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REVIEW

Socio-cultural and economic determinants and consequences of adolescent undernutrition and micronutrient deficiencies in LLMICs: a systematic narrative review

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Adolescent undernutrition is a persisting public health problem in low and lower middle income countries (LLMICs). Nutritional trajectories are complexly interrelated with socio-cultural and economic (SCE) trajectories. However, a synthesis of the SCE determinants or consequences of undernutrition in adolescents is lacking. We undertook a narrative review of published literature to provide a narrative overview of the SCE determinants and consequences associated with undernutrition among adolescents in LLMICs. We identified 98 articles from PubMed, SCOPUS, and CAB-Abstracts on determinants and consequences of undernutrition as defined by stunting, underweight, thinness, and micronutrient deficiencies. At the individual level, significant determinants included age, sex, birth order, religion, ethnicity, educational and literacy level, working status, and marital status. At the household level, parental education and occupation, household size and composition, income, socioeconomic status, and resources were associated with undernutrition. Only a few determinants at the community/environmental level, including residence, sanitation, school type, and seasonality, were identified. The consequences of adolescent undernutrition were mostly related to education and cognition. This review underscores the importance of the broad range of context-specific SCE factors at several levels that influence adolescent nutritional status and shows that further research on SCE consequences of undernutrition is needed.

Keywords: adolescence; consequences; determinants; LLMIC; undernutrition; micronutrient deficiencies

Introduction

The world faces the largest cohort of adolescents, aged between 10 and 19 years, ever.[1,2] Around 90% of these adolescents live in low- and middle-income countries (LMICs). As a result of this youth "bulge," LMICs are faced with the question of how to harness this demographic dividend, which occurs during a window of opportunity created by a shift to fewer dependent people relative to working-age individuals.[3] Adolescents are the future workforce, leaders, and bearers of the next generation. Improvement of their health and developmental outcomes through nutrition is currently seen as (another) second window of opportunity for "catch-up" growth.[4] Investing in adolescent nutrition improves not only children's health and developmental outcomes, but also those of their offspring, and consequently entire societies.[5] However, development and research programs in LMICs often focus on the first 1000 days, the first 5 years, or on women in their reproductive age since interventions in these life stages are widely believed to break intergenerational cycles of malnutrition, improving birth and pregnancy outcomes.[6,7]

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The life stage of adolescence is characterized by rapid biological growth, in which the social, economic, and cultural context of adolescents is decisive.[2,8,9] Many children in LMICs enter adolescence thin, stunted, anemic, and/or micronutrient deficient.[10] Throughout adolescence, nutrition is complexly interrelated with social, cultural, and economic trajectories including education, family formation (e.g., marriage and fertility), and labor participation;[11] disadvantages in these trajectories may influence nutritional status or the other way around. While the attention is shifting toward adolescent nutrition in international development and research,[9] evidence concerning SCE characteristics in relation to nutrition throughout adolescence is dispersed, highlighting a research gap in this area.

Additionally, there is a dearth of research on the SCE consequences of undernutrition during adolescence, although the effects of undernutrition during childhood on adult outcomes are well known. For instance, the relations between early childhood nutrition and cognition, learning, or educational achievements,[12–15] as well as between early childhood nutrition and economic productivity, wages, marriage, and fertility[16,17] are well established. But, there is a paucity of data on the effects of poor nutrition during adolescents' transitions into adulthood, and how their nutritional status is affected by their everyday life context.

To our knowledge, no reviews exist that summarize the SCE determinants and consequences of undernutrition during adolescence in LMICs. Nonetheless, Viner *et al.*[18] reviewed the social determinants of health in adolescents but did not specifically focus on nutrition or LMICs. Reviews including adolescent nutrition mostly focus on the determinants of overnutrition[19–23] or on the co-occurrence of stunting and overweight,[22] which is particularly interesting in light of the global nutrition transition.[23] A recent series of reviews on adolescent nutrition take into account eating patterns and behavioral patterns during adolescence but do not discuss the "social contexts that directly or indirectly affect adolescent nutrition" in LMICs which may include structural factors at a broader societal level, but also at the level of households and communities.[24–27] Similarly, although some studies focused on the effects of iron deficiencies on cognitive development in children,[28,29] no reviews focus on the SCE determinants or outcomes of adolescents' micronutrient status. The focus of existing reviews on adolescents has mostly been on the effect of micronutrient supplementation.[25,30–32]

In light of the challenge to unlock the potential of adolescents through improved nutrition, a synthesis on what affects, and which effects poor nutrition has throughout adolescence in a particular context is essential to tackle this challenge. Especially in LMICs where adolescents lag behind in several life domains, such a comprehensive picture could further inform research and context-specific programs that aim to understand and improve the health and developmental outcomes of adolescents. With this review, we aim to fill the research gap by providing a narrative overview of the SCE determinants and consequences associated with protein-energy undernutrition and micronutrient undernutrition/deficiencies among adolescents in low and lower middle income countries (LLMICs). Such a review may help to understand and improve efforts directed toward optimizing adolescent health and nutrition. Specific research questions are: (1) what are the SCE determinants of undernutrition and indexes of nutritional status during adolescence in LLMICs; (2) what are the SCE determinants of micronutrient status and deficiencies during adolescence in LLMICs; and (3) what are the SCE consequences of undernutrition and micronutrient deficiencies during adolescence in LLMICs? We focus on LLMICs because undernutrition remains the greatest concern and rates are only slowly declining;[23] for instance, more than a quarter of adolescent girls are reported to be underweight in 11 LLMICs and anemia is a severe public health problem among adolescent girls in 15 out of 21 LLMICs.[33]

Methods

Undernutrition encompasses both micronutrient deficiencies and macronutrient or protein-energy malnutrition. However, for the purpose of this review, the term *undernutrition* refers to stunting, underweight, and thinness, while nutritional status index(es) refers to the *Z*-scores of height-for-age (HA), weight-for-age (WA), weight-for-height (WH), and BMI-for-age (BA). Micronutrient status and related deficiencies included in this review are: vitamins A, C, D, B_{12}, iron, hemoglobin (Hb) status, anemia, iodine, zinc, folic acid, and calcium; these were selected based on evidence of the common micronutrient deficiencies during adolescence.[34]

Search method

A comprehensive search strategy was developed by using a variety of search terms for retrieving relevant literature. Two separate searches were performed between April and May 2017, one focused on undernutrition, the other on micronutrient deficiencies. Search queries built on five layers with relevant search terms. The first layer referred to "adolescence," as defined by the WHO (10–19 years).[4] The second layer included LLMICs in South and East Asia, Latin America, and Sub Saharan Africa (66 countries) derived from the World Bank list of economies.[35] The third layer included SCE aspects related to trajectories of labor participation, family formation, and education (e.g., marriage, cognitive skills, literacy, time use, household structure, and gender). The fourth layer referred to "associations" (e.g., determinants, factors, outcomes, consequences, and interrelations) since we aimed for studies that specifically focused on associations instead of prevalence rates only. The final layer differed for the two searches. In the "undernutrition" search, terms related to undernutrition (e.g., undernutrition, underweight, WA, stunting, HA, thinness, WH, and BA) were used, while for the micronutrient deficiencies search, these terms were replaced by micronutrients and deficiencies including hidden hunger, (iron deficiencies) anemia, iodine, folate, folic acid, vitamins A, B_{12}, C, and D, serum retinol, zinc, and calcium. Search queries were adapted to the requirements of the specific databases: PubMed, Scopus, and CAB Abstracts. Searches were limited to English/Dutch only and as from 1990 onward. In Scopus, we applied limits on document type, and in PubMed, we used MeSH terms for nutrition and adolescence and limited the search to humans. In total, 2554 papers were found for undernutrition, whiles 685 papers were found for micronutrient deficiencies.

Screening protocol

After duplication removal, a total of 2788 papers were screened on the basis of title and abstract. Quantitative empirical research and working papers were considered for inclusion when they showed associations between the variables of interest. Cohort and longitudinal, cross-sectional and intervention studies were considered for inclusion. Papers were excluded when they focused on diet associations with diseases or other issues (e.g., addictions, helminth infections, anorexia, diabetes, and blood pressure), unhealthy adolescents or migrants, biochemical processes, lifestyle/behavior (e.g., snacking, body image, and physical activity), or prevalence only. Studies including a broader age range or just part of the 10–19 years' range were excluded when there were no age-specific results (e.g., sample 6–12 should include specific data for 10–12 years). When a paper only reported differences between sexes without explanation or not taking into account any other variables, we rejected the paper. Qualitative research, methodology papers, review papers, editorials, and intervention studies without baseline information were excluded. Although we included terms as overweight and obesity in the queries, studies focusing on overnutrition were considered only when they included undernutrition as well. A full-text screening was performed on a total of 248 papers, after which 141 studies were rejected based on criteria mentioned above, or when the authors were not able to retrieve the full texts after having requested the papers from authors or research organizations ($n = 18$). Afterward, a manual search was performed in which bibliographies of eligible papers and relevant reviews were screened using the same procedure described above. Furthermore, we asked an external researcher to screen and add to this final list, and we checked our own databases for relevant papers ($n = 20$).

Transparency assessment

Finally, 111 papers underwent a transparency check in which they were graded against seven methodological criteria in order to assess interpretability: research aim or hypothesis, data collection methods, sampling plan and size, analysis method, conclusions, and limitations were either available (score 2), partly available (score 1), or missing (score 0). Almost a third of the papers scored at least one zero, but nine papers were excluded because they scored low (1 or 0) on multiple indicators. A total of 57 and 45 papers were included in this review for undernutrition and micronutrient deficiencies, respectively. Figure 1 provides an overview of the screening process based on the PRISMA criteria.[36]

Data extraction and analysis

Papers were thoroughly read and coded deductively as well as inductively using Atlas Ti for the

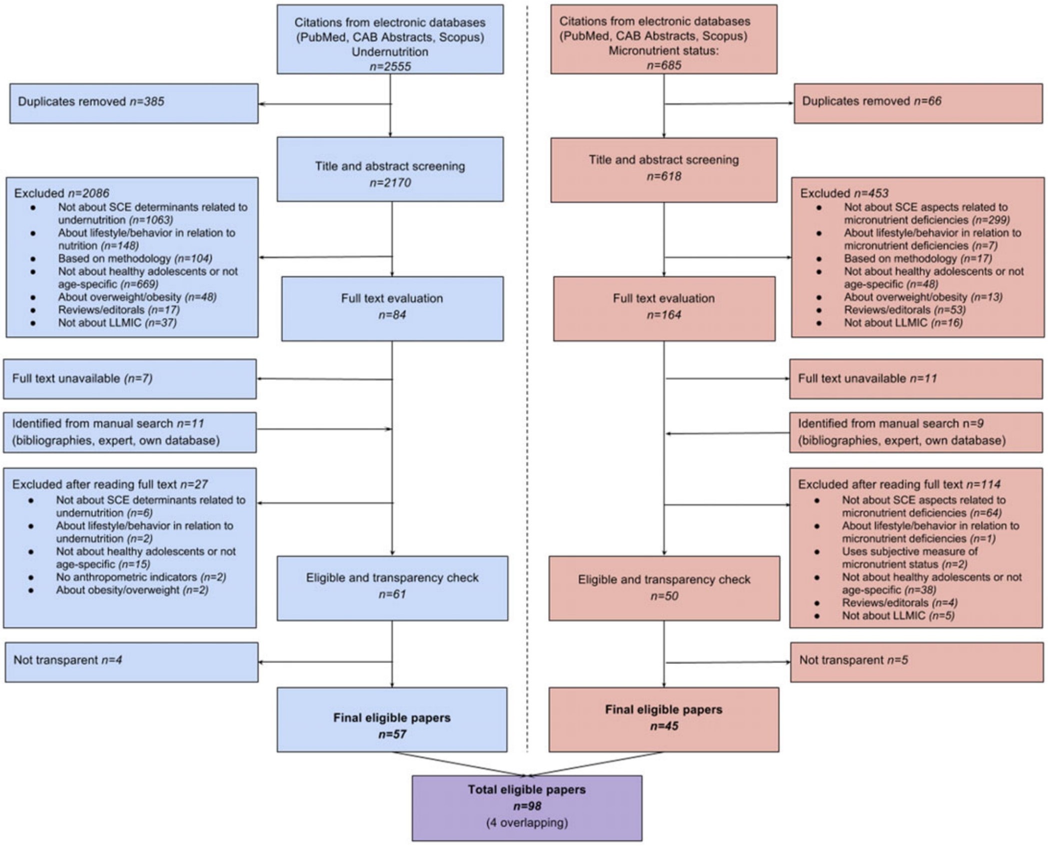

Figure 1. PRISMA flow diagram of the screening process, with undernutrition and micronutrient status combined.

undernutrition part after which results were transferred to an Excel sheet. For the micronutrient part, data were extracted into an Excel sheet directly. We recorded information on study design, methods, analysis, outcome measures, and all associations (significant and nonsignificant) between undernutrition/micronutrient deficiencies. Then, the two sheets were merged and findings were cross-checked and discussed by the researchers. Missing data or contradictory data were corrected and papers were assigned a specific code. Data were entered in four tables, the first including a general overview of characteristics for studies on determinants (Supplementary Table S1, online only) and consequences (Supplementary Table S2, online only) and focus of the final list of papers; this table also includes all SCE variables studied. Next, two tables were made in which all significant associations (positive/negative) were reported. Table 1 reports on the SCE determinants of undernutrition (categorical) and micronutrient deficiencies (categorical), while Table 2 includes SCE determinants of nutritional status index (HAZ, BAZ, WAZ, and WHZ) and micronutrient status (continuous). Within this categorization, determinants were categorized per level and clustered by domain (education, labor, household composition, etc.). Herein, we departed from Bronfenbrenner's human ecological model[37] and Dahlgren and Whitehead's social determinants of health model[38] and acknowledge that an individual's nutritional status is positioned within, and influenced by, a broader system of SCE contexts that are played out at several levels. Table 3 reports the consequences of undernutrition/nutritional status index and micronutrient deficiencies/status.

Results

Due to the high heterogeneity of outcome measures, the diverse range of study methods, and the lack of transparent methodological descriptions, we could

Table 1. Determinants of adolescent undernutrition and micronutrient deficiencies

	UNDERNUTRITION						MICRONUTRIENT DEFICIENCIES													
	Stunting		Underweight		Thinness		Vit A		Vit D		Iron def		Anemia		Iodine		Zinc		Folic	
Association	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
INDIVIDUAL LEVEL																				
Determinants																				
Sex																				
F									m35		m14		m14; m39	m30	m31				m21	
M	u47; u12; u36; u2; um3; u4; u31; um1; u16; u33		u49; u44; u43; u36; u2; um3; u33		u4; u42; u31; u6; u13; u16; u27; u48; u53								m22							
Age (F/M)	u49 m19; u51	um1	u49		u13	u42; u31; u15; u53			m23				m1; m30; m33						m21	
F	u41	u25; u7			u41								m9–10; m12	m29; m38						
M	u48												m22	m36						
Birth order	u38		u38		u6															
Ethnicity														m9; m11–12						
Religion (Muslim, Hindu versus Christian)	u36				u4									m9; m11–12, m26						
Marital status (married versus unmarried)													m9; m12							
Labor																				
Workload						u41														
Working status (working versus not-working)	u44	u4	um3			u4					um3		m19				um3		um3	
Education																				
Attendance		u40; u38																		
Drop-out											um3			m1						
Enrollment		um2; u20		um2	u13								m20							
Literacy level		u41												m26						
Educational level		u4				u7; u4								m9; m19; m25; m34						
No footwear													m38							
HOUSEHOLD LEVEL																				
Parental occupation		u44; u36		u44																
Maternal		u39		u36										um4 m19; m25						
Paternal		u40; um3; u31; um4; u39				um3; u46								m26; m39						
Parental education		u39; u48				u4; u53														
Maternal		u48; u11; u51; u4		u11; u52		u46		m37						m12						
Paternal		u33; u4		u33		um3; u46								m39						
SES		u16; u48; m19		u2		u7; u16; u25								m9–m10; m12; m21						
Income		um3; u4; um1; u39		u15		u50, u4; u19; u27; um3		um1				m22		m22; m28						

Continued

Table 1. *Continued*

	UNDERNUTRITION						MICRONUTRIENT DEFICIENCIES													
	Stunting		Underweight		Thinness		Vit A		Vit D		Iron def		Anemia		Iodine		Zinc		Folic	
Association	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
Resources (land, cattle, latrine, no. of living rooms, rented versus own, housing type, and access to piped water)		u44; um3; u33; um4 u49		u44; u33		um3; u53; m30								m26						
Household composition																				
No. of siblings	u36; u39		u36; u38		u38															
No. of servants		u40																		
No. of wives/polygamy	u36; u49																			
No. of sisters/women	u40																			
Living with guardian					u6															
Size	u11; u4; u31; m33; u39		u11; u49		u51; u4								m39							
Type of family (joint versus nuclear)	u44				u7									m19						
Food insecurity	u32; u51		u51		u51; u13								um4							
COMMUNITY LEVEL																				
WASH		u51		m30										m19; m30						
Residence																				
Rural (versus urban)	u36; u30; u4; u31; um4		u43; u36; u30		u30; u4; u15					m23			um4	m8–9; m12	m24					
Geographical zone														m9; m20	m6					
School type (public or poor versus private or rich)	u50; u36; u48; u4		u50; u36		u50								m36							
Scheduled caste (Dalit)	u49																			
Environmental																				
Season (other versus summer)									m23											
Before rain (versus after rains)													m29							
Harvest (versus hunger)							m24				m24	m24	m24						m24	

not conduct a meta-analysis. Hence, we focused on the breadth of the studies and synthesized the findings using a narrative approach. Starting with an overview of the papers, we then discuss findings for the two separate searches.

General characteristics

Our sample shows an increase in the number of papers on adolescent nutrition, with a rapid increase after 2008 and again 2013 that might reflect the increasing interest in adolescent undernutrition and micronutrient status, especially after the launches of the 2008 and 2013 *Lancet* series on maternal and child nutrition (Fig. 2).

Most of the published articles in our sample on adolescent undernutrition and micronutrient status focus on both males and females (57.7%). However, research on adolescent females only (38.2%) has been of particular interest in comparison to males (4.1%). A majority of the publications on undernutrition and micronutrient status of adolescents originate from India. Most of the publications (n = 28) from sub-Saharan Africa focused on undernutrition with less than a half of these publications focussing on adolescents' micronutrient status. We found only two studies originating from LLMICs in Latin America, both of which were on undernutrition. Most of the reviewed studies were cross-sectional in design. The fewer longitudinal studies we found (10.3%) studied mainly associations with adolescent undernutrition and nutrition status index, rather than micronutrient status.

Determinants of undernutrition and nutritional status indexes

In this section, the results on SCE determinants of adolescent undernutrition and nutritional status indexes are summarized per level. Acknowledging the different levels of data analysis, we differentiated between studies focusing on the relation between

Table 2. Determinants of adolescent nutritional status index (*Z*-score) and micronutrient status

	NUTRITIONAL INDEX						MICRONUTRIENT STATUS															
	H/A		W/A		W/H (BMI/A)		Vit A		Vit C		Vit D		Iron		Hb		Iodine		Ca		Folic	
Association	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
INDIVIDUAL LEVEL																						
Determinants																						
Sex																						
F	m17	u28 u35	u52		u52											m17 m21						m21
M	m31	u4 u5 u47		u47		u1 u4		m31			m35											
Age (F/M)	m17 m31	u1 u47 um4		u1 u47	u26	u1		m16	m16		m35	M27			m17	m26						
F		u3 u29 u41	u52	u9 u29	u1 u3 u52	u41	m2								m11							
M		u26		u26	u1 u26 u4		m4								m4							
Birth order																m7						
Ethnicity	u10 u38																					
Religion (Muslim and Hindu versus Christian)		u26		u26																		
Labor																						
Working status (working versus not-working)	u4				u4																	
Time spent in heavy work (carrying heavy goods)	u53																					
Education																						
Attendance	u21 u22 u34 u37		u34 u37		u34 u37																	
Enrollment	u22 um2														um2							
Literacy level															m11							
Educational level	u4 u24		u24		u4							M27									m40	
Migration to urban area	u22				u22																	
HOUSEHOLD LEVEL																						
Parental occupation																						
Maternal															m4							
Paternal															m4							
Parental education					u4																	
Maternal	u3 u17		u17		u3 u17																	
Paternal	u3		u3 u33				m4; m5								m34							
Parental literacy																						
Maternal															m11							
Paternal															m11							
SES	u24 u29 u33 u34 m19		u22 u24 u29 u33 u34		u34							m32							m32		m40	
Income	u4 u26		u26		u4 u27		m5		m22				m22		m11 m22				m22			
Per capita food expenditure	u17		u17		u17		m4–5															
Resources (land, cattle, latrine, no. of living rooms, rented versus own, housing type, access to piped water, and electricity)	u33 u35				u35										m3 m11							
Household composition																						
No. of siblings		u33																				
No. of servants																						
No. of wives/polygamy	u29		u29																			
Size		u4				u4		m16		m16				m41		m7						m40
Migration			u9		u9																	
Food insecurity		u8																				
COMMUNITY LEVEL																						
Residence																						
Rural (versus urban)		u4 u29 u30 u43		u30 u43		u4 u30 u34												m24			m24	
Hills (versus lowland)		u52																				
Slum (versus nonslum)		u23				u23																
Geographical zone													m24		m11		m6					

Continued

Table 2. *Continued*

	NUTRITIONAL INDEX						MICRONUTRIENT STATUS															
	H/A		W/A		W/H (BMI/A)		Vit A		Vit C		Vit D		Iron		Hb		Iodine		Ca		Folic	
Association	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–
School type (public or poor versus private or rich)		u36; u4		u43; u36																		
Scheduled caste (Dalit)																m11						
Season																						
Season (other versus summer)												m27										
Harvest (versus hunger)								m24								m24		m24				m24

determinants of undernutrition as indicated by stunting, wasting, and thinness (categorical), and between determinants of nutritional status index (continuous) as indicated by height for age (HAZ), weight for age (WAZ), and weight for height (WHZ) and BA, in which the latter two were grouped together under WHZ. Although in all studies height and weight measurements were taken, more studies first classified the study population into categories of nutritional status using height and weight indexes and then assessed the associations with SCE aspects, rather than directly analyzing growth index in relation to determinants (36 versus 31, respectively). Stunting and HA were more often used in relation to variables than other indicators or indexes. For the majority of the studies, the WHO/NCHS reference standards were used in which *Z*-score cutoff points of < -2 SD (standard deviation) were used to classify measurements into undernutrition. Other classifications used were BMI percentiles (WHO), sometimes converted to chronic energy deficiency, or US-CDC reference standards. In general, determinants and consequences significantly associated with undernutrition and nutritional status indexes can be found mostly at the adolescents' individual and household level (Table 1).

Individual level. At the adolescents' individual or micro level, several demographic determinants were identified as risk factors or predictors of stunting, underweight, and thinness. Mixed results were found regarding sex, with many studies reporting nonsignificant differences. Interestingly, studies reporting significant associations showed that boys were often worse off in terms of stunting and HAZ;[39–49] underweight and WAZ;[39,41–43,48,50–52] and thinness or WHZ.[39,44,45,47,53–58] Only three studies in Ghana, Ethiopia, and Cambodia found that height or WAZ was lower for girls when compared with boys.[59–61] Age was often reported to influence undernutrition. Four studies found that stunting increased with age in general, and in particular for boys.[50,62–64] The opposite was found for thinness that decreased with age in four studies[45,54,58,65] compared with only one study[56] that showed an increase. When looking at nutritional status indexes, studies showed similar, but also more varied results. For instance, while HA decreased significantly with age during adolescence, for both boys and girls,[39,53,66–70] here more studies[67,68,70] reported that HA and WA in girls decreased more compared with boys. Birth order was only in one study associated with underweight and stunting.[71] Religion was in three studies[41,44,69] associated with stunting, thinness, and decreased HA and WA, while ethnicity was only associated with HAZ in two studies.[71,72] Migration from a rural to an urban area in Senegal was positively associated with HAZ and WHZ.[73] Finally, two studies reported the adverse effects of poor personal hygiene practices on stunting and underweight.[63,74]

Regarding the labor trajectory, working and especially workload was associated with undernutrition.[43,51] However, a study in Nepal showed that HA was positively associated with time spent in heavy work,[75] and an Ethiopian study found that working was positively associated with HA and WHZ.[44]

Education is often mentioned in relation to nutritional status. School attendance and enrollment, educational and literacy levels were in general negatively associated with stunting, underweight, and thinness[44,70,71,76–79] and positively with HA, WA, and WHZ.[44,73,77,80–83] One Tanzanian study, however, found that school nonenrollment was associated with increased thinness explaining this by the fact that parents often perceived thin adolescents as physically not being ready to attend school.[56]

Household level. At the household level, factors related to parental characteristics, household

Table 3. Consequences of adolescent undernutrition and micronutrient status and deficiencies

A

	Nutritional status index				Micronutrient status			
	HAZ		WAZ		WHZ		Zinc	
Outcomes	+	−	+	−	+	−	+	−
Non-cognitive skills (self-efficacy, educational aspirations, and self-esteem)	u18							
Cognitive skills (mathematics, language, verbal comprehension, memory, reaction time, and intelligence)	u14; u21						m13	
Educational performance	u1		u1		u1, u34			
School attendance	u37; u21		u37					
Age at marriage				u45				

B

	Undernutrition						Micronutrient deficiency			
	Stunting		Underweight		Thinness		Iron deficiency		Anemia	
Outcomes	+	−	+	−	+	−	+	−	+	−
Cognitive skills (mathematics, language, verbal comprehension, memory, reaction time, picture completion test, and intelligence)	u21, m31; m15							m34		
Educational performance	u1			u1		u1				m19; m38

economic status and resources, household composition, and family type were often found to be associated with undernutrition. Generally, parental occupation was associated with lower stunting, underweight, and thinness,[41,43,45,51,66,76,84] but not with nutritional status indexes. Interestingly, paternal occupation was more often ($n = 6$) associated with stunting and thinness, when compared with maternal occupation, which was only in two cases protective against thinness and stunting.[41,84] Parental education was, in general, associated with better nutritional status; however, in contrast to parental occupation, here especially, maternal education was negatively associated with stunting and underweight[44,62,63,85] and positively with HAZ, WAZ, and WHZ.[48,86,87]

Within the economic domain, household economic status and socioeconomic status (SES) were commonly associated with nutritional status. Household and per capita income were negatively associated with stunting, underweight, and thinness[43,44,46,57,65,84,88,89] and to a lesser extent positively with HAZ, WAZ, and WHZ.[44,57,69,86] One study showed that per capita food expenditure was positively associated with all nutritional status indexes.[86] Likewise, SES, defined by a wide variety of indicators, was in 15 cases negatively associated with undernutrition or positively with nutritional status indexes.[42,47,48,62,64,68,73,79,81,82,90] Household resources, including land holdings, possession of cattle, the number of living rooms, rented versus owned home, and housing type

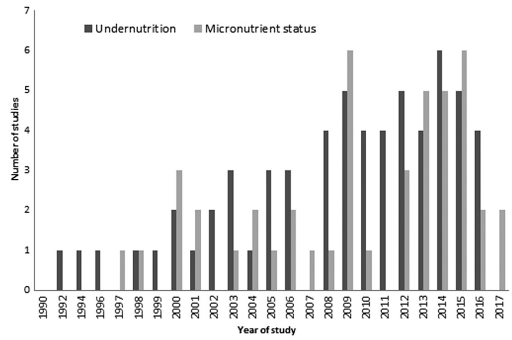

Figure 2. Number of published studies on the sociocultural/economic determinants of undernutrition and micronutrient status of adolescents in LLMICs between 1990 and 2017.

were negatively associated with undernutrition indicators[43,48,51,58,66,74] or, to a lesser extent, positively with HA and WHZ.[48,60] The lack of latrines (leading to open air defecation) and having a hand pump (instead of running water) were associated with BAZ.[60,74]

For household composition in relation to adolescent nutrition, several indicators were used. Significant associations were to a greater extent found for indicators of undernutrition than nutritional status indexes. Generally, household size was positively associated with undernutrition,[44,45,49,50,74,84,85] but only once with status indexes.[44] The number of siblings was in four studies positively associated with undernutrition.[41,43,71,84] This was more the case for girls, or when there were more girls in a household.[76] Only one study found a similar association with HAZ.[48] Polygamy, or the number of wives in a household, was positively associated with stunting,[41,62] while a study in Mali showed how this was negatively associated with HAZ and WAZ.[68] Living with guardians instead of own parents was associated with thinness only in one study,[55] and an increasing number of servants in a household was associated with decreased prevalence of stunting.[76] Furthermore, two studies showed that adolescents living in joint families were more likely to be stunted[51] or thin.[79] Similar to migration at the individual level, adolescents living in households who migrated from a rural to an urban area in Senegal had higher WHZ and WAZ than those who did not migrate.[91] Finally, food insecurity at the household level had a negative impact on adolescent undernutrition.[63,92] One study from Ethiopia showed that only in girls decreased HAZ was significantly associated with food insecurity.[93]

Community level. We found only a few determinants that focused on community-level factors. In general, rural residence, living in the hills versus lowlands, or living in slum areas were associated with undernutrition and status indexes.[41,44,45,52,65,66,75,82,94,95] Furthermore, school type was associated with undernutrition, with adolescents attending public, instead of private schools, showing higher rates of undernutrition or poor nutrition.[41,44,52,62,88] Living in a scheduled caste community was in one Indian study associated with stunting.[50]

Determinants of micronutrient status and deficiencies

In this section, the results on SCE determinants of adolescent micronutrient status and deficiencies are outlined. Generally, most of the reviewed studies on micronutrient status examined Hb status ($n = 40$) and iron status ($n = 13$). The determinants of vitamin A status were examined by 10 articles, while those of vitamin D status were examined by five articles. Few articles (≤ 5) reported on the determinants of folate, zinc, calcium, iodine, vitamin C, and vitamin B_{12} status. The statistical analysis procedure was commonly on the determinants of micronutrient deficiencies with logistic regression ($n = 21$) or simply bivariate analysis with chi-square ($n = 8$). Only two studies used a combination of both categorical (deficiencies) and continuous (status) outcome methods in the statistical analyses.

Individual level. Similar to undernutrition, mixed results were found regarding sex, with many studies reporting nonsignificant differences. Nevertheless, four studies showed that female sex was associated with a higher risk of anemia,[96,97] iron deficiency anemia (IDA),[96] and lower Hb levels.[64,98] Similarly, in India, when compared with adolescent boys, adolescent girls were more likely to be folate deficient[98] and vitamin D deficient.[99] Another study in Cambodia reported female sex as a risk factor for iodine deficiency, but male adolescents were in this study reported to have a lower retinol binding protein concentration and were more likely to have a marginal vitamin A status compared with their female peers.[61] Surprisingly, in a multicountry survey in Lakeside Tanzania, Mozambique, Ghana, Malawi, and Indonesia,[100] 12–14 years adolescent boys were more likely to be anemic than girls, and a study in Ethiopia also reported female sex to be protective of anemia.[74]

Generally, increasing age was found to be a risk factor for anemia,[74,101] vitamin D deficiency,[102] and folate deficiency[98] among male and female adolescents. Likewise, studies in Nigeria,[103] India,[104] and South Korea[105] found increasing age to be inversely associated with plasma retinol, Hb, and serum 25(OH)D, respectively, for both sexes. Among adolescent girls, four Indian studies reported increasing age as a determinant of anemia.[106–109] However, increasing age was in Kenya[110] and Ethiopia[111] protective of anemia for adolescent girls, while in Indonesia[112] protective for adolescent boys. Also, serum vitamin C, serum 25 (OH)D, and Hb status were in Nigeria,[103] India,[99] and the Philippines,[64] respectively, positively associated with increasing age. Among Bangladeshi adolescent girls[113] and boys,[114] age was positively associated with serum retinol as well as Hb status. Except in one study on Hb status from Nigeria, birth order was seemingly not an important determinant of poor micronutrient status.[115]

Only four studies examined the effect of working status or workload on micronutrient status, with two of the studies concluding that working girls had a higher risk of anemia and iron and zinc deficiency, compared with their nonworking peers.[43,116] Similarly, only a few ($n = 5$) of the reviewed studies examined the effect of marital status on micronutrient status, and this was generally on anemia. Two studies concluded that being married was related to a higher risk of anemia for adolescent girls.[107,109]

Late school enrollment[100] and dropping out of school[43] were seemingly risk factors for anemia and iron deficiency (ID), respectively. However, Ahankari *et al.* found dropping out of school to be protective of anemia among Indian adolescent girls.[106] Adolescent literacy and a higher educational level were generally protective of anemia.[104,107,116–118] Similarly, literacy[119] and a higher educational[120] level were positively associated with Hb and folate status, respectively. Nevertheless, educational level was once found to be inversely associated with serum 25(OH)D among South Korean adolescents.[105]

Also, there were differences in the risk of anemia by religion and/or caste in India.[107,109,119] Personal hygiene was in two studies found to be protective of anemia in India and Ethiopia.[74,116] Finally, one study in Ethiopia found that footwear was protective of anemia among adolescent girls.[111]

Household level. At the household level, a higher paternal education level was associated with a lower risk of anemia in Ethiopia,[97] higher Hb status in India,[118] as well as a higher serum retinol status in Bangladeshi adolescents.[114,121] Equally, a higher maternal education level was reportedly associated with a lower risk of anemia[109] and vitamin A deficiency (VAD)[122] in India and Indonesia, respectively. Paternal and maternal literacy were also found to positively predict a higher Hb status among Indian female adolescents.[119] Furthermore, a better maternal[66,116,117] and paternal[97,104] occupation status were both protective of anemia among Indian and Ethiopian adolescents. Likewise, paternal and maternal occupational status were positively associated with Hb status in Bangladeshi adolescents.[114]

Additionally, a higher SES was protective of anemia[107–109,116] and positively associated with serum calcium[123] and folate[120] status, yet inversely associated with a higher serum 25(OH)D.[123] Generally, a higher family income was associated with a lower risk of anemia,[124,125] ID,[124] and VAD.[46] Likewise, family income was positively associated with serum retinol,[121] serum ferritin,[124] and Hb status.[119,124] Dietary intake of Ca and vitamin C was also reportedly higher with increasing household income level among South Korean adolescent girls.[102] A unit increase in per capita expenditure on food was positively associated with a higher serum retinol among adolescent boys[114] and girls[121] in Bangladesh.

Overall, a larger family size was a risk factor for anemia,[97] and inversely associated with serum retinol and vitamin C status[103] besides serum ferritin,[126] Hb,[115] and folate status.[120] Bangladeshi adolescents living in their parent's houses,[127] as well as Indian adolescents living in a household with electricity,[119] were found to have a higher Hb status. Moreover, adolescent girls living in households with latrines were at a lower risk of anemia than those in households without latrines.[104] Remarkably, the prevalence of anemia was in one study significantly higher among adolescents living in nuclear families compared with their peers in extended or joint families; this was contrary to the association found between family type and stunting/thinness.[116] Finally, food insecurity was in one case reported to be associated with anemia.[66]

Community level. Surprisingly, residing in a rural community compared with an urban community was protective of anemia in Uganda and India,[107,109,128] as well as vitamin D deficiency[102] in South Korea. Only one study found that Ethiopian girls living in rural areas had higher rates of anemia.[66] Additionally, rural Mozambican adolescent girls had a higher serum folate status when compared with their peers from urban areas; however, rural girls were in this study more at risk of iodine deficiency.[129] Significant variations by geographical location in the prevalence of anemia, iodine deficiency, serum ferritin, Hb, and urinary iodine status were also observed.[100,107,119,129,130] Among South Korean adolescents, seasons other than summer were associated with a higher risk of vitamin D deficiency[102] or a lower serum 25 [OH]D level.[105] Equally, the risk of anemia was significantly higher before the rainy season in Kenya,[110] while the harvest season in Mozambique was associated with a higher risk of VAD and folate deficiency in all areas (city, coastal, and inland).[129] Finally, significant variations by season in the prevalence of anemia and ID were found in Mozambique, but these variations were dependent on the residing area.[129]

Consequences of undernutrition and poor micronutrient status

We found only 12 papers that reported on the SCE consequences of adolescent undernutrition.[53,61,80,82,83,111,116,131–135] Most of these studies focused on educational outcomes. A study by Dercon and Sanchez[132] showed how noncognitive skills such as self-efficacy, educational aspirations, and self-esteem are positively associated with HAZ, using data from the Young Lives multicountry cohort study. Data from the same study[131] and three other studies[61,80,135] associated cognitive skills negatively with stunting. School performance (e.g., grade attainment) was worse when adolescents had a low HAZ (stunted),[53,80,131,135] low WAZ (underweight),[53] and low WHZ (thin).[53,82] School attendance improved with a higher HAZ[80,83] and WAZ.[83] At the micronutrient level, two studies found an inverse association between anemia and grade attainment,[111,116] as well as IDA and cognitive skills such as Raven's Coloured Progressive Matrices among Cambodian male adolescents.[61] Another study provided significant evidence that memory and scores on Raven's progressive matrices test (intelligence) were positively associated with zinc level, while reaction time was negatively associated with zinc levels.[134] Finally, a somewhat older study from Bangladesh associated age at first marriage with weight, showing that greater body weight was associated with earlier age of marriage, even when this effect was adjusted for height, age at menarche, and socioeconomic factors. The author suggests that "better-nourished women are more attractive mates owing to their physical appearance and/or better health" (p. 94).[133]

Discussion

This review is to our knowledge one of the first attempts to capture the wide spectrum of SCE determinants and consequences of adolescent undernutrition and micronutrient deficiencies in LLMICs. We aimed to provide an overview of the SCE determinants of undernutrition and growth (RQ1) as well as micronutrient status and deficiencies during adolescence (RQ2). However, we found most determinants influencing undernutrition and micronutrient deficiencies at the individual and household level, which were mostly comparable for the two indicators of nutritional status. Indeed, such factors are well known to determine health across the life course and cultures.[18] We identified age, sex, birth order, religion, educational and literacy level, working and marital status, and personal hygiene as proximal, individual-level determinants of undernutrition and micronutrient deficiencies in adolescents. Determinants identified at the household level included parental education and occupation, family/household structure and size, household income, food security status, SES, and resources or assets within the household. Surprisingly, only a few determinants at the broader community level were identified, which included geographical location, place of residence (urban versus rural), community and school type, as well as seasonality; however, most of these determinants seem to relate to the physical and economic environment. This denotes the lack of research on the influences of the broader social, cultural, or political context on adolescent nutritional status, and supports the current consensus to address the "major systematic, policy, cultural and environmental barriers in the achievement of improved nutritional health for adolescent girls" but also boys.[136] Likewise, we found a lack of studies looking at SCE consequences in the domains of education, labor, and family formation (RQ3) of poor nutrition during adolescence in general, highlighting a pressing research gap. Most studies on consequences focused on the associations between adolescent undernutrition or micronutrient status and cognitive skills or educational attainment. Overall, we found evidence from three cohort studies that linear growth retardation or chronic undernutrition in adolescents is associated with poorer cognitive skills and educational performance.[116,131,132] These findings suggest that the adverse effects of malnutrition on educational performance are not only limited to childhood, but also manifest during adolescence. Similarly, cognitive skills and educational performance were positively associated with micronutrient status, although evidence was mostly cross-sectional, which makes it impossible to establish causal relations. Improvements in school attendance were also observed with an increase in HAZ, but again, the observed association was cross-sectional. We thus cannot conclude that better-nourished adolescents attend school more regularly, or state that these adolescents have a better nutritional status. In the domain of family formation, we found only one study that showed how nutritional status affected age at marriage, with heavier girls marrying earlier than lighter girls. Possible explanations offered were the correlations between weight and development of secondary sex characteristics or the cultural image that girls with normal weight (versus underweight) are perceived healthier or more attractive.[133]

Figure 3 summarizes the determinants and consequences of adolescent undernutrition and micronutrient deficiency that were derived from the papers. In Figure 3, we hypothesize that the community-level factors exert an influence on the household characteristics that intend to affect the individual-level determinants of nutrition. Under each larger concept are specific determinants that were found to influence the nutrition of adolescents in LLMICs significantly. We could not find determinants at the broader societal level that might affect adolescent nutritional status, indicating a research gap.

Age and sex

The WHO distinguishes between early (10–14 years) and late (15–19 years) adolescence. We included studies with subjects within this age range, but based on the numerous definitions on "adolescents" we came across, consensus on its definition seems to be lacking with boundaries between being an adolescent or adult somewhat blurred.[137] Particularly in studies targeting women of reproductive age, often, late adolescent girls are included without referring to adolescence at all.

Unfortunately, from our sample, we could not conclude which determinants were most crucial at what ages (late versus early adolescence) or for which sex. In general, we found mixed results, significant and nonsignificant, on the effects of age on nutritional status. Although nutrition differences vary with growth spurt timings,[138] a majority of the studies with significant associations between age and micronutrient status or stunting (and HA) in particular supported increasing age as a risk factor, while the prevalence of thinness seemed to decrease with age. This could support evidence that while stunted adolescents (particularly when entering adolescence stunted) might not be able to catch up or compensate for growth sufficiently, especially adolescent girls are better able to improve their body mass (WH) throughout adolescence.[138–140] However, evidence of catching up growth during adolescence is still limited.[34,138]

Similarly, sex differences in undernutrition were inconsistent. However, most studies reporting on sex differences showed that boys were significantly more likely to be stunted and underweight than girls during adolescence; this is in line with previous studies in Asia and Sub-Saharan Africa[22,34] that often relate this to boys' later and prolonged growth spurt.[40] In our sample, some authors hypothesize that the finding is related to the work activity hypothesis that refers to the "combined effects of increased energy expenditure and reduced presence at mealtimes," for instance, because of work or school (p. 359).[39] In addition, Dapi *et al.* attribute the differences to cultural practices that lead to better nutritional intake for girls, but also reason that because girls are often involved in cooking and shopping, they might eat in between meals and during cooking.[47] Studies reporting higher rates of undernutrition in girls often attributed this to

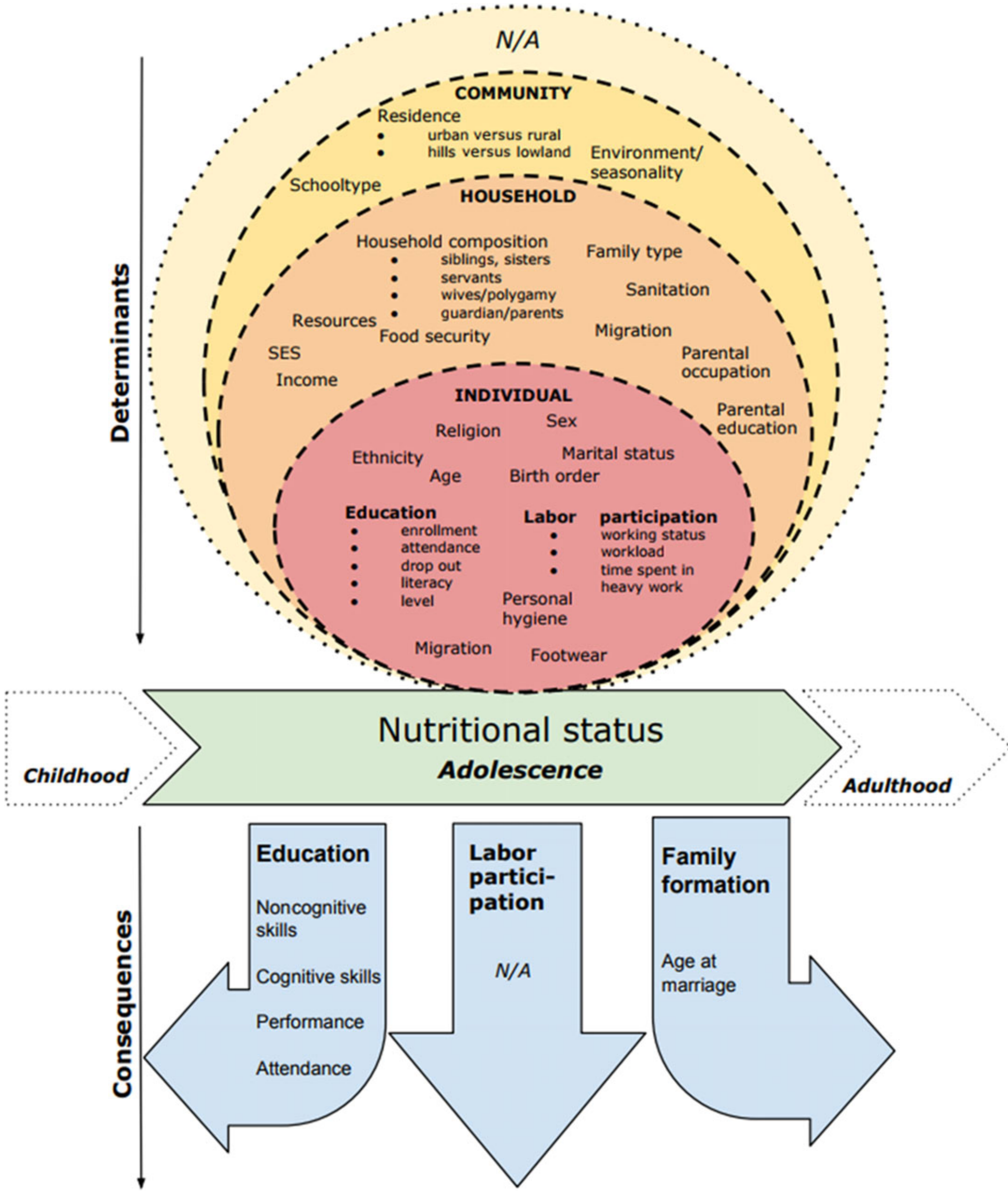

Figure 3. Hypothetical framework summarizing the determinants and consequences of adolescent undernutrition and micronutrient deficiencies in LLMICs.

gender discrimination and unfavorable intrahousehold food allocation practices, especially in cases where households had little income or were food insecure. Particularly in South Asia, women are more disadvantaged in accessing food.[141] This is supported by a review of intrahousehold food allocation that shows that inequities are more likely in food insecure or poor households, although this also depends on other factors such as religion, household size, social status, and women's bargaining power.[142] For instance, a study in the far west corner of Nepal showed that adolescent girls ended up second last, or last in case of daughters-in-law, in the household serving order, which could have influenced their nutritional status, especially in food insecure households.[143] Unequal treatment may thus result when households face extreme circumstances, leading to discrimination against vulnerable women.[144] Regarding micronutrient deficiencies, the opposite effect was found. Here, female sex proved to be a risk factor, particularly for low iron status and anemia. This is in line with other studies[140] and additionally explained by the increased iron requirements caused by the female growth spurt, menarche, and blood loss during menstruation.[7,145,146] Also, when compared with boys, the iron status of girls tends to worsen upon slowing down of growth.[138] Although there were mixed results for the effect of age on micronutrient status, a majority of the studies with significant associations between age and micronutrient status supported increasing age as a risk factor for poor micronutrient status[74,98,101–105] for both sexes—notably anemia among adolescent girls,[106–109] which may be related to the increased nutrient requirements with the growth spurt. Another explanation, which was not mentioned by any of these studies and can only be shown by including individual dietary intakes, may relate to pro-male food allocation processes in which girls are allocated fewer micronutrient-rich foods than boys. Data from the Young Lives cohort point toward such a pro-boy gap, showing how "disparities between mid-adolescent boys and girls are driven by the increased likelihood of boys to consume protein- and vitamin-rich foods" (p. 109).[147]

Family and fertility

Although some of the studies excluded adolescent married girls from their sample,[106,117,130] several Indian studies showed that married adolescent girls were at higher risk of anemia. In these contexts, marriage during adolescence often leads to early conception, which poses girls at increased risk due to the already increased demands of iron during adolescence.[10] Marrying young also means leaving the natal home and moving in with in-laws, a transition that often leads to a change in social status and access to food, which may negatively influence nutritional status.[109]

Birth order has been cited as an important determinant of malnutrition among infants and young children showing for instance that earlier-born children (lower birth order) were favoured in terms of intrahousehold food allocation practices, particularly in challenging circumstances.[148,149] Moreover, some studies show that the poorer nutritional status of later born children might be due to already depleted maternal stores caused by multiple pregnancies.[150] However, except three studies,[55,71,115] we did not find much evidence on the associations between birth order and adolescent nutritional status. It may be that, over time, its effect is diluted. For instance, Horton[148] observed that later-born children are born when per capita resources are smaller as total household income and assets do not increase concomitantly with family size. Thus, the effect of increasing birth order in adolescence may be masked by poor living conditions and its resultant effect of poor dietary intake. Although our sample shows inconsistent findings, results from a Brazilian birth cohort showed that during adolescence, firstborns were heavier and taller than later-borns, due to their higher sensitivity to catch up growth.[151]

In contrast, family size, as well as the number of siblings, was often mentioned as risk factors for poor nutritional status. Larger families spend extra resources in meeting their nutrition and health needs thereby putting a strain on already limited resources. The resultant effect may be decreased dietary diversity or intake affecting nutritional status. In such circumstances, vulnerable groups in the household including adolescents may be at a higher risk of malnutrition. The association with the number of siblings was especially found in studies on girls. The authors attribute this to unequal feeding practices and household food distribution.[84] Bird, in her review on the intergenerational transmission of poverty, found that children with more siblings tend to be more malnourished as resources are directed to the youngest or older children, with stronger effects in poor households.[152] Regarding family type, the prevalence of anemia was in one study significantly higher among adolescents living in nuclear families compared with their peers in extended or joint families,[116] which suggests the relative importance of family support in the prevention of anemia. Viner *et al.*[18] argued that family connectedness is one of the most critical factors that protect against poor health outcomes in adolescence. On the contrary, stunting and thinness were highly prevalent in Indian joint families, which could be explained by the effects of family size or lower social status of adolescent girls within these families. Interesting is the link between stunting and polygamy that was found in two Nigerian studies. The authors attribute the higher rates of stunting mainly to poverty and increased household size. The combined effects of polygamy, which occurs more often in low SES groups, and low earning capacity might affect nutritional status.[41] However, the authors recommend further research as there might be other underlying mechanisms explaining differences in undernutrition.

Religion and ethnicity

The role of religion and ethnicity in determining nutritional status is quite ambiguous. Within India, the differences in anemia were context-specific, and no particular religion or caste was notably at a higher risk. The differences were mostly attributed to differences in cultural dietary patterns and, or socioeconomic conditions that vary with religion, or caste groups. Likewise, within the same country, variations by geographical location were partly attributed to disparities in diet and prevalence and incidence of infections and diseases. Although an Indian study found that the prevalence of stunting was higher in adolescents who belonged to the Dalit (scheduled caste) community without providing an explanation, Omigbodun *et al.*, who found that Muslim adolescents were worse off in comparison to Christian adolescents in terms of stunting and thinness, argue that religion might act "indirectly in situations where practices within certain social strata would lead to deprivation" (p. 670).[41]

Education and occupation

The majority of studies were conducted in a school setting. This design implies that the prevalence of undernutrition is underestimated if nonenrolled adolescents, who might be more vulnerable and disadvantaged in several life domains, are excluded. Indeed, studies by de Lanerolle-Dias *et al.*[43] and Hall *et al.*[100] showed that female school dropouts, and adolescents who dropped out in early adolescence, or enrolled later in school, were notably more vulnerable to undernutrition, both in terms of macro and micronutrients and despite the same level of nutritional knowledge. Possible explanations include the additional burden that outside school labor activities place on nutritional status, the relation with SES and household income, and exposure to school nutrition interventions.[44] On the contrary, Ahankari *et al.*[106] found that school drop-outs had a lower risk of anemia compared with enrolled girls. They argued that nonenrolled girls were generally engaged in agricultural-related employment, with earnings more likely to be spent on nutritional foods that may have improved their Hb. A similar effect was found in other studies where having a job and workload was associated with HAZ and WHZ.[44] Reverse causation, in which undernutrition constrains workload, might be a possible explanation.[75] However, two studies also concluded that working girls had a higher risk of anemia and iron and zinc deficiency compared to their nonworking peers,[43,116] showing that the additional small income generated by working girls may not always have a positive effect on their nutritional status.[153]

The studies underscore the importance of adolescent education and literacy level as well as parental education and literacy level in reducing the risk of undernutrition, (mainly for stunting) and micronutrient deficiencies. Generally, education and/or literacy may improve healthier behavior practices and nutritional status via increased awareness and knowledge. Only one study showed how adolescent educational level was inversely associated with serum 25(OH)D.[105] Similarly, another study found SES inversely related to serum 25(OH)D,[123] but both associations were attributed to unhealthy lifestyle and sedentary behavior, a change in practices that is likely to emerge as part of the nutrition transition in LMICs.

Parental education was positively associated with nutritional status; particularly stunting seemed to decrease. However, most studies showed an association between maternal education and improved nutrition. This finding is in line with studies on children's nutritional status, indicating that maternal education reduces the odds of particularly stunting.[153] However, Vollmer *et al.* found that maternal and paternal education were equally important in reducing childhood undernutrition.[154] It may be that better-educated parents are more likely to have better-paying jobs. Parental occupation was indeed associated with better nutritional status. In contrast to education, we found that paternal occupation was more often associated with better nutrition, even though women's increased earning opportunities result in a different allocation of resources in favor of nutrition through improved bargaining power.[144]

Additionally, occupation may increase household income and/or SES, which were both consistently linked with a lower risk of undernutrition and micronutrient deficiency. Similarly, studies showed that households with more resources lowered the risk of poor nutritional status. Overall, household resources are indicative of SES or income level. Higher SES is generally associated with higher purchasing power and consequently improved household access to diverse foods.[155–157] However, again, a complete consensus on the definition of SES is lacking.[158] It is usually measured by determining education, income, occupation, or a composite of these dimensions.[159] Filmer & Pritchett[160] recommended the use of household durable assets index for SES, but in our sample, the concept was interchangeably based on education and/or occupational status, land size, household income, type of school attended (government or private), or (per capita) income. Only seven authors used a more comprehensive description of SES based on these recommendations, which makes it complex to generalize the effect of SES on adolescent nutritional status. Moreover, as Bradley and Corweyn state, "the relations between particular SES indicators and health factors may be quite complex," (p. 374) with the associations appearing less steep in more egalitarian contexts.[158] Nonetheless, we found that "SES" was generally positively associated with adolescent nutritional status. This is to be expected in LMICs and supported by previous research on the "nutrition pathway," which shows that inadequate dietary intake results from low SES, leading to poor nutritional status and delayed growth.[158]

Environment and community

At the community level, particularly place of residence and environmental factors were found significantly associated with malnutrition. Mainly, studies showed that adolescents in rural areas were worse off in terms of stunting, thinness, and underweight. However, contrary to the generally held notion that the risks of micronutrient deficiencies are higher in rural than urban communities, several studies showed that residing in a rural community was protective of anemia, vitamin D deficiency, and associated with a higher folate status. Although most studies did not explain the rural–urban variation, this is in line with the literature on the rural–urban divide. In Sub-Saharan Africa for instance, it was found that urban–rural differentials are persistent when controlled for SES, but also that this gap is narrowing in more countries due to the increase of urban malnutrition, and widened in a few countries because of the decline of urban malnutrition.[161] Indeed, rapid urbanization has resulted in an explosion of poor urban settings that house large numbers of adolescents, with increased health risks for young people in such settings.[162]

Finally, the observed seasonal variations in micronutrient status were in part attributed to seasonal variation in the availability and access to food, notably, the micronutrient-rich food. Several studies have indeed shown seasonality variations in dietary intake.[163–166] The implication of the finding may be that interventions that aim to improve the nutritional status of adolescents in the context of LMICs need to recognize the role of seasonality on nutritional status to incorporate initiatives to prevent undesirable seasonal declines in nutrient intake and consequently nutritional status.

Limitations

Despite a thorough set up of this systematic review, certain limitations should be considered when interpreting our findings. First, the set of eligible papers revealed a high heterogeneity in outcome measures, selected SCE variables, data collection methods, levels of data analysis, and study settings. This made it infeasible to conduct a meta-analysis within the scope of this review. For instance, although underweight and thinness refer to the same for adolescents and are defined by BAZ < -2SD,[167] some of the reviewed authors defined thinness using WH, while others also defined underweight with WA but these were mostly articles published before the recommendations of De Onis and the WHO in 2007.

Also, most of the studies were cross-sectional in design and thus, inferences of possible associations are speculative and the results are limited to describing co-occurrences. Furthermore, the review is based on primary, quantitative studies only. We acknowledge that SCE determinants and even consequences of undernutrition might be derived from qualitative studies as well. However, we found these studies to be rare, while at the same time considering them highly important in order to consider the adolescents' own perspectives on growing up and nutrition in relation to SCE aspects. Such studies would yield, for instance, valuable insights into empowerment, decision-making processes, agency, and social status within households, which might influence their nutritional status. Although we attempt to consider gray literature as much as possible by conducting extensive electronic and manual searches in three databases, bibliographies, expert advice, and own databases, we cannot be certain that we captured all relevant gray literature. Finally, eligible papers undergo quality appraisal in order to ensure trustworthiness and adequate interpretation of findings.[168] However, besides that this would require having access to all available supplementary and process-related information, such an appraisal was impossible due to the heterogeneity of methods and number of papers. Nonetheless, we undertook a transparency check to ensure that the eligible studies were clear in their objective, sampling plan and size, data collection, statistical methods, conclusions, and limitations.

Implications

This review shows that despite increasing interest in adolescent nutrition, few studies take into account adolescents' complex everyday life contexts and their entire pathways of transitions into adulthood. Most studies focus on single-factor determinants at the household and individual level, while factors at the community and broader societal level, which are the root causes, deserve more attention. The magnitude and direction of associations were found to be context-specific. Thus, interdisciplinary, longitudinal research on and *with* adolescents that focuses on the interrelations between context-specific life trajectories is vital in order to truly understand the transition into adulthood and thereby optimizing health and other developmental outcomes.

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Supporting Information

Additional supporting information may be found in the online version of this article.

File S1. List of countries: World Bank classification of lower and lower middle income countries.

Table S1. General characteristics of reviewed studies.

Table S2. Consequences of undernutrition and micronutrient deficiencies reviewed articles assessed.

Author contributions

Conceived and designed the study: D.M.; contributed to the survey tools: F.A., S.O., H.B., and I.B.; literature search and analysis: D.M. and F.A.; reviewed literature search: S.O., H.B., and I.B.; wrote the first draft of the manuscript: D.M. and F.A.; contributed to the writing of the manuscript: S.O., H.B., and I.B.; prepared the final content of the manuscript: D.M., F.A., H.B., and I.B. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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