiratory rate, and diarrhea defined as ≥ 3 liquid stools, or > 9 stools of normal consistency in 24 h, or mucus or blood in liquid stool.	Year divided into 3 seasons: Summer (Mar–Jun); Rainy (Jul–Oct); Winter (Nov–Feb).	Chi-squared test	URI (incidence) (I); Diarrhea (incidence) (I)	● URI symptoms significantly higher in winter compared to the rainy and summer seasons ($p < 0.001$). ● No significant difference in the seasonal incidence of diarrhea (no p-value reported).	N/A
10. Pathela et al., 2006	Bangladesh; Prospective; Children 0–2 years of age; (n = 252)	Pregnant women from 10 villages in Mirzapur invited to participate in a longitudinal morbidity surveillance project. Infants followed twice weekly from birth until 2 years of age. Data collected on frequency and consistency of child's stool reported by mother/ caregiver in past 24 h. Diarrhea defined as ≥ 3 liquid stools or any stools containing blood	Month of year; Year divided into 3 seasons: Winter (undefined), Spring (Mar–Apr), Summer (Jun–Jul)	Bivariate and multivariate logistic regression	Diarrhea (incidence and risk) (I)	● Risk of diarrhea significantly higher in spring and summer as vs. winter season ($p < 0.001$ and $p < 0.05$, respectively)	First child in family, age group, prior diarrhea, exclusive breastfeeding, presence of household chickens, washing water source
11. Ahmed et al., 2008	India; Cross-sectional; Children < 5 years of age; (n = 11,284)	A multi-stage sample procedure used and households with children < 5 years of age selected from villages in Kashmir for inclusion in the survey. Data collected by maternal recall. Diarrhea definition not provided.	Year divided into 4 seasons: Summer, Spring, Winter, Autumn	Chi-squared for difference in proportions	Diarrhea (prevalence) (I)	● Significantly higher ($p < 0.05$) prevalence of diarrhea during summer vs. other seasons ● Prevalence of diarrhea highest in the age group 6–11 months of age	age
12. Samarawickrema et al., 2008	Sri Lanka; Prospective; n = 41 pregnant women recruited during spray season and n = 25 women recruited during pre-spray season	Women aged 20–30 from a rural farming community in Southern Sri Lanka who presented for delivery at a base hospital were recruited	Year divided into two seasons: spray season (July–August); pre-spray season (December)	*t*-tests and chi-square tests	Fetal butyrylcholin-esterase (BChE) activity, Superoxide dismutase (SOD);	● No significant differences in fetal SOD enzyme levels between seasons. ● During the spray season, significantly lower mean cord	N/A

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Table 1 (*continued*)

Ref.	Country; Study Design; Sample	Study description	Season exposure metric	Type of analysis	Outcomes (Immediate (I) or Underlying (U) determinant)	Summarized main results	Potential confounders considered in analyses
		into the study. At delivery, 2 ml of maternal blood and 5 ml of cord blood were collected. 2 ml of breast milk was collected within 24 h post-partum. Samples were analyzed for the presence of four organo-phosphorus compounds (OPCs). DNA damage to erythrocytes was examined.			Levels and DNA damage (U)	blood BChE activity ($p = 0.04$), higher production of MDA ($p < 0.001$) vs. pre-spray season. ● Only two subjects had detectable levels of OPC residue in maternal blood, cord blood or breast milk.	
13. Rupa et al., 2012	India; Prospective; Children 0–12 months of age; ($n = 210$)	Birth cohort in Vellore Block (Tamil Nadu state). At birth, and at monthly visit, nasopharyngeal swabbing was conducted. Swabs and maternal recall of symptoms used to diagnose infection. Upper respiratory infection (URI) defined as identification of bacterial colonization.	Year divided into 3 seasons: Summer (Mar–Jun); Autumn (Jul–Oct); Winter (Nov–Feb)	Bivariate and Multivariate regression	URI(risk) (I)	● Risk of infection 1.67 times higher in winter vs. autumn ($p < 0.001$), 1.3 times higher in winter vs. summer ($p < 0.001$) and 1.2 times higher in summer vs. autumn ($p < 0.001$); ● Children significantly more likely to have infection in winter vs. summer and significantly less likely in autumn vs. summer ($p < 0.001$ and $p = 0.002$, respectively)	sex, parental occupation, father education, mother education, house type, birth weight, members in house, passive smoking, firewood used for cooking, water source
14. Das et al., 2016	India; Repeated Cross-sectional; infants 0–8 months of age; $n = 20{,}793$ mothers of 0–5 month old years and $n = 10{,}130$ mothers of 6–8 month old infants	Five rounds of surveys conducted in 8 randomly selected districts n in Bihar. Using a multi-stage sampling strategy, 19 Anganwadi centers, followed by 4 eligible households were randomly selected. Mothers interviewed regarding edible items given to infants 0–5 months of age in the past 24 h and about age of weaning for infants 6–8 completed months of age. Exclusive breastfeeding (EBF) based on recall of food items in past 24 h.	Year divided into two season: winter (November–February); Autumn/Spring and winter (January–October)	Simple and multiple adjusted logistic regression	EBF (U)	● For infants 0–5 months of age, odds of EBF greater during the autumn/spring and winter vs. summer ($p < 0.05$) ● For infants 6–8 months of age, those with ≥ 3 months of the EBF period during the winter season had significantly higher odds of EBF ($p < 0.05$).	gender, religion, caste, economic status, mother's education, age

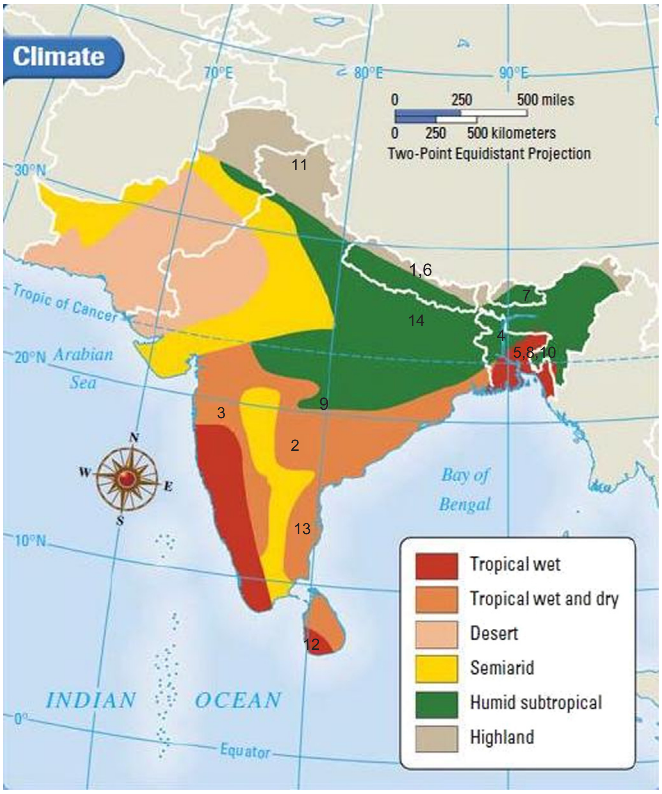

Fig. 3. Map of South Asia and location of included studies.

practices. In India, seasonal variation in infant feeding practices, as measured by exclusive breastfeeding (EBF), were observed. The odds of children aged 0–5 months of age being exclusively breastfed, or the odds of infants aged 6–8 months having received EBF for the recommended duration (six months) were greater in winter as compared to non-winter months ($p < 0.05$). In this setting, authors postulate that summer months corresponded to a period of more limited availability of food, which may have influenced the decision for mothers to supplement breastmilk (Das et al., 2016).

In contrast, Panter-Brick (1991) conducted a time allocation study across seasons in Nepal and revealed a different seasonal trend in infant feeding behaviors that depended on ethic group (n = 16 Tamang and n = 8 Kami mother-infant (1–38 months of age) pairs. The authors found that for Tamang mother-infant pairs, there was no significant seasonality in nursing behaviors for children less than two years of age. In contrast, among Kami mother-infant pairs, there was significant seasonality in nursing interval ($p < 0.05$), frequency ($p < 0.01$) and mean feed duration ($p < 0.001$) in favor of increased mean time, increased frequency and decreased interval in the monsoon season compared to other seasons. These differences represented an approximately three-fold difference in these nursing behaviors over the course of the year (Panter-Brick, 1991).

6.4. Health

One study was identified that examined the association between season and exposure to air pollutants. In rural Sri Lanka, Samarawickrema et al. (2008) examined seasonal variation in exposure to air pollutants associated with pesticide use in agriculture. Pregnant women were recruited during pesticide spray (July–August and January–February; summer and late winter months) and non-spray (December) seasons (early winter) and fetal cord blood samples were examined for evidence of possible negative effects of exposure to organophosphorus compounds (OPCs) on the fetus (n = 66). Although mothers recruited during the non-spray season also had some exposure to OPC's from previous spray seasons, cord blood samples obtained during the spray season had lower mean butyrylcholinesterase activity ($p = 0.04$) and increased production of malondialdehyde ($p < 0.001$), both indicators of fetal oxidative stress and DNA damage, as compared to the non-spray season (Samarawickrema et al., 2008).

7. Seasonality of proximal determinants of undernutrition in pregnant and lactating women

Four studies from three South Asian countries (Bangladesh, India and Nepal) were identified that examined the seasonality of three nutrition determinants (food security, dietary intake and activity) in pregnant and lactating women.

7.1. Diet and energy expenditure

Two prospective studies conducted in India report findings for dietary intake outcomes. Schmid et al. (2007) examined the dietary intake of mothers (n = 96) in two seasons (summer and rainy) within control villages of a randomized controlled trial. Median maternal intakes of all nutrients (energy, protein, carbohydrates, fat, dietary fibre, iron, vitamin-A) except for vitamin-C were higher during summer

Table 2
Reported outcomes on seasonal variation of proximal determinants of undernutrition during the first 1000 days of life in rural South Asia.

Outcomes reported in literature	Total studies reporting outcome	Significant finding	Null/Non-significant finding (N)	Reported season/s of adverse effect
Pregnant and Lactating Women				
Diet Diversity Score	1	1	0	Spring/Summer
Dietary intake (Protein and energy)	1	1	0	Summer; Monsoon
Dietary intake (energy, protein and other nutrients)	1	1	0	Monsoon
Food Security Score	1	1	0	Monsoon
Total energy expenditure	1	1	0	Monsoon
Activity score	1	1	0	Winter
Children 0–2 years of age				
Dietary intake (energy, protein and other nutrients)	1	1	0	Winter
Breastmilk intake	1	1	0	Monsoon
Exclusive Breastfeeding	1	1	0	Summer
Breastfeeding practices (feed duration, feed interval, feed frequency)	1	1	0	Winter
Diarrhea Incidence	4	3	1	Summer; Monsoon
Diarrhea Prevalence	1	1	1	Spring/Summer
Incidence ARI	3	3	0	Monsoon; Winter
Organophosphorus compounds	1	1	0	Monsoon; Winter

(April) as compared to the rainy season (August) ($p \leq 0.05$) (Schmid et al., 2007). This study did not provide separate analyses for mothers of different physiological status, so it is unclear, however, if this trend was the same for pregnant, lactating and non-pregnant non-lactating women.

Rao et al. (2009), in cohort of pregnant women (n = 633) in rural Maharashtra, India, report a seemingly different risk period for poor diets. Protein and energy intake, as well as activity scores were collected at 18 and 28 weeks of gestation and compared across seasons. Median energy and protein intakes were significantly higher in winter (September–January) as compared with the summer (February–May), or the rainy season (June–September) ($p = 0.001$) (Rao et al., 2009). Median total activity scores were similarly higher in winter, as compared to either the summer or the rainy season ($p < 0.001$). The authors observe that body mass index reached a nadir when activity was high (November).

One prospective study in Nepal also examined seasonal variation in energy expenditure in a group of 24 pregnant or lactating women, and 19 non-pregnant non-lactating (NPNL) across seasons (Panter-Brick, 1993). The patterns they observed were different than those reported in India. Women, regardless of pregnancy or lactation status, had significantly higher energy expenditure during the monsoon period (July–September), relative to the late winter (January–March) ($p = 0.009$ and $p = 0.018$ for NPNL and pregnant and lactating women, respectively). According to the international classification of activity, the physical activity level of women in these communities during periods of high work demands would be classified as very heavy (Panter-Brick, 1993). No significant changes in the body mass for the total group, however, were observed.

7.2. Food

In a cross-sectional study of pregnant women in rural Bangladesh (n = 288), household food security [HFIAS] and diet diversity scores were examined across seasons (Stevens et al., 2017). Median HFIAS scores were significantly higher in the late winter/early summer period (February–April) than during the monsoon (June–August) and early winter periods (October–December) ($p = 0.006$ and $p = 0.009$, respectively). Median diet diversity scores in pregnant women (n = 288) were significantly lower in the late winter/early summer (February–April) and summer (April–June) periods as compared to the early winter period (October–December). No seasonal variation in mid-upper arm circumference was observed (Stevens et al., 2017). Authors theorized that seasonal variation in food security was related to the yearly cycles in "Monga," or pre-harvest periods when households frequently face food shortages (Stevens et al., 2017).

8. Discussion

This review, based on a comprehensive search of the PubMed literature, revealed a small and incomplete body of evidence to document seasonal patterns in individual proximal risk factors for undernutrition during the first 1000 days of life in rural South Asia. Few well-designed longitudinal studies were available, and large variability in reported outcomes frequently prevented direct comparisons of results. Most available research in the region derived from India and Bangladesh. Evidence for the existence and extent of seasonal variation in the proximal determinants of undernutrition in early life must thus, at this time, be assessed based on the entire body of literature, as opposed to literature disaggregated by either category of undernutrition determinant, or by country.

The findings from this review are compelling because all of the available studies identified in PubMed reported significant seasonal variation for at least one of the proximal determinants of undernutrition. For diarrhea, the general pattern appeared to be one of increased incidence and prevalence of diarrhea during summer and rainy seasons relative to the winter. For ARI, there was some evidence that both the winter and the monsoon seasons may be periods of higher risk for young children. The one study reporting dietary intake outcomes in young children suggested that the winter period was a relatively higher risk period for poor dietary intake. In contrast, the two studies reporting on feeding practices suggested that exclusive breastfeeding and time spent in feeding behaviors were relatively better in winter and monsoon months, respectively. The one study that examined a health determinant suggested that markers of fetal oxidative stress were associated with maternal exposure to a pesticide spray season that occurred in early winter.

Among studies reporting outcomes for the proximal determinants of undernutrition in pregnant and lactating mothers, the seasonal patterns were similarly mixed. The two studies that reported dietary intake outcomes suggested that the summer and monsoon periods were associated with greater risk for poor dietary intake. The two studies reporting on energy expenditure and activity patterns reported that the winter and monsoon periods were associated with heavy labor. The one study that examined food security reported higher food insecurity during the summer.

This review is important because it permits the identification of key gaps in the available evidence base on the effects of seasonality on the proximal determinants of undernutrition in early life in rural South Asia. It also highlights potentially important caveats that may exist in seasonality research (e.g. differential age effects, importance of cultural beliefs and practices, etc.) that should be considered in the design of future studies. This review can thus serve as a useful tool for hypothesis generation for future research. Based on the overall body of literature identified in PubMed, there appears to be consistency in the reporting of the existence of significant seasonal variation in many of the proximal determinants of undernutrition in early life in rural South Asia. Findings from this published literature, however, are not always consistent with regards to the timing of increased risk; each of the three most commonly defined seasons in South Asia (summer, winter and monsoon) were negatively associated with one or more of the proximal determinants of undernutrition. This variability may be attributed to several factors, including differences in measurement techniques, sample size and analytical approach. It is also possible, however, that the observed variation reflects differences in underlying factors, such as location-specific patterns of agricultural work, food availability and beliefs and practices regarding work and diet during pregnancy and lactation.

The lack of consistency in seasonal patterns of proximal risk factors for undernutrition, the small number of studies identified in PubMed (overall and by category of determinant), inherent weaknesses in the design of studies, and small sample sizes, prevents making any strong inference about whether a particular season in South Asia is associated with greater risk for undernutrition in early life. From this literature, we are also not able to answer important questions about the magnitude of seasonal differences in undernutrition risk factors, the extent to which such seasonal variation is context-specific, or associated with actual seasonal changes in health and nutritional status. Our simplified seasonal definition, although useful for the purposes of this review, cannot capture the complexities and nuances of seasons that may be unrelated to climate. The small size of this body of literature necessitated comparisons across contexts where potentially important differences in seasonal characteristics (e.g. access to irrigation, types of crops grown, women's participation in agricultural labor, etc.), may exist. Differences in seasonal characteristics may be associated with important differences in patterns of risk factors for undernutrition throughout the year. Finally, the restriction of our search to PubMed was appropriate for the exploratory nature of this review, but may have resulted in some relevant studies not being included in this review. The following discussion identifies several important areas for consideration in future research as well as implications for seasonality-focused policy and programming.

8.1. Seasonality research and policy should be more context-specific

Seasonality, in terms of extreme temperature and rainfall variability, is a shared feature of much of the tropical and sub-tropical world. Seasonality is multi-dimensional, and any observed negative associations between season and nutritional status reflects varying exposure to risk factors throughout the year, susceptibility of individuals and populations to these risk factors, and the effectiveness of any coping strategies utilized to mitigate risk factors. Anecdotal and empirical evidence suggest that the experience of seasonality varies broadly based on factors including, but not limited to, location, wealth and gender (Devereux et al., 2012). Other factors, such as access to irrigation and programs and policies intended to mitigate seasonal risk (e.g. food support programs during seasons of food shortage) may have important influences on the local experiences of seasonal stress (Devereux et al., 2012).

Evidence from affluent countries indicate that weather cycles do not seem to translate into the same seasonal variation in factors, such as food availability, as they do in developing country. Some researchers thus question the assumption that changes in the weather are the root cause of adverse seasonal impacts. Sabates-Wheeler and Devereux (2012) argue that poverty, not the weather, is the primary driver of adverse outcomes associated with seasons. Factors such as wealth inequalities, access and distribution, and the interaction of these factors with agro-ecological conditions, livelihoods, tastes and preferences likely vary across countries in the developing world (Sabates-Wheeler and Devereux, 2012). The body of seasonality literature conducted outside of South Asia (e.g. the Gambia), although valuable, may have limited applicability elsewhere.

8.2. Seasonality research and policy should prioritize the first 1000 days of life

Despite the increasingly recognized importance of the first 1000 days of life, this review revealed an evidence gap for seasonality research focused on this age group in rural South Asia (Martorell, 2017). Much of the available literature, particularly for earlier seasonality studies, collapses children into broad age categories (e.g. 1–5 years) and frequently excludes children less than six months of age. The susceptibility to various risk factors for undernutrition, however, has been shown to vary with the age of the child (e.g. difference in risk of diarrhea). Other research also highlights the uniqueness of the 0–6 months period, which begs for the more widespread inclusion of young infants in surveillance and the consideration of this age group separately from older infants (Mason et al., 2014; Martorell and Young, 2012). Future research should be age-disaggregated in order to explore potential differences in risk for adverse seasonality that may depend on age at exposure. Available national and regional datasets (e.g. District Level Health Surveys) could be explored for opportunities to answer some of these questions.

This review also revealed a dearth of evidence for the seasonality of the determinants of nutritional status in pregnant and lactating women. Seasonal variation in women's health and nutritional status by physiological status, and the possible trade-offs between work demands and childcare are needed to inform seasonal policies and programs. Work during the peak agricultural season may simultaneously increase income for the family, but may also lead to negative outcomes for women and children (e.g. reduced time for food preparation and childcare, etc.). A more complete understanding of these trade-offs will help build the evidence of both positive and negative outcomes associated with seasonality in agriculture-nutrition pathways.

8.3. Aspects of seasonality remain overlooked

The negative associations between season and undernutrition are arguably most well recognized for the “hungry” season, or the pre-harvest period associated with food shortages in many settings. As suggested in the available PubMed literature, other seasons of the year may also be associated with an increase in risk factors for poor health and nutritional status. For example, improved access to irrigation in many rural areas has reduced dependence on a single yearly harvest. Patterns of seasonal risk factors (e.g. reduced food availability) may thus be dramatically different than in rain-fed agricultural areas. On the other hand, increased access to irrigation could potentially increase heavy agricultural labor demands and increase time constraints for women during an additional cropping season. A growing body of evidence suggests that climate change will be associated with seasons that are more variable and less predictable than in the past (Easterling et al., 2000). Researchers and policymakers should be cautioned against single season focused public health interventions that neglect potentially critical pieces of a complex seasonality puzzle.

In 2009, the Institute for Development Studies (IDS) following its path-breaking work on seasonality in the early 1980s, convened a conference entitled “Seasonality Revisited” in order to bring renewed attention to seasonality, after it arguably fell off the research and policy agenda in the late 1990s. As part of this convening, and as a chapter of the book subsequently published, Chambers (2012) identified seasonal factors that have been generally ignored in past seasonality research (e.g. “defecation behavior and infection from feces” and “neglected aspects of nutrition and energy use”). Our search in PubMed revealed a continued dearth of research in these areas. The dynamic complexity of seasonality, thus remains incompletely understood by researchers and policy makers who are often “season-proof” and “season blind” (Chambers, 2012).

8.4. Clear policy and program implications need to be acted upon

Seasonality is an important consideration for nutrition-relevant policy and programming because its effects can determine whether a policy or program can work at all, or can work optimally. The wider literature on seasonality frequently discusses “poverty traps” – that is, where seasonal effects on a livelihood determinant tips the household over the edge, beyond its coping capacity, requiring a drastic response that cannot easily be reversed (e.g. selling land) (Devereux et al., 2012). There may be other types of “nutrition traps” – less obvious but very damaging, if the seasonal ratchet effects on child growth results in stunting with all of the associated short and long term deleterious consequences (Martorell, 2017).

The design and implementation of programs to support child growth therefore need to incorporate seasonality in a range of nutrition-relevant drivers. This requires context-specific understanding of the main drivers and how they are affected by seasonality. Essentially, when considering the links between agriculture and nutrition, as shown in the TANDI framework, any program designer/manager would want to know what such a system looks like if it were viewed through a seasonal lens. Would the pathways be similar, would the entry points for intervention stay the same, or would more important ones be revealed? With regard to the major constraints on women's time that may occur due to seasonality of female agricultural labor demand, for example, what changes to program design and/or implementation may be required? How can such programs or interventions help women and families cope? Are they providing options to ease caring capacity constraints? For agricultural programs to become more nutrition-sensitive, they may need to focus more on stability, and reducing risk, *as well as* diet quality – quite different from the prevailing focus on productivity and yield. One past approach to address the range of risks, vulnerabilities and stresses associated with, or exacerbated by seasonality, was to build in short term compensatory programs. Such ‘concertina programs’ (which can expand and contract as required to operate at specific times of the year) may provide employment and reduce food insecurity by stabilizing rather than maximizing food crop production, or they may comprise seasonal social protection programs (possibly including food aid or food-for-work) (Longhurst, 2016).

Season-proofing, or helping to ensure that policies and programs are immune to the possibly deleterious effects of season, has proved to be a step too far for many policy shapers and makers for several reasons. First, a seasonally sensitive analysis and response is not just technical, but also political– as some may gain from it, while others (the poor and voiceless) are more likely to lose. Food price hikes, for example, can benefit larger farmers who are net sellers. Seasonality may always exist, but *adverse* seasonality is frequently driven by the politics of access and distribution (Devereux et al., 2012). A second reason is that seasonal data from surveillance systems are thin on the ground, expensive to collect and analyze, and context-specific (which further amplifies cost). Many surveys are either timed during accessible times of the year when seasonal stress is least, or they aggregate data over the entire year. Researchers or policy makers that seek to understand the determinants of poor growth using either of these approaches may fail to see specific times or seasons of the year that have the greatest potential for harm or for benefit. Season-proofing may also result in major implementation challenges (e.g. accessibility during the rainy season) as well as issues related to the temporary hiring of workers for short periods of the year to address seasonal stress and shocks.

Lastly, any policy recommendations targeted to address adverse seasonality in maternal and young child undernutrition must be considered in the context of a larger food and health system. As illustrated in the TANDI framework, multiple distal drivers of undernutrition, separately or in combination with seasonality, also exert an important influence on the various pathways linking agriculture and nutrition. Distal drivers of undernutrition include a diverse array of complex and often interacting factors. For example, policy drivers of inequality, that may occur at both the state and national levels, will interact with socioeconomic factors at the community and household levels to drive both inter and intra household inequality. Such factors may be important determinants of if, and how, households and individuals actually experience seasonal stress (Devereux et al., 2012). Therefore, policies and programs related to including, but not excluded to, agricultural labor markets, health systems, education, women's empowerment, etc. must be considered in conjunction with more targeted seasonal programs and policies. A more in-depth evaluation of the distal drivers of undernutrition, and potential interactions with seasonality will also inform important hypothesis generating activities for future research.

9. Conclusions

Rural South Asian mothers and infants are among those most vulnerable to undernutrition and to seasonal stress. Despite a relatively consistent pattern of seasonal variation in growth reported in developing countries, this review suggests that the mechanisms to help explain the associations between season and undernutrition (via an association of season with the proximal determinants of undernutrition) are poorly elucidated in rural South Asia. The body of literature identified in our comprehensive search of PubMed was limited in terms of size and quality (study design and sample size). The outcomes reported across studies were also highly variable and not amenable to meaningful comparisons across studies. The consistent finding of significant seasonal variation in all 14 identified studies, however, is compelling and useful for hypothesis generation for future research. Because seasonal stress is likely to increase in future years due to climate change, researchers and policy makers should carefully consider seasonality in the proximal determinants of undernutrition discussed here, as well as more distal determinants, that were outside the scope of the present review, in nutrition sensitive and specific programs and policies for the treatment and prevention of undernutrition in early life (Easterling et al., 2000).

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Declarations of Interest

None.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gfs.2018.08.008.

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