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Spatial farming systems diversity and micronutrient intakes of rural children in Ethiopia

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Abstract

Own production contributes much of the food supply in smallholder production systems in low- and middle-income countries like Ethiopia. Understanding the potential as well as constraints of these production systems in terms of nutrient supplies is thus a critical step to design interventions to improve nutrient intakes. The objectives of this study were (1) to assess the usual total intakes of vitamin A, iron and zinc among rural children and (2) to investigate whether the intakes these nutrients are associated with differences in the dominant farming systems between spatial clusters. Using nationally representative intake data of 4,902 children 6–35 months of age, usual intake and the proportion of inadequate intakes of vitamin A, iron and zinc were calculated. A multi-level model was used to examine the association between individual-level and cluster-level variables with the usual total dietary intakes of these nutrients. The diet was dominated by starchy foods. Consumption of animal source foods, vitamin A-rich fruits and vegetables was low. We found a high prevalence of inadequate intake of vitamin A and zinc (85.4% and 49.5%, respectively). Relatively, low prevalence of inadequate intake of iron (8.4%) was reported. The spatial farming systems diversity across the rural clusters explained 48.2%, 57.2% and 26.7% of the observed variation in the usual total dietary intakes of vitamin A, iron and zinc, respectively. Our findings indicated the importance of farming system diversity at the landscape level as one of the determinant factors for individual usual total dietary intakes of vitamin A, iron and zinc.

KEYWORDS
cluster farming system, Ethiopia, micronutrient, nutrient adequacy, rural, usual intake

1 | INTRODUCTION

Micronutrients, comprising both minerals and vitamins, are essential for growth and development of the human body. During the first 2 years of childhood, micronutrient requirements are high, and inadequate intake during this period could result in deficiencies leading to high susceptibility to infection and mortality, limited cognitive and physical development and reduced productivity during adulthood (Biesalski & Black, 2016; Biesalski & Jana, 2018; Salgueiro et al., 2002) Globally, micronutrient deficiencies are widespread, and yet the largest proportion of children with key micronutrient deficiencies lives in low and middle-income countries (Bailey et al., 2015; Bhutta &

Salam, 2012; Ramakrishnan, 2002). In Ethiopia, children living in rural areas are the most at risk for commonly occurring micronutrient deficiencies, such as iron, vitamin A and zinc due to high level of poverty, food insecurity and intestinal parasitic infections (Desalegn et al., 2014; Gebreegziabher et al., 2020), and the magnitude of the problem varies considerably across the different administrative regions (Ethiopian Public Health Institute, 2016).

In the context of developing countries, poor diet quality compounded with low bioavailability is often a major determinant of micronutrient deficiencies (Beal et al., 2017; Gibbs et al., 2011; Gibson et al., 1998). To alleviate micronutrient deficiencies, cereal-based complementary foods are usually given to breast fed children in Ethiopia. However, these traditional cereal-based complementary foods are mostly calorie-rich and insufficient in key micronutrients to meet the daily requirements (Abeshu et al., 2016; Baye et al., 2013). Thus, improving the quality and diversity of diets has been recommended as major strategies to improve micronutrient intakes (Arsenault et al., 2013; Muslimatun & Wiradnyani, 2016; Zhang et al., 2016). However, the success of this strategy is related to the availability and accessibility of foods, which largely depend on the food production system (Girard et al., 2012; Thamilini et al., 2019).

The food production pathway is the most direct agriculture-nutrition pathway by which own production translates into consumption (Gillespie et al., 2019). However, two contrasting views have been documented on the relationship between production diversity and diet from previous studies conducted in low- and middle-income countries. The first view argues that on-farm production diversity was consistently associated with increased household dietary diversity in smallholder farmer households (Ecker, 2018; Jones, 2017; Jones et al., 2014; Romeo et al., 2016). The second view argues that market access had a strong association than on-farm production diversity to increase household dietary diversity (Koppmair et al., 2016; Sibhatu et al., 2015). However, the evidence underlying the relationship from both views has the following limitations: (1) research has focused at the household level and overlooked the status of the most vulnerable member of the household, and (2) nutrient intakes were repeatedly measured using a proxy indicator (via dietary diversity score) which is limited to show the status of a specific nutrient of interest. In Ethiopia, given the dependency of rural households on agricultural production for sustaining their livelihoods, exploring the local context from the nutrition perspective could help to identify the problem as well as options to address the risk for the different micronutrient deficiencies among rural children who are already the most at risk.

Ethiopia is characterized by diverse topography and agro-climatic features that determine the production systems. A thoughtful understanding of the farming systems diversity across the rural areas will provide a framework to explore and design agricultural interventions for improving nutritional outcomes, particularly diets. Hence, the current analysis attempts to investigate the extent to which farming systems diversity, as defined by spatial classification of landscapes into a broadly 'distinct' patterns of farming systems, are correlated with usual total intake of vitamin A, iron and zinc among rural children in Ethiopia using a multi-level analysis approach. We hypothesized that (1) clusters (landscapes) with simplified (less diverse) farming system would be associated with high inadequate nutrient intake, and (2) the spatial farming system diversity is associated with the variability in nutrient intake.

Key messages

- The diet of rural children in Ethiopia is limited in diversity to provide adequate intake of vitamin A, iron and zinc.
- The spatial variability in vitamin A, iron and zinc inadequacy is mostly associated with farming system features.
- Understanding the local context in rural setting is crucial to explore and design nutrition sensitive and other complementary interventions that address micronutrient malnutrition.

2 | METHODS

2.1 | Study design and population

This analysis was conducted using data from the national food consumption survey (NFCS) in Ethiopia. The NFCS was a cross-sectional survey where a nationally and regionally representative sample of children 6 to 35 months of age was randomly selected from the different administrative regions. The survey used a multi-stage sampling design to ensure collection of dietary information from the range of different ethnic, geographic, socioeconomic and cultural settings. The country was stratified into nine geographical regions (Afar, Tigray, Amhara, Oromiya, Gambella, Benshangul Gumuz, Southern Nations and Nationalities and Peoples' [SNNP], Somalia and Harari) and two administrative cities (Addis Ababa and Dire Dawa). Then, each region was stratified into urban and rural areas or clusters. In the first stage of sampling, enumeration areas (EAs) or clusters composed of mainly rural and fewer urban areas were selected using probability proportion to EA or cluster size in each region. In the second stage, about 20 to 26 households per EA or cluster were selected using a simple random sampling technique.

Initially, the data consisted of a sample of 6,703 children from a total of 319 clusters. However, we excluded urban clusters due to the fact that urban clusters do not depend on their own production for consumption. We then focused our analysis on a total of 4,902 children from 228 rural clusters (Figure 1). Household demographic and socioeconomic information was retrieved from the NFCS and included in the analysis. Detailed information on the survey methodology was published elsewhere (Ethiopian Public Health Institute, 2013).

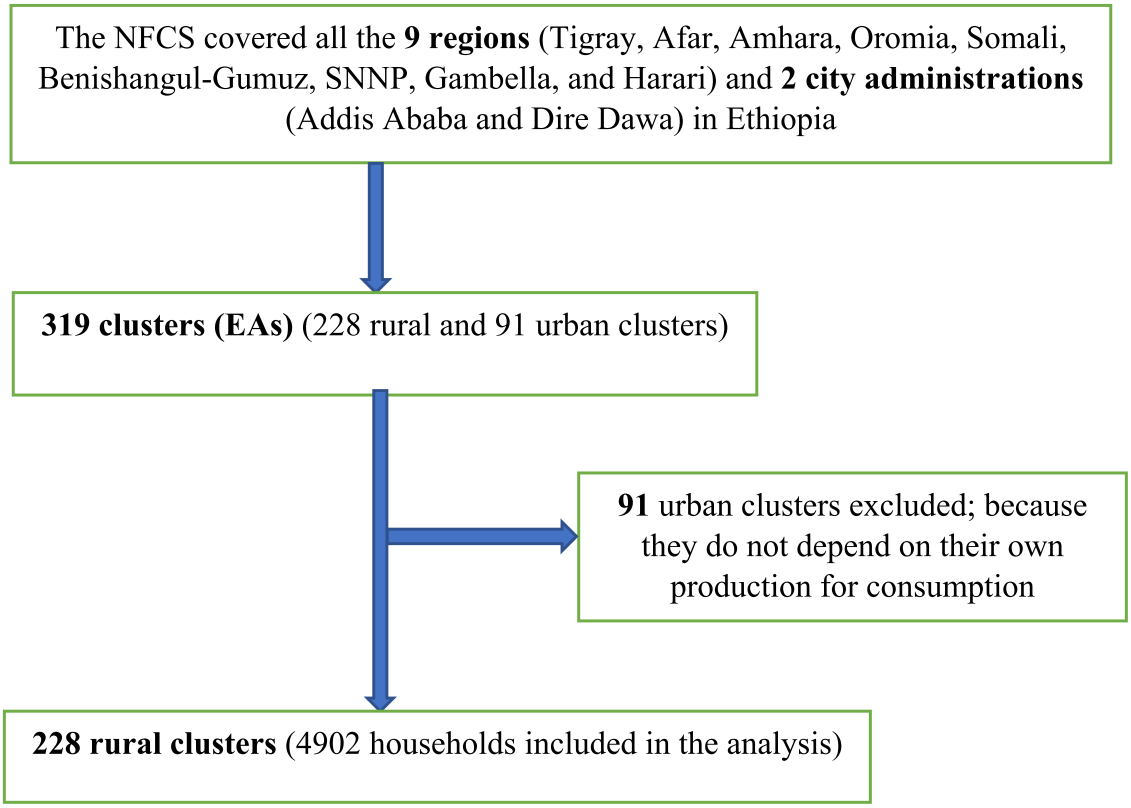

FIGURE 1 Flow chart showing the clusters and study participants included in the study

2.2 | Data collection methods

2.2.1 | Dietary intake data collection

Dietary data on the type and amount of food consumed by a child in the previous day were collected using a multi-pass single 24-h recall method (Gibson & Ferguson, 2008). The interview was administered by trained data collectors, and the mother or caregiver of the child was the respondent. A detailed description of the method of data collection is found elsewhere (Ethiopian Public Health Institute, 2013). Nutrient intakes, such as vitamin A, iron and zinc from foods consumed, were calculated using the Ethiopian food composition table part III and part IV (EHNRI, 1998a, 1998b). Only nutrients contributed from food sources were considered in this analysis.

2.2.2 | Farming systems data for clusters

The farming systems data for each cluster were obtained primarily from the Famine Early Warning System Network (FEWS NET; https://fews.net) and IFPRI's Harvest Choice (https://harvestchoice.org/products/data) databases, where clusters were classified based on the dominant pattern of farm activities and livelihoods using expert knowledge approach. Furthermore, available literature sources were referred to complement the existing data on farming systems (Amede et al., 2017). Based on those resources, a total of 10 farming systems were identified for the study clusters: agro-pastoral, highland maize mixed, highland barley-wheat mixed, highland perennial, highland teff mixed, lowland sesame mixed, pastoral, sorghum-chat mixed, sorghum mixed and western-lowland maize mixed. The farming system dominating a cluster is denoted as 'cluster farming system' (Figure 2). Moreover, cluster level data on food security were compiled from FEWS NET and included in the analysis.

2.3 | Data analysis

2.3.1 | Usual nutrient intake estimation

Usual nutrient intake estimation for a population of interest require a repeated 24-h dietary recall on at least a sub-sample of the population in order to account for within-person variability. However, the Ethiopian national food consumption survey was a single 24-h recall data, and a statistical adjustment using an external variance estimate from a repeated nationally representative dietary intake survey (in our case from Uganda) for a similar target group was made on the dataset to estimate the usual intake. The statistical adjustment was done using a 1-day method developed by the National Cancer Institute (NCI) and Institute for Global Nutrition at the University of California, Davis (Luo et al., 2019) to estimate

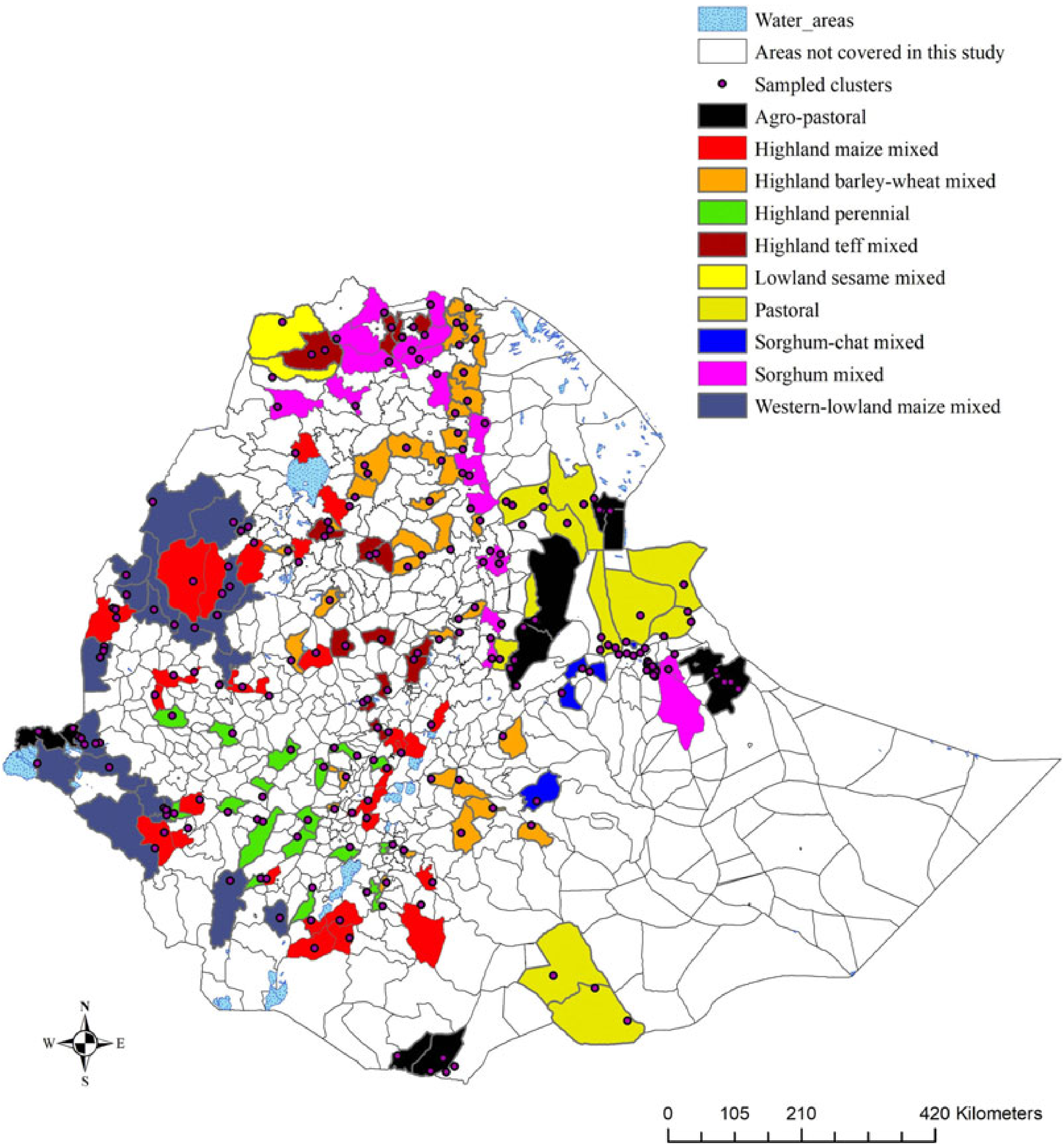

FIGURE 2 Spatial distribution of the sampled rural clusters by the dominant farming systems in Ethiopia, NFCS 2011

the usual total intake of vitamin A, iron and zinc. The method uses two SAS macros: TRAN1 and DISTRIB. The TRAN1 macro is used to generate parameter estimates for nutrients consumed every day by the majority of individuals after covariate adjustment for a day of the week using a Box-Cox transformation. Parameter estimates from TRAN1 were further used as input for the DISTRIB macro to estimate the distribution of usual intake via a Monte Carlo simulation. For each nutrient intake estimation, separate TRAN1 and DISTRIB macros were used.

2.3.2 | Nutrient adequacy assessment

Adequacy of nutrients was assessed using the estimated average requirements (EARs; the average daily nutrient intake level estimated to meet the requirements of half of the population of healthy individuals) as defined by the Institute of Medicine (IOM) and the International Zinc Nutrition Consultative Group (IZiNCG) for vitamin A and zinc, respectively, according to sex and age. Accordingly, the prevalence of inadequacy was estimated as the proportion of children with usual nutrient intakes below the EAR for vitamin A (Institute of Medicine, 2006) and zinc (International Zinc Nutrition Consultative Group, 2019). The EAR cut-off point method was not used for iron since the distribution of iron requirement among children is skewed. Thus, we used the full-probability approach proposed by the Institute of Medicine (IOM) adjusted for an iron bioavailability of 10% (World Health Organization, 2006). These three dietary reference values set by the Institute of Medicine (IOM) for vitamin A, International Zinc Nutrition Consultative Group (IZiNCG) for zinc and World Health Organization (WHO) for iron was chosen due to its wide range of use in the context of developing countries. Considering the local food preparation and processing practices (e.g., fermentation for cereals-based foods) which reduces the absorption inhibitors (e.g., phytate) (Abebe et al., 2007; Umeta et al., 2005), bioavailability adjustment for iron at 10% and zinc at 30% were set to estimate the prevalence of inadequacy of intake of these nutrients (International Zinc Nutrition Consultative Group, 2019; World Health Organization, 2006).

2.3.3 | Dietary diversity score

A dietary diversity score (DDS) was calculated for each child by categorizing individual foods consumed in quantities ≥10 g in the previous 24 h into the United Nations Children's Fund (UNICEF) seven food groups (World Health Organization, 2010). Though the use of the minimum threshold (≥10 g) has not yet been tested in Ethiopia, the use of this threshold is recommended to exclude foods that are consumed in small amount and has been tested in other developing countries. Using this threshold improved the performance of the dietary diversity score in predicting adequate micronutrient intakes (Daniels et al., 2009; Kennedy et al., 2007; Mahmudiono et al., 2020). Accordingly, a child with DDS of four food groups or more is categorized as a low-risk for micronutrients inadequacy (Kennedy et al., 2007).

2.4 | Statistical analysis

The analysis was started by exploring the distribution of the data. Accordingly, quantitative response variables (vitamin A, iron and zinc intakes) were checked for normality using a histogram. In the case of non-normality, square root transformation method was used. The transformed variables were tested and confirmed for normality and constant variance, and therefore, the ANOVA estimates are reliable. Then, normally distributed data were presented as means and standard deviations (SD), whereas for skewed distribution, we presented medians (interquartile range). One-way analysis of variance (ANOVA) and chi-square test were used to compare the mean DDS and the minimum food group consumption between cluster farming systems, respectively. Sample weight was applied for descriptive values, such as proportions and averages (e.g., mean DDS).

At individual-level, information on sex, age and food groups consumed were available for each selected child in the household. However, because maternal and household related factors greatly affect the nutritional status of a child in the household, we considered maternal education status, total household size and household socioeconomic status as additional individual-level factors in the modelling process. To examine the association between individual-level variables and cluster-level variables such as farming systems and food security with the usual total dietary intake of vitamin A, iron and zinc among rural children, we used multi-level models with parameter estimation using the maximum likelihood technique. A two-level random intercept linear model was used in the analysis by adjusting for individual-level variables (child age, child sex, household socioeconomic status and caretaker or mother educational status) and cluster-level variables (farming system and food security status) in subsequent models. Accordingly, in Model 1 (null model), neither the individual-level nor the cluster-level variables were included. Individual-level variables were included in Model 2, whereas cluster-level variables were included in Model 3. Lastly, both individual- and cluster-level variables were included in Model 4. Measures of association between individual-level variables, cluster-level variables with the specified micronutrient intakes were presented as regression coefficients in the fixed part of the model, whereas the cluster level variability was presented as the 'intra-class correlation' and percentage change in variance in the random effect part of the model. The statistical level of significance was set at $p < 0.05$.

Model considerations and estimation:

$$
\begin{aligned}
&\mathrm{Y}_{\mathrm{ij}} = \beta_{0\mathrm{j}} + \beta_{1\mathrm{j}}\mathrm{X}_{1\mathrm{ij}} + \beta_{2\mathrm{j}}\mathrm{X}_{2\mathrm{ij}} + \beta_{3\mathrm{j}}\mathrm{X}_{3\mathrm{ij}} + \beta_{4\mathrm{j}}\mathrm{X}_{4\mathrm{ij}} + \varepsilon_{\mathrm{ij}}, \ldots\ldots\ldots\ldots(\text{Level 1})\\
&\beta_{0\mathrm{j}} = \gamma_{00} + \gamma_{01}\mathrm{W}_{1\mathrm{j}} + \gamma_{02}\mathrm{W}_{2\mathrm{j}} + \mu_{0\mathrm{j}}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\text{Level 2})\\
&\beta_{1\mathrm{j}} = \gamma_{10},\\
&\beta_{2\mathrm{j}} = \gamma_{20},\\
&\beta_{3\mathrm{j}} = \gamma_{30},\\
&\beta_{3\mathrm{j}} = \gamma_{40},
\end{aligned}
$$

Mixed model:

$$
\begin{aligned}
\mathrm{Y}_{\mathrm{ij}} = {} & \gamma_{00} + \gamma_{10}X_{1\mathrm{ij}} + \gamma_{20}X_{2\mathrm{ij}} + \gamma_{30}X_{3\mathrm{ij}} + \gamma_{40}X_{4\mathrm{ij}} + \gamma_{01}W_{1\mathrm{j}} + \gamma_{02}W_{2\mathrm{j}} + \mu_{0\mathrm{j}}\\
& + \epsilon_{\mathrm{ij}}.
\end{aligned}
$$

Using variable names:

$$
\begin{aligned}
&\mathrm{Y}_{\mathrm{ij}} = \beta_{0\mathrm{j}} + \beta_{1\mathrm{j}}\mathit{CAge}_{\mathrm{ij}} + \beta_{2\mathrm{j}}\mathit{CSex}_{\mathrm{ij}} + \beta_{3\mathrm{j}}\mathit{SES}_{\mathrm{ij}} + \beta_{4\mathrm{j}}\mathit{MEdu}_{\mathrm{ij}} + \varepsilon_{\mathrm{ij}}, \ldots\ldots\text{Level 1}\\
&\beta_{0\mathrm{j}} = \gamma_{00} + \gamma_{01}\mathit{ClFar}_{\mathrm{j}} + \gamma_{02}\mathit{ClFoSec}_{\mathrm{j}} + \mu_{0\mathrm{j}}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Level 2}\\
&\beta_{1j} = \gamma_{10},\\
&\beta_{1j} = \gamma_{20},\\
&\beta_{1j} = \gamma_{30},\\
&\beta_{1j} = \gamma_{40},
\end{aligned}
$$

Mixed model:

$$
\begin{aligned}
\mathrm{Y}_{\mathrm{ij}} = {} & \gamma_{00} + \gamma_{01}\mathit{ClFar}_{\mathrm{j}} + \gamma_{02}\mathit{ClFoSec}_{\mathrm{j}} + \gamma_{10}\mathit{CAge}_{\mathrm{ij}} + \gamma_{20}\mathit{CSex}_{\mathrm{ij}} + \gamma_{30}\mathit{SES}_{\mathrm{ij}}\\
& + \gamma_{40}\mathit{MEdu}_{\mathrm{ij}} + \mu_{0\mathrm{j}} + \epsilon_{\mathrm{ij}},
\end{aligned}
$$

where Y_{ij} = dependent variable (nutrient intake) measured for child i in cluster j; $CAge_{ij}$ = age of child i in cluster j; $CSex_{ij}$ = sex of child i in cluster j; SES_{ij} = household socio-economic status of child i in cluster j; $MEdu_{ij}$ = mother educational status of child i in cluster j; $ClFar_j$ = type of farming system in cluster j; $ClFoSec_j$ = food security status in cluster j; β_{0j} = intercept for the jth cluster; β_{1j}, β_{2j}, β_{3j}, β_{4j} = regression coefficient associated with X_{ij} for jth cluster; γ_{00} = overall mean intercept; γ_{01}, γ_{02} = regression coefficient associated with cluster level variables; γ_{10}, γ_{20}, γ_{30}, γ_{40} = overall slope adjusted for cluster level variables; ϵ_{ij} = random error and μ_{0j} = random effects at cluster j adjusted for cluster level variables on the intercept.

2.5 | Ethical considerations

The survey was ethically approved by Scientific and Ethical Review Office (SERO) committee of Ethiopian Health and Nutrition Research Institute. Informed consent was obtained from caregivers who were interviewed.

3 | RESULTS

3.1 | Descriptive characteristics of study participants and clusters

The general characteristics of the study participants and the clusters included in this study are summarized in Table 1. Children were not equally distributed among cluster farming systems (e.g., the majority were from the highland barley-wheat mixed cluster farming system [24.3%]), whereas few were from the lowland sesame mixed cluster farming system (1.0%). A large proportion of mothers or caregivers were illiterate (72.0%) and from poor households (57.6%).

3.2 | Consumption of optimum food groups

Across the cluster farming systems, children had a very low diet diversity score (about an average of 2), and more than 90% had below the recommended minimum intake of four or more food groups per day (Table 2; World Health Organization, 2010). The diets were dominated by energy-rich staples such as cereals, roots and tubers irrespective of the diversity of farming systems (Figure 3). The contribution of other food groups differed between cluster farming systems. For instance, the staple diets were primarily supplemented with dairy products in pastoral and agro-pastoral farming systems, legumes in cereal dominated farming systems (highland maize mixed, highland-barley-wheat mixed, highland-teff mixed, lowland-sesame mixed and sorghum mixed) and vitamin A rich fruits and vegetables in highland perennial and Western-lowland maize mixed farming systems. The contribution of flesh foods and eggs were generally very low (Figure 3).

TABLE 1 Study population and clusters characteristics of rural children in Ethiopia (n = 4,092), NFCS 2011

Variable	Number of children	(%)
Individual and household-level characteristics		
Child age		
6–11 months	974	21.2
12–23 months	2,000	41.4
24–35 months	1,928	37.4
Child sex		
Male	2,611	53.4
Female	2,291	46.6
Household socioeconomic status		
Poor	2,652	57.6
Middle	1,266	25.1
Rich	984	17.3
Caretaker/mother education		
No education	3,600	72.0
Primary (1–4)	662	15.0
Primary (5–8)	465	9.5
High school and above	175	3.6
Cluster level characteristics		
Farming system	Number of clusters	(%)
Agro-pastoral	25	2.0
Highland maize mixed	33	23.0
Highland barley-wheat mixed	38	24.3
Highland perennial	19	13.8
Highland teff mixed	17	14.3
Lowland sesame mixed	3	1.0
Pastoral	21	1.1
Sorghum-chat mixed	17	5.4
Sorghum mixed	25	12.7
Western-lowland maize mixed	30	2.5
Food security status		
Food insecure clusters	108	33.7
Food secure clusters	120	66.3

3.3 | Usual total dietary intakes and adequacy of vitamin A, iron and zinc

The usual total dietary intake (as expressed in median) of vitamin A in children in the different cluster farming systems was below the estimated average requirement (EAR), as shown in Table 3. Nevertheless, a considerable difference in the usual total dietary intake of vitamin A was observed across the cluster farming systems. In particular, children from pastoral, agro-pastoral, highland perennial and Western-lowland maize mixed cluster farming systems had a usual total dietary vitamin A intake of more than twice as high as that of their counterparts from cereal dominated cluster farming systems, such as lowland sesame mixed, sorghum mixed and highland barley-wheat mixed. Due

TABLE 2 Dietary diversity score (DDS) and consumption of optimum food groups among rural children in Ethiopia, NFCS 2011

Dominant farming system per cluster	Number of children	Mean DDS (SD)	Consumption of 4 or more food groups (%)
Agro-pastoral	555	1.4 ± 1.0^{d}	4.5
Highland maize mixed	698	1.8 ± 0.9^{c}	4.7
Highland barley-wheat mixed	750	1.8 ± 0.9^{c}	5.0
Highland perennial	441	1.8 ± 0.9^{c}	4.5
Highland teff mixed	382	1.8 ± 1.0^{bc}	5.0
Lowland sesame mixed	67	1.8 ± 1.0^{bc}	3.6
Pastoral	445	1.9 ± 1.0^{bc}	8.9
Sorghum-chat mixed	387	2.3 ± 1.0^{a}	12.8
Sorghum mixed	519	1.8 ± 1.0^{bc}	4.8
Western-lowland maize mixed	658	2.0 ± 0.9^{b}	6.2
Total	4,902	1.8 ± 1.0	5.3

Note: Mean values without a common superscript are significantly different at $p < 0.05$. Superscripted letters are used to show the statistical significance of mean DDS between the cluster farming systems.

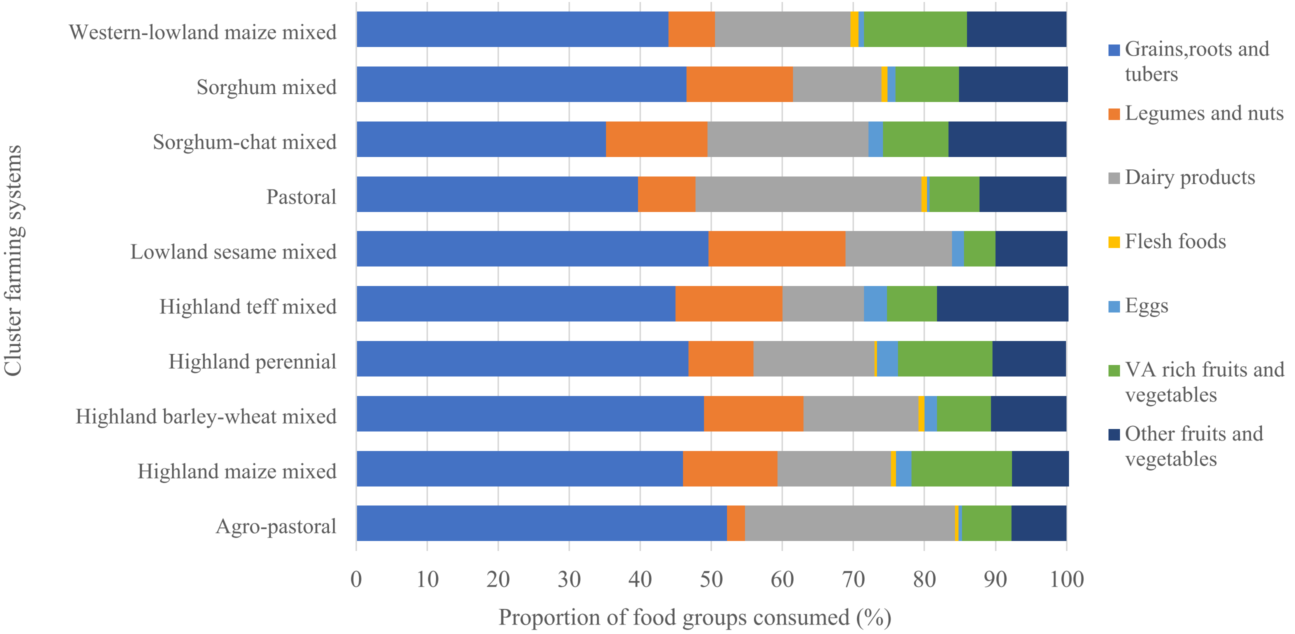

FIGURE 3 Proportion (%) of daily food group intake of rural children by cluster farming system in Ethiopia, NFCS 2011

to a low usual total dietary intake of vitamin A in clusters with cereal dominated farming systems, more than 80% of children residing in those clusters were unable to meet the requirement for vitamin A from their diet. By contrast, the highest usual total dietary intake of vitamin A was reported for children from clusters dominated by pastoral, agro-pastoral, highland perennial and Western-lowland maize mixed farming systems. However, the proportion of children living in those clusters with inadequate vitamin A intake remained high (ranging from 75.0% to 79.3%).

Usual total dietary intake of iron was generally high across the different cluster farming systems. However, relatively intake for children from clusters with pastoral and agro-pastoral farming systems was lower compared to the other clusters. As a result, a significant proportion of children living in those two cluster farming systems had a higher prevalence of inadequacy for iron (Table 3). By contrast, low usual total dietary intake of zinc was commonly found across the cluster farming systems. However, children living in highland perennial farming systems had the highest prevalence of inadequacy for zinc.

3.4 | Factors affecting the usual total dietary intake of vitamin A, iron and zinc

Tables 4–6 present the multi-level linear regression model analysis results that examine the association between individual-level variables and cluster-level variables with the usual total dietary intake of vitamin A, iron and zinc among rural children. Based on the null models intra-class correlation coefficient (ICC) results, 73.0%, 31.0% and 24.2% of the variation in the usual total dietary intake of vitamin A, iron and zinc, respectively, were attributed to the difference between clusters (Model 1; Tables 4–6).

In the subsequent models, we added individual- and cluster-level variables to assess their relationship with usual total dietary intakes of nutrients and explain the variation across the clusters. Among the individual-level variables, child age, sex and household socioeconomic status were associated with the usual total dietary intake of vitamin A, iron and zinc (Model 2; Tables 4–6). The association remained unchanged when controlling for cluster-level variables (Model 4; Tables 4–6). Consumption of an optimum number of food groups (four and more food groups) had a significant positive effect on the usual total dietary intake of iron and zinc, but not on vitamin A intake (Model 2). In contrast, maternal education status and household size had no significant effect on the usual total dietary intakes of vitamin A, iron and zinc (Models 2 and 4; Tables 4–6). The inclusion of these individual-level variables in the model explained 2.8%, 7.0% and 6.7% of the variation observed in the usual total dietary intakes of vitamin A, iron and zinc, respectively (Model 2; Tables 4–6).

Although the usual total dietary intakes of vitamin A and zinc were generally low (Table 3), the diversity of farming systems observed at clusters contributed significantly to differences in the usual intakes and explained majorly the observed variation. For instance, compared to pastoral cluster farming system, children from clusters dominated by highland maize mixed, highland barley-wheat mixed, highland teff mixed, lowland sesame mixed, sorghum-chat mixed and sorghum mixed farming systems had a significantly lower usual total dietary intake of vitamin A (Model 3; Table 4). There was no difference observed in the usual total dietary intake of vitamin A between pastoral, agro-pastoral, highland perennial and Western lowland maize mixed cluster farming systems. However, vitamin A intake for children from highland perennial and Western lowland maize mixed cluster farming systems was numerically lower than children from pastoral cluster farming systems. The diversity of farming systems across the rural clusters, where these sampled children reside, explained about half (48.2%) of the variation observed in the usual total dietary intake of vitamin A among children. Cluster-level food security did not affect the usual total dietary intake of vitamin A (Table 4).

Likewise, the usual total dietary intake of iron was significantly different between clusters with different farming systems and the observed trend seems quite the opposite in pattern (positively for iron) compared to the influence of cluster farming systems had on the usual total dietary intake of vitamin A (Model 3; Tables 4 and 5). More than half (57.2%) of the variation observed in the usual total dietary intake of iron among children was explained by differences in dominating farming systems in clusters (Table 5). Cluster-level food security was associated with usual total dietary intake of iron (Model 3; Table 5), but the association was lost in a fully adjusted model (Model 4; Table 5).

TABLE 3 Usual intake and prevalence of inadequate intake of vitamin A, iron and zinc among rural children by cluster farming system in Ethiopia, NFCS 2011

Farming system	n	Vitamin A (μg RAE)			Iron (mg)			Zinc (mg)		
		Median	IQR	Inadequate intake (%)	Median	IQR	Inadequate intake (%)	Median	IQR	Inadequate intake (%)
Agro-pastoral	555	67.6	[22.2, 180.2]	78.8	8.9	[4.9, 14.7]	20.3	2.1	[1.3, 3.2]	48.0
Highland maize mixed	698	54.8	[16.5, 150.0]	82.1	10.7	[6.3, 17.4]	5.1	1.9	[1.2, 3.0]	52.0
Highland barley-wheat mixed	750	27.4	[7.0, 86.4]	89.7	11.8	[7.1, 19.0]	2.6	2.0	[1.2, 3.2]	49.4
Highland perennial	441	66.8	[22.3, 176.5]	79.0	9.8	[5.7, 16.1]	7.7	1.8	[1.0, 2.8]	57.2
Highland teff mixed	382	36.3	[10.0, 108.5]	87.2	11.6	[7.0, 18.4]	2.4	2.1	[1.3, 3.3]	46.0
Lowland sesame mixed	67	15.9	[4.1, 50.0]	95.2	11.2	[6.7, 18.0]	3.6	2.4	[1.5, 3.5]	40.4
Pastoral	445	81.6	[27.5, 210.4]	75.0	7.3	[3.9, 12.7]	25.6	2.0	[1.2, 3.2]	50.3
Sorghum-chat mixed	387	52.1	[16.9, 142.8]	83.6	11.1	[6.6, 17.9]	7.7	2.2	[1.4, 3.4]	44.2
Sorghum mixed	519	22.3	[5.6, 72.7]	91.4	13.8	[8.2, 22.2]	3.3	2.3	[1.4, 3.5]	43.2
Western-lowland maize mixed	658	63.7	[19.7, 173.3]	79.3	11.2	[6.5, 18.5]	5.9	1.9	[1.1, 3.0]	54.0
Total	4,902	40.7	[11.2, 121.8]	85.4	11.3	[6.7, 18.3]	8.4	2.0	[1.2, 3.2]	49.5

Note: Inadequate intake (%), the percentage of a group with usual intake below the EAR; the EARs for vitamin A and zinc were taken from the IOM (Institute of Medicine, 2006) and IZINCG (Intrenational Zinc Nutrition Cosultataive Group) respectively. EAR values: vitamin A (210 μg/d); zinc (2.0 mg/d); for iron, a full probability approach was used instead of the EAR cut-off method.

Abbreviations: EAR, estimated average requirements; IQR, interquartile range (25th, 75th percentiles); RAE, retinol activity equivalent.

TABLE 4 Multilevel mixed linear regression model predicting usual total dietary vitamin A intake among rural children in Ethiopia

Fixed effects	Model 1 (null) Coef.	Model 2 Coef.	Model 3 Coef.	Model 4 Coef.
Individual-level (Level 1) variables				
Intercept	10.8	8.8	13.0	11.1
Child age		0.10***		0.10***
Child sex				
Male (reference)				
Female		0.10**		0.10**
Socio-economic status				
Middle (reference)				
Poor		−0.004		−0.01
Rich		0.23**		0.23**
Total household size		0.01		0.01
Mother education				
Primary (1–4) (reference)				
No education		0.05		0.04
Primary (5–8)		0.15		0.15
High school and above		0.17		0.17
Food groups consumed				
Below 4 food groups (reference)				
4 and above food groups		0.14		0.14
Cluster-level (Level 2) variables				
Farming system				
Pastoral (reference)				
Agro-pastoral			0.48	0.52
Highland maize mixed			−1.94***	−1.98***
Highland barley-wheat mixed			−4.70***	−4.78***
Highland perennial			−0.74	−0.80
Highland teff mixed			−4.05***	−4.22***
Lowland sesame mixed			−6.12***	−6.27***
Sorghum-chat mixed			−1.38*	−1.45*
Sorghum mixed			−4.22***	−4.31***
Western-lowland maize mixed			−1.01	−1.11
Food security				
Food secure cluster (reference)				
Food insecure cluster			0.02	−0.03
Random effects				
Variance (cluster)	7.49***	7.70***	3.88***	3.95***
ICC (%)	73.0	78.0	58.0	64.0
Explained variation (PCV) (%)	Reference	2.8	48.2	47.2

Note: Model 1: a model with no covariates; Model 2: with only individual-level factors; Model 3: with cluster-level factors; Model 4: with both individual and cluster level factors.
Abbreviations: ICC, intra-class correlation coefficient; PCV, proportional change in variance.
*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

The usual total dietary intake of zinc was less affected by the dominant farming systems in clusters. About one fourth (26.7%) of the variation observed was explained by the differences in dominant farming systems in clusters (Table 6). The association was significantly varied across cluster farming systems. In particular, in most cereal dominated systems (highland-barley-wheat mixed, highland-teff

TABLE 5 Multilevel mixed linear regression model predicting usual total dietary iron intake among rural children in Ethiopia

Fixed effects	Model 1 (null) Coef.	Model 2 Coef.	Model 3 Coef.	Model 4 Coef.
Individual-level (Level 1) variables				
Intercept	3.56	2.65	2.88	2.00
Child age		0.04***		0.04***
Child sex				
Male (reference)				
Female		0.05***		0.05***
Socio-economic status				
Middle (reference)				
Poor		0.07***		0.07***
Rich		0.16***		0.17***
Total household size		0.01		0.01
Mother education				
Primary (1–4) (reference)				
No education		0.01		0.02
Primary (5–8)		0.05		0.05
High school and above		0.04		0.03
Food groups consumed				
Below 4 food groups (reference)				
4 and above food groups		0.07*		0.07*
Cluster-level (Level 2) variables				
Farming system				
Pastoral (reference)				
Agro-pastoral			0.16	0.17*
Highland maize mixed			0.74***	0.73***
Highland barley-wheat mixed			0.87***	0.83***
Highland perennial			0.56***	0.52***
Highland teff mixed			0.89***	0.82***
Lowland sesame mixed			0.80***	0.74***
Sorghum-chat mixed			0.60***	0.56***
Sorghum mixed			0.94***	0.90***
Western-lowland maize mixed			0.78***	0.73***
Food security	Coef.	Coef.	Coef.	Coef.
Food secure cluster (reference)				
Food insecure cluster			0.10*	0.08
Random effects				
Variance (cluster)	0.152***	0.141***	0.065***	0.063***
ICC (%)	31.0	37.0	16.0	21.0
Explained variation (PCV) (%)	Reference	7.0	57.2	58.6

Note: Model 1: a model with no covariates; Model 2: with only individual-level factors; Model 3: with cluster-level factors; Model 4: with both individual and cluster level factors.

Abbreviations: ICC, intra-class correlation coefficient; PCV, proportional change in variance.

**p* < 0.05. ***p* < 0.01. ****p* < 0.001.

mixed, lowland-sesame mixed and sorghum mixed), children tended to have a higher usual total dietary intake of zinc compared to their counterparts from pastoral cluster farming systems (Models 3 and 4; Table 6). On the other hand, children from highland perennial cluster farming systems tended to have a lower usual total dietary intake of zinc compared to children from pastoral cluster farming systems (Models 3 and 4; Table 6). Moreover, the influence of cluster-level food security status on the usual total dietary intake of zinc was

TABLE 6 Multilevel mixed linear regression model predicting usual total dietary zinc intake among rural children in Ethiopia

Fixed effects	Model 1 (null) Coef.	Model 2 Coef.	Model 3 Coef.	Model 4 Coef.
Individual-level (Level 1) variables				
Intercept	1.52	1.20	1.44	1.13
Child age		0.01***		0.01***
Child sex				
Male (reference)				
Female		0.02**		0.02**
Socio-economic status				
Middle (reference)				
Poor		0.02*		0.02**
Rich		0.03***		0.03***
Total household size		0.002		0.002
Mother education				
Primary (1–4) (reference)				
No education		0.01		0.01
Primary (5–8)		0.02		0.02
High school and above		0.01		0.01
Food groups consumed				
Below 4 food groups (reference)				
4 and above food groups		0.03**		0.03**
Cluster-level (Level-2) variables				
Farming system				
Pastoral (reference)				
Agro-pastoral			0.04	0.05
Highland maize mixed			0.03	0.02
Highland barley-wheat mixed			0.08*	0.07*
Highland perennial			−0.03	−0.05
Highland teff mixed			0.14***	0.11**
Lowland sesame mixed			0.19**	0.17*
Sorghum-chat mixed			0.06	0.05
Sorghum mixed			0.14***	0.13***
Western-lowland maize mixed			0.04	0.03
Food security				
Food secure cluster (reference)				
Food insecure cluster			0.05**	0.04*
Random effects				
Variance (cluster)	0.015***	0.014***	0.011***	0.011***
ICC (%)	24.2	30.2	19.5	25.3
Explained variation (PCV) (%)	Reference	6.7	26.7	26.7

Note: Model 1: a model with no covariates; Model 2: with only individual-level factors; Model 3: with cluster-level factors; Model 4: with both individual and cluster level factors.
Abbreviations: ICC, intra-class correlation coefficient; PCV, proportional change in variance.
**p* < 0.05. ***p* < 0.01. ****p* < 0.001.

significant and consistent in both models (Models 3 and 4; Table 6); which implied children from food-insecure clusters tended to have a higher usual total dietary intake of zinc than children from food secured clusters.

4 | DISCUSSION

Prior attempts made to show the nexus between the food production and consumption in Ethiopia were measured based on indicators such as dietary diversity, energy and nutrient production at the household level (Aweke et al., 2020; Baye et al., 2019; Sibhatu et al., 2015; Tesfaye, 2020). The relationship at the individual level in terms of nutrient intakes remained unknown. This is the first study to our knowledge that estimated individual-level dietary usual total intakes of vitamin A, iron and zinc from nationally representative data of rural children in Ethiopia and further examined the influence of contextual factors associated with intakes of these nutrients. To attain our objectives, we followed an advanced methodological approach (for usual intake estimation and statistical modelling) to determine the adequacy of these nutrients among children and the variability in nutrient intakes attributed to individual- and cluster-level factors.

The diverse agro-climatic and ecological conditions of Ethiopia have led farmers to adopt a diverse farming system that fit into the local context to produce foods and generate income to support their livelihoods. Unexpectedly, the dietary pattern was more or less similar across the cluster farming systems except in pastoral and agro-pastoral clusters. The diet of rural children in this analysis was heavily dominated by starchy foods (cereals, roots and tubers) mainly rich in energy and lack animal source foods, which are a good source of micronutrients such as vitamin A, zinc and iron (Murphy & Allen, 2003). However, in pastoral and agro-pastoral cluster farming systems, children's diet constitutes relatively more consumption of animal source foods (e.g., particularly, milk) due to their high dependency on livestock to support their livelihoods (Abegaz et al., 2018; Potts et al., 2019). In general, the monotonous nature of children's diet across the different rural clusters in our analysis might be attributed to seasonality, in our case the time of the survey (May–July), where there were no major harvest in most parts of the country that define food availability and household consumption as previously stated in different studies (Ferro-Luzzi et al., 2001; Hirvonen et al., 2015; Potts et al., 2019; Sibhatu & Qaim, 2017).

Although the study covered clusters with diverse farming systems that could potentially produce a variety of foods of both animal and plant origin, consumption of diverse nutrient-dense foods was very limited (only about 5.0% of children had the minimum recommended intake of four food groups or more), and inadequacy of vitamin A and zinc was widely observed in these cluster farming systems. For instance, the inadequacy of vitamin A was prominent in cereal dominated clusters farming systems (such as lowland sesame mixed, sorghum mixed, highland barley-wheat mixed, highland teff mixed, sorghum-chat mixed and highland maize mixed) compared to pastoral, agro-pastoral, highland perennial and Western lowland maize mixed cluster farming systems. This could be because the current dietary practice in these clusters is dominated by staple grains that could only provide between 7.0% (in lowland sesame mixed) to 26.0% (in highland maize mixed) of the estimated average requirement of vitamin A for children. By contrast, consumption of animal source vitamin A-rich foods in pastoral and agro-pastoral clusters farming systems and consumption of vitamin A-rich vegetables, tubers and fruits in highland perennial and Western lowland maize mixed clusters farming systems (Demissie et al., 2009) have potentially reduced the prevalence of inadequacy of vitamin A among children living in these clusters. Yet the amount and proportion of children who have consumed these foods remain low in these clusters and only 30.0 to 39.0% of the estimated average requirement of vitamin A could be met from their current diet. Our current findings are comparable to previous studies on the dietary habit of young children in Ethiopia where consumption of vitamin A-rich foods from both animal and plant sources were limited to provide adequate vitamin A intake (Demissie et al., 2009; Eshete et al., 2018; Kim et al., 2019).

Low prevalence of inadequate intake of iron was observed in the majority of cluster farming systems except for children from pastoral (with a prevalence of 25.6%) and agro-pastoral (with a prevalence of 20.3%) cluster farming systems. Particularly, in cereal dominated cluster farming systems (sorghum mixed, highland teff mixed, highland barley-wheat mixed, lowland sesame mixed, highland maize mixed and sorghum-chat mixed), the reported low inadequacy of iron could be attributed to consumption of unrefined staple grains high in iron (as a result of soil iron contamination during threshing; Guja & Baye, 2018). Although traditional food preparation practice (e.g., fermentation) has the potential to reduce the phytate content, yet phytate intake associated with consumption of unfermented and unrefined cereal-based foods could potentially limit the absorption of iron required by the body.

Compared with vitamin A and iron, the prevalence of inadequate usual total dietary zinc intake among children seems 'evenly' distributed across the cluster farming system. In this sense, differences in the prevalence of inadequate usual total dietary zinc intake between clusters farming systems were minimal except in highland perennial clusters. This could be primarily associated with low to negligible consumption of animal source foods between clusters, which are a good source of zinc (Dror & Allen, 2011; Neumann et al., 2002; Zhang et al., 2016). Though rearing livestock is an integral part in most of the clusters farming systems, much of their products are not consumed by the household members. Instead, these products are either sold out to raise income and buy cheaper staple for consumption (Abegaz et al., 2018; Haileselassie et al., 2020) or preserved for special occasions, such as religious holidays and fasting seasons (Abegaz et al., 2018; Haileselassie et al., 2020). Moreover, the availability of zinc for the body may further be affected by consumption of unfermented cereal-based foods high in phytate (Gibson et al., 2010; Umeta et al., 2005).

Given the discrepancy between biochemical and dietary based estimate of population nutrient status, we tried to see the harmony between our findings and other national level micronutrient status studies, particularly in rural settings. Although dietary-based estimates lack a well-defined cut-off to indicate the severity of the problem for a particular nutrient at a population level, the high prevalence of inadequate intake of vitamin A (85.4%) and zinc (49.5%) among children in rural clusters supports the conclusion that children living in rural areas are at high risk for vitamin A

(24.7%) and zinc (24.0%) deficiencies, which suggest a potentially severe public health problem (Demissie et al., 2010; Tessema et al., 2019). Our dietary estimate of low prevalence of inadequate usual total dietary iron intake (8.4%) and biochemical estimate of low prevalence of iron deficiency (17.8%) were comparable (Ethiopian Public Health Institute, 2016). However, a significant proportion of children living in pastoral and agro-pastoral cluster farming systems suffer from high prevalence of inadequate intake of total dietary iron.

The findings from the regression model showed that usual total dietary intakes of vitamin A, iron and zinc among rural children were associated more with differences in the dominant farming systems between clusters than individual-level factors. Understanding the factors, particularly differences in the dominant farming systems in the country, provides a framework to explore the potential options and constraints to design an intervention to address nutrient inadequacies among children who are the most at-risk groups.

The findings of this analysis should be interpreted with some caution considering the strength and limitations of the study design and dataset used. Logistic and resource constraints limited the collection of multiple days dietary intake data from a nationally representative sample of children and the dataset we used were a single 24-h recall which might be affected by within-person and between-person variations. However, we employed an appropriate statistical method to adjust the within-person variation, between-person variation and important covariates that may influence intake of micronutrients (e.g., day of the week). Based on this, we estimated the usual total dietary intake distribution to assess the prevalence of inadequate intakes of vitamin A, iron and zinc quantitatively based on nationally representative data. Furthermore, we used a multi-level analysis to determine the factors that influence nutrient intakes of children at individual and cluster levels. These two methodological approaches enabled us to estimate the extent of inadequate intakes of nutrient among children in rural Ethiopia and determined the spatial variability of the problem taking both individual and community factors simultaneously into account. On the other hand, we recognized some of the limitations are worth noting. First, for those children who were breastfed during the survey time, the contribution of breast milk to nutrient intakes was not considered in the analysis, and this probably affected the prevalence of inadequacy among breastfed children. However, given the low breast milk nutrient content among rural mothers in Ethiopia (Z. Abebe et al., 2019; Gebre-Medhin et al., 1976), the reported prevalence estimate is less likely to be overestimated. Second, the NFCS was done during the lean season of Ethiopia (between May and July), and the seasonal food shortage in rural households might affect the consumption and contribute to low nutrient intakes. Third, the individual and cluster level factors included in the model were not exhaustive (e.g., market access) to explain the entire variation observed in nutrient intakes. However, given the time of the survey was carried out, the individual intake estimates would not be significantly affected by household market access. Lastly, the cross-sectional design of the survey did not allow us for a causal interpretation of individual and cluster level factors on the usual total dietary nutrient intakes of children.

Household agricultural food production is considered as a direct pathway through which agriculture impact nutrition in terms of access to and availability of food for consumption (Danton & Titus, 2018; Gillespie et al.,2019). Although the current production system considered in this analysis was short of providing adequate micronutrients, the variation in intake of nutrients observed across the clusters farming systems further reiterates the importance of this pathway in rural Ethiopia. Hence, understanding the association between individual nutrient intakes and the food production system at a landscape level, which we argue critically influence both the consumption and the food environment, could offer an entry point to explore the potential of the system beyond staple food production and to strategically design and integrate nutrition-sensitive agriculture interventions. From a policy perspective, this finding could be used as input to support the execution of the newly developed nutrition-sensitive agriculture strategy of the country (MoANR & MoLF, 2016). To maximize the impact of agricultural interventions on nutrition, future studies need to consider the role of other pathways such as women in agriculture activity, market access and function at different agriculture seasons.

5 | CONCLUSION

In conclusion, our findings show that the diets of rural children in Ethiopia were sub-optimal and inadequate to meet the requirements for vitamin A and zinc. Although the usual total dietary intakes of these nutrients were generally low, the differences in intakes observed between clusters dominated by different farming systems was remarkably high. Understanding the association between farming system at the landscape level and inadequate intakes of nutrients among rural children could help to explore interventions that fit into the local context and concomitantly address the nutritional problems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

CONTRIBUTIONS

TM designed the study, performed the statistical analyses, composed the draft manuscript and is responsible for the final content of the manuscript. JCJG, I.D.B, TD and FB supervised the statistical analysis and draft manuscript preparation. JCJG, I.D.B, TD, FB, RR and TB critically reviewed the manuscript. All authors have read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the Ethiopian Public Health Institute.

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REFERENCES

Abebe, Y., Bogale, A., Hambidge, K. M., Stoecker, B. J., Bailey, K., & Gibson, R. S. (2007). Phytate, zinc, iron and calcium content of selected raw and prepared foods consumed in rural Sidama, Southern Ethiopia, and implications for bioavailability. *Journal of Food Composition and Analysis*, *20*(3–4), 161–168. https://doi.org/10.1016/j.jfca.2006.09.003

Abebe, Z., Haki, G. D., Schweigert, F. J., Henkel, I. M., & Baye, K. (2019). Low breastmilk vitamin A concentration is prevalent in rural Ethiopia. *European Journal of Clinical Nutrition*, *73*(8), 1110–1116. https://doi.org/10.1038/s41430-018-0334-4

Abegaz, G. A., Hassen, I. W., & Minten, B. (2018). Consumption of animal-source foods in Ethiopia: Patterns, changes, and determinants.

Abeshu, M. A., Lelisa, A., & Geleta, B. (2016). Complementary feeding: Review of recommendations, feeding practices, and adequacy of homemade complementary food preparations in developing countries—Lessons from Ethiopia. *Frontiers in Nutrition*, *3*(October), 1–10. https://doi.org/10.3389/fnut.2016.00041

Amede, T., Auricht, C., Boffa, J.-M., Dixon, J., Mallawaarachchi, T., Rukuni, M., & Teklewold-Deneke, T. (2017). A farming system framework for investment planning and priority setting in Ethiopia.

Arsenault, J. E., Yakes, E. A., Islam, M. M., Hossain, M. B., Ahmed, T., Hotz, C., Lewis, B., Rahman, A. S., Jamil, K. M., & Brown, K. H. (2013). Very low adequacy of micronutrient intakes by young children and women in rural Bangladesh is primarily explained by low food intake and limited diversity. *The Journal of Nutrition*, *143*, 197–203. https://doi.org/10.3945/jn.112.169524

Aweke, C. S., Lahiff, E., & Hassen, J. Y. (2020). The contribution of agriculture to household dietary diversity: Evidence from smallholders in East Hararghe, Ethiopia. *Food Security*, *12*(3), 625–636. https://doi.org/10.1007/s12571-020-01027-w

Bailey, R. L., West, K. P. Jr., & Black, R. E. (2015). The epidemiology of global micronutrient deficiencies. *Annals of Nutrition & Metabolism*, *66*(suppl 2), 22–33. https://doi.org/10.1159/000371618

Baye, K., Guyot, J. P., Icard-Vernière, C., & Mouquet-Rivier, C. (2013). Nutrient intakes from complementary foods consumed by young children (aged 12-23 months) from North Wollo, northern Ethiopia: The need for agro-ecologically adapted interventions. *Public Health Nutrition*, *16*(10), 1741–1750. https://doi.org/10.1017/S1368980012005277

Baye, K., Hirvonen, K., Dereje, M., & Remans, R. (2019). Energy and nutrient production in Ethiopia, 2011–2015: Implications to supporting healthy diets and food systems. *PLoS ONE*, *14*(3), 1–12. https://doi.org/10.1371/journal.pone.0213182

Beal, T., Massiot, E., Arsenault, J. E., & Smith, M. R. (2017). Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLoS ONE*, *12*(4), 1–20. https://doi.org/10.1371/journal.pone.0175554

Bhutta, Z. A., & Salam, R. A. (2012). Global nutrition epidemiology and trends. *Annals of Nutrition and Metabolism*, *61*(suppl 1), 19–27. https://doi.org/10.1159/000345167

Biesalski, H. K., & Black, R. E. (2016). Malnutrition and the first 1,000 days of life: Causes, consequences and solutions. *World Review of Nutrition and Dietetics*, *115*, 1–15. https://doi.org/10.5860/choice.51-0915

Biesalski, H. K., & Jana, T. (2018). Micronutrients in the life cycle: Requirements and sufficient supply. *Nutrition and Food Science*, *11*(March), 1–11. https://doi.org/10.1016/j.nfs.2018.03.001

Daniels, M. C., Adair, L. S., Popkin, B. M., & Truong, Y. K. (2009). Dietary diversity scores can be improved through the use of portion requirements: An analysis in young Filipino children. *European Journal of Clinical Nutrition*, *63*(2), 199–208. https://doi.org/10.1038/sj.ejcn.1602927

Danton, H., & Titus, S. (2018). Taking action: Five ways to improve nutrition through agriculture now. *Global Food Security*, *18*(April), 44–47. https://doi.org/10.1016/j.gfs.2018.07.005

Demissie, T., Ali, A., Mekonen, Y., Haider, J., & Umeta, M. (2010). Magnitude and distribution of vitamin A deficiency in Ethiopia. *Food and Nutrition Bulletin*, *31*(2), 234–241. https://doi.org/10.1177/156482651003100206

Demissie, T., Ali, A., & Zerfu, D. (2009). Availability and consumption of fruits and vegetables in nine regions of Ethiopia with special emphasis to vitamin A deficiency. *Ethiopian Journal of Health Development*, *23*(3), 216–222. https://doi.org/10.4314/ejhd.v23i3.53242

Desalegn, A., Mossie, A., & Gedefaw, L. (2014). Nutritional iron deficiency anemia: Magnitude and its predictors among school age children, southwest ethiopia: A community based cross-sectional study. *PLoS ONE*, *9*(12), 1–13. https://doi.org/10.1371/journal.pone.0114059

Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. *Food and Nutrition Bulletin*, *32*(3), 227–243. https://doi.org/10.1177/156482651103200307

Ecker, O. (2018). Agricultural transformation and food and nutrition security in Ghana: Does farm production diversity (still) matter for household dietary diversity? *Food Policy*, *79*(June), 271–282. https://doi.org/10.1016/j.foodpol.2018.08.002

EHNRI. (1998a). Food Composition Table for Use in Ethiopia. Part III.

EHNRI. (1998b). Food Composition Table for Use in Ethiopia. Part IV.

Eshete, T., Kumera, G., Bazezew, Y., Mihretie, A., & Marie, T. (2018). Determinants of inadequate minimum dietary diversity among children aged 6–23 months in Ethiopia: secondary data analysis from Ethiopian Demographic and Health Survey 2016. *Agriculture & Food Security*, *7*(66), 1–8. https://doi.org/10.1186/s40066-018-0219-8

Ethiopian Public Health Institute. (2013). Ethiopia National Food Consumption Survey.

Ethiopian Public Health Institute. (2016). Ethiopian National Micronutrient Survey Report.

Ferro-Luzzi, A., Morris, S. S., Taffesse, S., Demissie, T., & D'Amato, M. (2001). Seasonal undernutrition in rural Ethiopia: Magnitude, correlates, and functional significance. In International Food Policy Research Institute.

Gebreegziabher, T., Regassa, N., Wakefiel, M., Pritchett, K., & Hawk, S. (2020). Disparities in the prevalence and risk factors of anaemia among children aged 6–24 months and 25–59 months in Ethiopia. *JNS Journal of Nutritional Science*, *9*, 1–8. https://doi.org/10.1017/jns.2020.29

Gebre-Medhin, M., Vahlquist, A., Hofvander, Y., Uppsäll, L., & Vahlquist, B. (1976). Breast milk composition in Ethiopian and Swedish mothers. I. Vitamin A and β carotene. *American Journal of Clinical Nutrition*, *29*(4), 441–451. https://doi.org/10.1093/ajcn/29.4.441

Gibbs, M., Bailey, K. B., Lander, R. D., Fahmida, U., Perlas, L., Hess, S. Y., Loechl, C. U., Winichagoon, P., & Gibson, R. S. (2011). The adequacy of micronutrient concentrations in manufactured complementary foods from low-income countries. *Journal of Food Composition and Analysis*, *24*(3), 418–426. https://doi.org/10.1016/j.jfca.2010.07.004

Gibson, R. S., Ferguson, E. L., & Lehrfeld, J. (1998). Complementary foods for infant feeding in developing countries: Their nutrient adequacy and improvement. *European Journal of Clinical Nutrition*, *52*(10), 764–770. https://doi.org/10.1038/sj.ejcn.1600645

Gibson, R. S., Bailey, K. B., Gibbs, M., & Ferguson, E. L. (2010). A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food and Nutrition Bulletin*, *31*(2), 134–146. https://doi.org/10.1177/15648265100312s206

Gibson, R. S., & Ferguson, E. L. (2008). An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes in developing countries. *HarvestPlus.*, *34*, 107–108. https://doi.org/10.1063/1.2914415

Gillespie, S., Poole, N., van den Bold, M., Bhavani, R. V., Dangour, A. D., & Shetty, P. (2019). Leveraging agriculture for nutrition in South Asia: What do we know, and what have we learned ? *Food Policy*, *82*(October 2018), 3–12. https://doi.org/10.1016/j.foodpol.2018.10.012

Girard, A. W., Self, J. L., McAuliffe, C., & Olude, O. (2012). The effects of household food production strategies on the health and nutrition outcomes of women and young children: A systematic review. *Paediatric and Perinatal Epidemiology*, *26*(SUPPL. 1), 205–222. https://doi.org/10.1111/j.1365-3016.2012.01282.x

Guja, H., & Baye, K. (2018). Extrinsic iron from soil contributes to Hb regeneration of anaemic rats: Implications for foods contaminated with soil iron. *British Journal of Nutrition*, *119*(8), 880–886. https://doi.org/10.1017/S0007114518000338

Haileselassie, M., Redae, G., Berhe, G., Henry, C. J., Nickerson, M. T., Tyler, B., & Mulugeta, A. (2020). Why are animal source foods rarely consumed by 6–23 months old children in rural communities of Northern Ethiopia? A qualitative study. *PLoS ONE*, *15*(1), 1–21. https://doi.org/10.1371/journal.pone.0230527

Hirvonen, K., Taffesse, A. S., & Hassen, I. W. (2015). Seasonality and household diets in Ethiopia. *Public Health Nutrition*, *19*(10), 1723–1730. https://doi.org/10.1017/S1368980015003237

Institute of Medicine. (2006). Dietary DRI reference intakes: The essential guide to nutrient requirements.

International Zinc Nutrition Consultative Group. (2019). Determining the risk of zinc deficiency: Assessment of dietary zinc intake. *IZiNCG Technical Brief*, *3*(3). https://static1.squarespace.com/static/56424f6ce4b0552eb7fdc4e8/t/5c1abb0870a6adf8eb61d85b/1545255689912/IZiNCG_Technical+Brief+%239_final.pdf

Jones, A. D. (2017). On-farm crop species richness is associated with household diet diversity and quality in subsistence- and market-oriented farming households in Malawi. *Journal of Nutrition*, *147*(1), 86–96. https://doi.org/10.3945/jn.116.235879

Jones, A. D., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy*, *46*, 1–12. https://doi.org/10.1016/j.foodpol.2014.02.001

Kennedy, G. L., Pedro, M. R., Seghieri, C., Nantel, G., & Brouwer, I. (2007). Dietary diversity score is a useful indicator of micronutrient intake in non-breast-feeding Filipino children. *Journal of Nutrition*, *137*(2), 472–477. https://doi.org/10.1093/jn/137.2.472

Kim, S. S., Nguyen, P. H., Tran, L. M., Abebe, Y., Asrat, Y., Tharaney, M., & Menon, P. (2019). Maternal behavioural determinants and livestock ownership are associated with animal source food consumption among young children during fasting in rural Ethiopia. *Maternal and Child Nutrition*, *15*, 1–9. https://doi.org/10.1111/mcn.12695

Koppmair, S., Kassie, M., & Qaim, M. (2016). Farm production, market access and dietary diversity in Malawi. *Public Health Nutrition*, *20*(2), 325–335. https://doi.org/10.1017/S1368980016002135

Luo, H., Dodd, K. W., Arnold, C. D., & Engle-stone, R. (2019). A new statistical method for estimating usual intakes of nearly-daily consumed foods and nutrients through use of only one 24-hour dietary recall. *The Journal of Nutrition*, 00, 1–7.

Mahmudiono, T., Andadari, D. P. P. S., & Segalita, C. (2020). Difference in the association of food security and dietary diversity with and without imposed ten grams minimum consumption. *Journal of Public Health Research*, *9*(3), 316–320. https://doi.org/10.4081/jphr.2020.1736

MoANR, & MoLF. (2016). Nutrition Sensitive Agriculture Strategy Ministry of Agriculture and Natural Resource (MoANR) Ministry of Livestock and Fisheries (MoLF) (Issue October).

Murphy, S. P., & Allen, L. H. (2003). Nutritional importance of animal source foods. *American Society for Nutritional Sciences*, *133*, 3932–3935.

Muslimatun, S., & Wiradnyani, L. A. A. (2016). Dietary diversity, animal source food consumption and linear growth among children aged 1–5 years in Bandung, Indonesia: A longitudinal observational study. *British Journal of Nutrition*, *116*, S27–S35. https://doi.org/10.1017/S0007114515005395

Neumann, C., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research*, *22*(1–2), 193–220. https://doi.org/10.1016/S0271-5317(01)00374-8

Potts, K. S., Mulugeta, A., & Bazzano, A. N. (2019). Animal source food consumption in young children from four regions of ethiopia: Association with religion, livelihood, and participation in the productive safety net program. *Nutrients*, *11*(354), 1–16. https://doi.org/10.3390/nu11020354

Ramakrishnan, U. (2002). Prevalence of micronutrient malnutrition worldwide. *Nutrition Reviews*, *60*(5), S46–S52. https://doi.org/10.1301/00296640260130731

Romeo, A., Meerman, J., Demeke, M., Scognamillo, A., & Asfaw, S. (2016). Linking farm diversification to household diet diversification: Evidence from a sample of Kenyan ultra-poor farmers. *Food Security*, *8*(6), 1069–1085. https://doi.org/10.1007/s12571-016-0617-3

Salgueiro, M. J., Zubillaga, M. B., Lysionek, A. E., Caro, R. A., Weill, R., & Boccio, J. R. (2002). The role of zinc in the growth and development of children. *Nutrition*, *18*, 510–519. https://doi.org/10.1016/S0899-9007(01)00812-7

Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences*, *112*(34), 10657–10662. https://doi.org/10.1073/pnas.1510982112

Sibhatu, K. T., & Qaim, M. (2017). Rural food security, subsistence agriculture, and seasonality. *PLoS ONE*, *12*(10), 1–15. https://doi.org/10.1371/journal.pone.0186406

Tesfaye, W. (2020). Crop diversification, household nutrition and child growth: Empirical evidence from Ethiopia.

Tessema, M., de Groote, H. D., Brouwer, I. D., Feskens, E. J. M., Belachew, T., Zerfu, D., Belay, A., Demelash, Y., & Gunaratna, N. S. (2019). Soil zinc is associated with serum zinc but not with linear growth of children in Ethiopia. *Nutrients*, *11*, 1–14. https://doi.org/10.3390/nu11020221

Thamilini, J., Wekumbura, C., Mohotti, A. J., Kumara, A. P., Kudagammana, S. T., Silva, K. D. R. R., & Frossard, E. (2019). Organized Homegardens Contribute to Micronutrient Intakes and Dietary Diversity of Rural Households in Sri Lanka. *Frontiers in Sustainable Food Systems*, *3*(October). https://doi.org/10.3389/fsufs.2019.00094

Umeta, M., West, C. E., & Fufa, H. (2005). Content of zinc, iron, calcium and their absorption inhibitors in foods commonly consumed in Ethiopia. *Journal of Food Composition and Analysis*, *18*, 803–817. https://doi.org/10.1016/j.jfca.2004.09.008

World Health Organization. (2006). Guidelines on food fortification with micronutrients.

World Health Organization. (2010). Indicators for assessing infant and young child feeding practices.

Zhang, Z., Goldsmith, P. D., & Winter-Nelson, A. (2016). The importance of animal source foods for nutrient sufficiency in the developing world: The Zambia scenario. *Food and Nutrition Bulletin*, *37*(3), 303–316. https://doi.org/10.1177/0379572116647823

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