Patterns and determinants of dietary micronutrient deficiencies in rural areas of East Africa

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Abstract

Micronutrient malnutrition is a large public health problem in many developing countries, but its dimensions and determinants are not yet clearly understood, especially with respect to sub-Saharan Africa. Based on 24-hour recall data from rural households in Rwanda, Uganda and Tanzania, this study analyzes dietary patterns to provide a comprehensive picture of the risk of micronutrient deficiencies, with particular emphasis on bioavailable vitamin A, iron and zinc intakes. The results confirm that micronutrient deficiencies are widespread and positively correlated with calorie deficiency. Regression analysis suggests that income growth will bring about important nutritional improvements. However, more targeted interventions are needed, especially for controlling vitamin A deficiency. Promising avenues include basic education, women empowerment, promotion of home gardens, awareness campaigns and vitamin A biofortification. Spatial differences within and across regions indicate that detailed knowledge of local conditions is imperative for designing and targeting effective food and nutrition policies.

Keywords: micronutrient deficiency; determinants; nutrient intake; dietary patterns; East Africa

Dans beaucoup de pays en voie de développement, la malnutrition entraînant une carence en micronutriments représente un problème important de la santé publique. On ne connaît pas encore très bien son amplitude et ses déterminants, tout particulièrement lorsqu'il s'agit de l'Afrique subsaharienne. Basée sur des données du rappel de 24 heures concernant des foyers en zone rurale du Rwanda, de l'Ouganda et de la Tanzanie, cette étude analyse les régimes alimentaires afin de fournir une image détaillée du risque de déficiences en micronutriments, avec un accent particulier mis sur les prises biodisponibles de vitamine A, fer et zinc. Les résultats confirment que les déficiences en micronutriments sont généralisées, et positivement corrélées à la déficience en calories. L'analyse de la régression suggère qu'une

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augmentation des revenus entrainera une amélioration nutritionnelle importante. Néanmoins, des interventions plus ciblées sont nécessaires, en particulier pour le contrôle de la déficience en vitamine A. Les moyens prometteurs comprennent une éducation basique, l'habilitation des femmes, la promotion des potagers individuels, la prise de conscience des campagnes et de la biofortification de la vitamine A. La différence spatiale dans et au travers des régions indique qu'une connaissance détaillée des conditions locales est impérative pour concevoir et cibler des politiques efficaces en matière d'alimentation et de nutrition.

Mots-clés : *déficience en micronutriments ; déterminants ; absorption de substances nutritives ; régimes alimentaires ; Afrique de l'Est*

1. Introduction

Micronutrient malnutrition is a large public health problem throughout the developing world. Chronic micronutrient deficiencies are associated with morbidity and mortality among millions of young children and pregnant women (UNICEF/MI, 2004). Deficiencies in iron, iodine, vitamin A and zinc are of particular concern in terms of global public health. Except for iodine, little progress has been made in controlling micronutrient deficiencies in sub-Saharan Africa; indeed, in some countries the situation is deteriorating (Mason et al., 2005). More than 40% of preschool children living south of the Sahara suffer from vitamin A deficiency. About 70% of all children under five and almost half of all pregnant women are anemic, mainly because of dietary iron deficiency (Mason et al., 2005). Micronutrient deficiencies are particularly widespread in rural regions (Smith et al., 2000).

The problem mainly results from a diet lacking in sufficiently absorbable amounts of one or more essential vitamins or minerals (WHO/FAO, 2003). Deficiencies are thus typically associated with certain dietary patterns. Understanding these patterns can provide important information about the relationship between food consumption and the risk of micronutrient malnutrition. Food consumption and nutrient intake patterns and their adequacy have been examined for different population groups in a number of African countries (e.g., Murphy et al., 1992; Mazengo et al., 1997). However, much less research has been carried out on identifying the socioeconomic factors driving dietary deficiencies. While household demand for calories has been estimated for different rural settings in East Africa (Braun et al., 1991; Abdulai & Aubert, 2004a), relatively little is known about the determinants of micronutrient consumption. Such knowledge is crucial for effectively designing and targeting nutrition intervention strategies. The only study we are aware of for sub-Saharan Africa is by Abdulai and Aubert (2004b), who estimated the demand for calories and micronutrients in Tanzania.

Our study adds to the literature by providing a comparative analysis of micronutrient intakes and deficiencies in rural areas of three East African countries, Rwanda, Uganda and Tanzania. Special emphasis is on bioavailable vitamin A, iron and zinc.[1] In addition, calorie intakes are considered in order to analyze links between undernourishment and micronutrient deficiencies. Using 24-hour dietary recall survey data, we present a comprehensive analysis of dietary patterns. To gain insights into the risk of multiple nutritional deficiencies, we examine the correlation between calorie and bioavailable micronutrient intakes. Furthermore, we use

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[1] We do not consider iodine intakes and deficiencies in this study, since information on the consumption of iodized salt is not available for our sample populations. Worldwide, crucial improvements in reducing iodine deficiency disorders have been achieved due to increased coverage with iodized salt. UNICEF/MI (2004) estimate that 90% of all households in Rwanda, 95% in Uganda and 67% in Tanzania consume iodized salt.

reduced-form demand models to estimate socioeconomic factors that determine calorie and micronutrient intakes. We explicitly account for the issue of micronutrient bioavailability, which has been neglected in previous nutrient demand studies (Weinberger, 2001; Abdulai & Aubert, 2004b). Tontisirin et al. (2002) argued that micronutrient bioavailability tends to be lower in the diets of poor than of rich households owing to a lower consumption of vegetables, fruits and animal-source foods. Accordingly, when not properly accounting for bioavailability, income effects on micronutrient status might be systematically underestimated.

Thus, the objectives of this study to document and compare patterns of calorie and micronutrient intakes, to assess dietary adequacy and to analyze socioeconomic determinants in different rural areas of East Africa, taking particular account of micronutrient bioavailability. The rest of this article is structured as follows. The next section describes the survey data. After the methodologies are explained and the empirical results are presented. The last section discusses the major findings and concludes.

2. Data

This study is based on stratified random sampling surveys carried out in rural areas of Rwanda, Uganda and central-northeastern Tanzania in 2003/04. Data were collected from farm households in typical districts. These districts were chosen purposely, such that they represent the observed heterogeneity in terms of agro-ecological, infrastructure and social conditions.[2] Within each district, villages and households were selected randomly. The number of households per village was adjusted to village size. In total, data from 235 Rwandan, 278 Ugandan and 376 Tanzanian households were obtained, with farming representing the main occupation for 88%, 92% and 96% of the households, respectively.

In order to achieve high information quality on food consumption, the interviews were conducted with the person mostly responsible for food choice and preparation in the households, mostly but not always a woman. We refer to this person as the 'meal preparer'. A one-time 24-hour dietary recall was used to collect data on food intake quantities. For purchased foods, prices were recorded. Respondents were asked to estimate the food quantities eaten and the drinks taken by all household members over the preceding day. They were asked to list all foods and drinks (excluding water), including those consumed away from home, for each meal separately (and the same for snacks). All days of the week were equally represented in the samples. The survey was carried out at the household level, since meals were mostly eaten jointly by all household members from a shared pot, which complicated the collection of individual level data.

Twenty-four-hour recalls are a common survey method in nutritional sciences, allowing for detailed assessments of the dietary patterns on a particular day. Compared to other survey methods (e.g. food expenditure surveys with longer recall periods), 24-hour recalls have several advantages. They survey the food quantities eaten by all household members, whereas food expenditure surveys capture the total food entering the household, not all of which is

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[2] In Rwanda, the districts surveyed were Rulindo and Bicumbi (in Kigali Rural Province), Maraba and Gikonko (in Butara Province) and Cyanzarwe and Nyamyumba (in Gisenyi Province). In Uganda, they were Kisoro and Kasese (in the Western Region), Rakai (in the Central Region), and Soroti, Mayuge and Mbale (in the Eastern Region). In Tanzania, they were Arumeru (in Arusha Region), Kongwa (in Dodoma Region), Singida Rural (in Singida Region) and Muheza (in Tanga Region).

actually eaten by household members. Some amounts might be wasted, fed to pets or given to guests or hired laborers. This can lead to an overestimation of actual food intakes in food expenditure surveys, especially among richer households (Bouis, 1994). In addition, over- and under-reporting tend to be low in 24-hour recalls, since people's memories are better over a period. The design of 24-hour recalls in a meal-specific format also facilitates the application of algorithms approximating the interaction of dietary factors that influence micronutrient bioavailability (Gibson & Ferguson, 1999).

But there are also some general concerns. One-time 24-hour recalls can provide a satisfactorily valid account of nutrient intakes in populations at a group level. However, the day-to-day variation in intakes differs by nutrient, particularly when there are seasonal variations in food supply. The intra-individual variability has been found to be generally larger than the inter-individual variability (Beaton et al., 1983). This implies that mean usual nutrient intakes of population groups might be reasonably estimated from one-day observations, whereas estimated prevalence rates of nutritional deficiencies are often not representative (Todd et al., 1983). To determine the proportions of nutrient-deficient persons in populations, nutritionists therefore recommend repeated 24-hour recalls (Gibson, 2005). The intra-individual variability is usually low for calories, moderate for minerals and high for some vitamins (Beaton et al., 1983).

During the pre-test interview phase of our survey, the variation of household food intakes over several consecutive days turned out to be very low in the study areas. It can therefore be expected that the intra-individual variability in nutrient intakes within the same season is relatively low in our context. However, distinct variability in food and nutrient intake patterns between agricultural seasons is typical in rural areas. Our surveys were conducted, each within a period of less than six weeks, between November 2003 and February 2004, starting with Rwanda, followed by Uganda and Tanzania. Interviews were carried out in the period after the short rainy season. The survey periods in Uganda and Rwanda were before the harvest of the short-season crops, whereas in Tanzania the harvest was already in progress at the time of the survey. Against this background, caution is warranted when extrapolating to seasons other than the ones specifically surveyed.

3. Methodology

3.1 Dietary analysis

Our analysis addresses different aspects of dietary quality, namely dietary diversity, food and nutrient intake patterns and dietary nutrient adequacy. Calculations are carried out at the household level and results are presented in terms of sample means. The diversity of diets is a key component of healthy nutrition and is positively associated with nutrient adequacy in the developing world (Ruel, 2003). Particularly in regions where people eat from a shared pot, dietary diversity is a useful first-cut indicator of people's micronutrient status (Torheim et al., 2004). Diets in poor households are typically based on plant-source foods that consist of high shares of starchy staples and usually contain few vegetables and fruits and little or no animal-source foods. Dietary diversity is commonly measured using a simple count of different food items or food groups consumed over a given time period (Ruel, 2003). We use food variety scores (FVS), i.e. the number of different food items eaten in a household over the day surveyed.

To assess dietary patterns, the food quantities from the 24-hour recalls are converted into calorie and micronutrient amounts using the nutrient database for standard references of the US Department of Agriculture (USDA, 2005).[3] Calorie and micronutrient intakes are calculated for prepared food portions as eaten. For analytical purposes, it is necessary to attribute nutrient intakes recorded at the household level to individual family members. We assume that food is distributed according to individual calorie requirements. We employ adult equivalent (AE) weights, which express each household member as some fraction of an adult male. As reference for weighting sex and age groups, we use the mean daily calorie requirements for moderate activity levels as suggested by FAO/WHO/UNU (2001).[4]

To estimate dietary calorie and micronutrient deficiencies, intake amounts are compared with standard levels of requirements available from the literature. We define a household as deficient if its intake is below the requirement. Standard requirements are given on a per capita basis and need to be adjusted to the AE weights. The reference value for calorie intakes is the minimum requirement as given by FAO (1996). The per capita requirement for sub-Saharan Africa is estimated at 1,800 kcal per day. To assess dietary micronutrient deficiencies, we use estimated average requirements (EARs) for individuals. For vitamin A, we use the EARs for application in developing countries as proposed by IOM (2000). Estimated average iron and zinc requirements for typical East African diets are not available from published sources. For iron, we apply the EARs of IOM (2000), which are defined for typical diversified North American diets of high bioavailability, and adjust them to the bioavailability levels that are consistent with the household-specific dietary patterns in our samples. The bioavailability of diets is usually categorized in three levels, low, moderate and high, based on the dietary composition. The criteria applied here are as presented by Gibson and Ferguson (1999). For zinc, we employ the EARs as reported by IZiNCG (2004). The requirements are given for two categories: mixed or refined vegetarian diets, and unrefined, cereal-based diets. On the basis of the average dietary patterns in our samples, we place the diets of Rwanda and Uganda in the first category and the those of Tanzania in the second.

3.2 Adjustments for bioavailability

Bioavailability is defined as the fraction of an ingested nutrient that is available for utilization in normal physiological functions or storage (Jackson, 1997). For vitamin A, bioavailability is essentially determined by the bioconversion of provitamin A carotenoids, which are present in different types and concentrations in many plant-source foods. Bioconversion defines the proportion of bioavailable carotene converted to retinol (Castenmiller & West, 1998). Retinol is the active form of vitamin A in the human body and as such available only from animal-source foods. Based on recent research, USDA (2005) food composition tables use carotenoid conversion rates of 12:1 for all-trans-β-carotene and 24:1 for all other provitamin A carotenoids, which are double the conversion rates suggested by the Food and Agricultural Organization (FAO) and the World Health Organization (WHO) (West et al., 2002). Thus, studies using FAO/WHO food composition tables considerably overstate vitamin A intakes,

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[3] Nutrient contents for some indigenous vegetables are not available from the USDA database. In these few cases, we used the nutrient contents of similar food items given in the database. We cross-checked these amounts with limited data available for indigenous vegetables (Weinberger & Msuya, 2004).

[4] Female and male children under the age of five are weighted with 0.5 AE, and female and male children aged 5 to 14 years with 0.7 and 0.8, respectively. Females over 15 years are weighted with 0.8 AE. The reference group includes males over 15 years of age.

particularly in populations with largely vegetarian diets. The comparability of our vitamin A intake estimates with those from most previous studies is therefore limited.

For iron and zinc, bioavailability depends mainly on the composition of diets and meals (Hurrell, 1997; Sandström, 1997). Food composition tables cannot account for dietary interactions of inhibiting and enhancing factors in iron and zinc absorption from composite and thus they report amounts as ingested from single foods – called gross intake amounts in the following. We use gross intake amounts to analyze levels of dietary iron and zinc deficiencies, because – as explained above – the applied EARs already account for bioavailability. However, for the other parts of the analysis, we compute bioavailable iron and zinc intakes, taking into account dietary factors that influence mineral absorption.

For each household, the bioavailable iron intake is computed on a meal-specific basis and then summed up over the day. The algorithm used here was developed by Murphy et al. (1992). It factors in the amount of heme and non-heme iron, the amount of ascorbic acid and the amount of protein from meat, fish and poultry. Heme iron, which is only present in animal tissues, is assumed to account for 40% of the total iron in meat, fish and poultry, with an average bioavailability rate of 25%. The specification of the bioavailability level for the remaining, non-heme iron takes into account enhancing effects resulting from the simultaneous ingestion of muscle proteins and ascorbic acid, as suggested by Murphy et al. (1992).[5] The mean bioavailability of non-heme iron amounts to 9.0% in the Rwandan, 9.3% in the Ugandan and 6.3% in the Tanzanian sample.

For zinc, adjustments are based on absorption rates proposed by IZiNCG (2004). For Rwanda and Uganda, we apply the absorption rates given for mixed or refined vegetarian diets of 34% for women, 26% for men and 31% for children, and for Tanzania, absorption rates for unrefined, cereal-based diets of 25% for women, 18% for men and 23% for children.

3.3 Estimating calorie and micronutrient intakes

Our analysis of the determinants of calorie and micronutrient intakes uses reduced-form demand functions, which are derived from Lancaster's goods characteristics model (Lancaster, 1971). In accordance with Abdulai and Aubert (2004b), Bouis and Novernario-Reese (1997) and Weinberger (2001), we assume that nutrient intake is a function of income and various other socioeconomic factors. Our calorie and micronutrient intake models take the following form:

$$\ln N = \alpha + \beta \ln Y + \gamma \ln X + \delta \ln Z + \varepsilon ,$$

where N is the amount of calorie or bioavailable micronutrient intake expressed in terms of adult equivalents, Y denotes household income, X is a vector of standard household characteristics, and the vector Z comprises variables identifying households' access to nutrient-rich foods. α, β, γ and δ are parameters to be estimated, and ε is a random error term. We use a double-log specification, as this shows the best goodness of fit. To explore differences in the socioeconomic determinants underlying households' nutritional status, the

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[5] Similar corrections for inhibiting effects from polyphenols in tea and phytates as well as for the nutritional and health status of individuals are not possible since the required data are not available.

estimation functions are regressed for each nutrient and each sample separately. Table 1 gives definitions and summary statistics of the variables entering the models.

Table 1: Variable definition and summary statistics

Variable	Definition	Mean (standard deviation)		
		Rwanda	Uganda	Tanzania
Calorie intake	Calorie intake in kcal per AE and day	2034 (927)	2225 (1566)	3125 (1405)
Vitamin A intake[a]	Vitamin A intake in µg RAE per AE and day	283 (654)	280 (580)	207 (388)
Iron intake	Bioavailable iron intake in mg per AE and day	1.68 (1.13)	1.42 (1.19)	2.14 (2.06)
Zinc intake	Bioavailable zinc intake in mg per AE and day	2.30 (1.18)	2.86 (2.68)	3.72 (2.37)
Food expenditure	Food expenditure per capita and day in US$	0.23 (0.14)	0.43 (0.36)	0.34 (0.18)
Household size	Number of persons per household (heads)	5.60 (2.15)	8.07 (3.99)	6.08 (2.45)
Female (dummy)	The meal preparer is female.	0.66	0.64	1.00
Age	Age of the meal preparer in years	36.9 (12.5)	41.3 (15.3)	36.5 (10.2)
Primary school (dummy)[b]	The meal preparer completed primary school.	0.54	0.51	0.83
Secondary school (dummy)[b]	The meal preparer completed secondary school or higher education levels.	0.16	0.16	0.05
Home garden (dummy)	Household has a home garden for vegetable and fruit cultivation.	0.82	0.68	0.68
Market distance	Distance of the household location to the nearest market place in km	7.4 (5.3)	5.3 (3.1)	28.3 (16.6)
District 1 (dummy)[c]	Household is located in Bicumbi (Rwanda), Mayuge (Uganda), or Kongwa (Tanzania).	0.17	0.17	0.28
District 2 (dummy)[c]	Household is located in Gikonko (Rwanda), Mbale (Uganda), or Singida (Tanzania).	0.17	0.18	0.26
District 3 (dummy)[c]	Household is located in Maraba (Rwanda), Rakai (Uganda), or Muheza (Tanzania).	0.16	0.16	0.28
District 4 (dummy)[c]	Household is located in Cyanzarwe (Rwanda), or Kasese (Uganda).	0.17	0.17	-
District 5 (dummy)[c]	Household is located in Nyamyumba (Rwanda), or Soroti (Uganda).	0.16	0.16	-
Observations		235	278	376

Note: One adult equivalent (AE) weight equals 1.28 persons in the Rwandan, 1.31 in the Ugandan and 1.26 in the Tanzanian sample on average.
[a] RAE = retinol activity equivalent.
[b] The reference variable denotes no education level completed.
[c] The reference variable denotes Rulindo District (Rwanda), Kisoro District (Uganda) and Arumeru District (Tanzania), respectively.

Household incomes are proxied by per-capita daily food expenditures converted into US dollars based on official exchange rates. Food expenditures are derived from food price and quantity data available from the 24-hour recalls. These expenditures are composed of market expenditures for food purchases and opportunity values for home-produced foods, collected foods and food gifts. Opportunity values are defined as the median market prices at district level. For a few foods, such as some indigenous vegetables, prices are not available from the survey data at all; in these cases, we consulted local market price statistics. Accurate data on non-food expenditures or household incomes are not available. However, as expenditure on food constitutes the largest budget share of households in low-income countries, food expenditure is a reasonable indicator of poor households' income, especially in rural areas. Given the rural-urban poverty gap in sub-Saharan Africa (Sahn & Stifel, 2000) and Engel's law, the shares of food expenditure on total expenditure in the areas under study are likely to considerably exceed national averages. The national averages of food expenditure account for 69% of the total expenditure in Rwanda, 47% in Uganda and 66% in Tanzania (Ruel et al., 2005). The food expenditures in our samples amount to less than half of the mean food expenditures at national level as reported by Ruel et al. (2005).

The vector X comprises variables for household size and individual characteristics of the meal preparer, including sex, age and education level. Household size is used to account for possible economies of scale in food consumption (Deaton & Paxton, 1998). In contrast to most previous studies (Bouis & Novernario-Reese, 1997; Weinberger, 2001), which used characteristics of the household heads, who are mostly male and typically not in charge of food preparation, we explicitly account for gender roles in household nutrition. We use the education level as a proxy for nutritional knowledge, following Behrman and Wolfe's (1984) finding that women's education is a key determinant of household nutritional status.

Households' access to nutrient-rich foods enters the models through the vector Z. In line with Weinberger (2001), a dichotomous variable specifying whether or not the household has a home garden is incorporated in our models. Home gardens, where mostly vegetables and fruits are grown, are expected to have a positive effect on micronutrient intakes. Households' access to marketed foods is proxied by a variable capturing the distance to the nearest marketplace. In accordance with the sample design, district dummies are included to control for possible location-specific factors such as infrastructural endowment and agro-ecological conditions. Furthermore, a cluster corrected model estimation procedure is applied (Deaton, 1997) to control for potential correlations between household observations from the same villages that might result from similar agricultural production conditions or other unobserved micro-level factors.

A general problem of demand models of the form applied here is the potential endogeneity of income, which can lead to upwardly biased estimates. This is often referred to as the efficiency-wage hypothesis, which argues that workers' income determines the nutritional status, which affects the labor productivity and which, in turn, translates into the compensation for the provided labor (Bliss & Stern, 1978). Bouis and Novernario-Reese (1997) and Weinberger (2001) used an instrumental variable approach to deal with this problem. Unfortunately, our datasets do not comprise suitable instruments. Yet it should be noted that an instrumental variable approach is not universally accepted as an appropriate solution. Subramanian and Deaton (1996) argue that standard simultaneous equation techniques are not suitable for coping with the possibility of reverse causation between labor productivity and nutrition. Moreover, for farm households as mostly observed here, the efficiency-wage hypothesis might be less relevant, because the profitability of farming

activities depends on a variety of factors other than nutrition. Therefore, if simultaneity exists in our context, we expect the resulting bias to be small.

4. Results

4.1 Dietary patterns

A healthy, nutrient-balanced diet can be achieved by consuming a variety of foods in adequate amounts. In our three samples, the estimated FVS indicates poor dietary diversity. The mean number of different food items consumed over the day surveyed amounts to only 6.7 in Rwanda, 5.9 in Uganda and 8.7 in Tanzania. Thus, the diets comprise a relatively narrow range of foods, which limits the provision of micronutrients to few sources and makes sufficient intakes difficult. Savy et al. (2005) report a similarly low FVS of 8.3 for rural Burkina Faso, applying 24-hour recall data to women's food consumption. Fifty-eight percent of the households in Rwanda, 30% in Uganda and 27% in Tanzania consume fewer than three meals (of solid foods) a day. Often the same dish, or in only slightly modified form, is eaten for both lunch and dinner. If breakfast is taken at all, it mostly consists of porridge purely based on staple foods.

The diets in all three samples are poorly balanced and largely plant-based. As Table 2 shows, animal products are rarely consumed. Only in Tanzania do fish and partly beef provide notable amounts of micronutrients. Staple foods, which include cereals, roots, tubers and plantains, account for the major share of the total food quantity consumed. They add up to about 70% in Rwanda and Uganda and to about 60% in Tanzania. Staples provide somewhat more than 70% of the calorie intake in all three samples. Tanzanian diets are dominated by cereals, mainly maize, whereas in Rwanda and Uganda sweet and Irish potatoes are the main sources of calories. The diet of some Ugandan households also contains considerable amounts of plantains, cassava and maize. The consumption of other cereals such as rice, sorghum, millet and wheat is low in all three samples.

Olivier Ecker, Katinka Weinberger and Matin Qaim

Table 2: Food and nutrient intakes and requirements (at sample means per AE and day)[a]

	Rwanda					Uganda					Tanzania				
	Quantity (g)	Calories (kcal)	Vit. A[b] (μg RAE)	Iron (mg)	Zinc (mg)	Quantity (g)	Calories (kcal)	Vit. A[b] (μg RAE)	Iron (mg)	Zinc (mg)	Quantity (g)	Calories (kcal)	Vit. A[b] (μg RAE)	Iron (mg)	Zinc (mg)
Cereals	67	132	0	1.4	0.3	223	621	0	4.6	3.3	643	2083	0	16.3	11.3
Roots/tubers & plantains	1239	1316	30	4.8	3.1	875	975	87	3.9	1.9	187	213	6	0.6	0.4
Pulses	249	321	0	5.3	2.5	235	333	1	5.1	2.5	81	134	0	1.6	1.0
Leafy vegetables	92	22	106	1.6	0.6	65	14	128	1.0	0.3	54	13	85	1.0	0.3
Other vegetables	145	44	135	0.8	0.5	65	17	49	0.3	0.3	148	36	82	0.8	1.0
Fruits	24	24	1	0.1	0.1	61	49	11	0.2	0.2	13	9	3	0.0	0.0
Meat	10	15	0	0.4	0.2	12	26	1	0.3	0.7	26	53	1	0.8	1.5
Fish	18	28	11	0.2	0.2	6	9	3	0.1	0.0	46	70	27	0.5	0.4
Dairy products & eggs	5	2	0	0.0	0.0	13	5	0	0.0	0.1	65	23	2	0.0	0.3
Edible oils & fats	10	88	0	0.0	0.0	9	79	0	0.0	0.0	43	288	1	0.2	0.1
Sugars & condiments	17	26	0	0.0	0.0	30	89	0	0.0	0.0	54	172	0	0.0	0.0
Beverages	36	15	0	0.0	0.0	12	8	0	0.0	0.0	33	31	0	0.4	0.4
Total	**1912**	**2034**	**283**	**14.7**	**7.5**	**1606**	**2225**	**280**	**15.6**	**9.4**	**1393**	**3125**	**207**	**22.3**	**16.6**
Standard deviation	942	927	654	8.4	3.9	1204	1566	580	13.9	8.7	622	1405	388	11.7	10.3
Requirements		*2299*	*311*	*22.5*	*7.4*		*2352*	*305*	*22.1*	*7.3*		*2265*	*311*	*21.2*	*10.0*
Prevalence of deficient households															
(%)		*68*	*81*	*87*	*54*		*69*	*77*	*80*	*50*		*27*	*85*	*56*	*26*

Note: Intakes are reported for foods as eaten. Nutrient intakes are given in amounts as ingested from single foods. For iron and zinc, gross intake amounts are shown (bioavailability levels are factored in iron and zinc requirements).
[a] One adult equivalent (AE) weight equals 1.28 persons in the Rwandan, 1.31 in the Ugandan and 1.26 in the Tanzanian sample on average.
[b] RAE = retinol activity equivalent.

Staple foods are also the main sources of iron and zinc. Gross mineral intakes from staples are highest for Tanzania, where iron and zinc from cereals amount to 73% and 68% of total intakes, respectively. In Uganda, 55% of iron and zinc intakes come from staples, predominantly from cereals. In Rwanda, staples provide less than half of the total iron and zinc intakes. Another important source of minerals in Rwanda and Uganda is pulses, which account for roughly one third of the total gross intakes. The most consumed pulses are beans, and partly groundnuts in Uganda. Vegetables provide relatively low amounts of minerals in the study areas: less than 10% of total zinc and iron intakes in Uganda and Tanzania and up to 17% in Rwanda.

Vegetables, however, are the main source of vitamin A. Among the leafy vegetables, amaranth is particularly important. Other vegetables that provide significant amounts of vitamin A are tomatoes and pumpkins. Sixty-three percent of total vitamin A intake in Uganda, 81% in Tanzania and 85% in Rwanda comes from vegetables. In addition, plantains are an important vitamin A provider in Uganda, and fish in Tanzania. Nonetheless, the consumption of vegetables and fruits in most sampled households is much too low for a healthy diet, particularly considering the low consumption of animal-source foods. The mean quantity of vegetables and fruits consumed in the Rwandan sample is about half of the (AE-adjusted) minimum recommended quantity of 400 g per capita as suggested by WHO/FAO (2003), and much less than half in the Ugandan and Tanzanian sample. Compared to national consumption averages estimated from household expenditure surveys, the vegetable and fruit intakes in our Rwandan and Tanzanian samples are higher by about 40 g and 15 g per AE, but lower by about 40 g per AE in the Ugandan sample (Ruel et al., 2005).[6]

4.2 Dietary nutritional deficiencies

On the basis of single-day observations, comparisons of mean total intakes of micronutrients with EARs suggest a high risk of micronutrient malnutrition, although there are crucial differences across the three study regions (see Table 2). Overall, dietary deficiencies are slightly less prevalent in Tanzania, which can partly be explained by seasonality effects. As mentioned, in Tanzania the survey coincided with the harvest of the short-season crops, whereas in the other two countries the surveys were carried out shortly before the harvest. Nevertheless, in all three samples, mean vitamin A intakes are below EARs, and the percentage of households with inadequate vitamin A intakes is high. In contrast, zinc is available in sufficient amounts at sample means. Nevertheless, owing to unequal distribution, about half of the Rwandan and Ugandan households and one fourth of the Tanzanian households have inadequate zinc intakes. Mean iron intakes fall short of the EARs in Rwanda and Uganda, but not in Tanzania. However, the majority of households in all three study regions have iron intakes below their requirements.

As can be seen from the prevalence of households with inadequate calorie intakes, the risk of undernourishment is also higher among the sampled households in Rwanda and Uganda than in Tanzania. Our mean calorie intake estimates of the Rwandan and Ugandan samples are lower than the comparable calorie consumption estimates given by Smith et al. (2006); for Tanzania, they are about equal to those of Smith et al. Using food expenditure data, Smith et al. (2006) estimated calorie consumption at 2,335 kcal in rural Rwanda, 3,482 kcal in rural

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[6] Note that our estimates are based on portions as eaten (see above).

Uganda and 3,134 kcal in rural Tanzania (converted to our samples' AE weights). The percentages of households with inadequate calorie consumption are estimated country-wide at 61% in Rwanda, 32% in Uganda and 38% in Tanzania (Smith et al., 2006). Compared to calorie availability estimates derived from food balance sheets, we find values lower than the (AE-adjusted) national averages in Rwanda (2,650 kcal) and Uganda (3,118 kcal) and higher values than the national average in Tanzania (2,470 kcal) (FAO, 2006). This pattern also holds for zinc availability estimates as derived from food balance sheets: IZiNCG (2004) reports national averages of 9.0 mg in Rwanda, 12.3 mg in Uganda and 10.0 mg in Tanzania (converted to our samples' AE weights) and prevalence rates of deficiency of 40%, 24% and 38%, respectively. For iron consumption, comparable numbers are available only for rural Tanzania. Using 24-hour recall surveys carried out during the rainy planting season and repeated during the dry season, Mazengo et al. (1997) found a mean iron intake of 30 mg among middle-aged men.

4.3 Correlation of calorie and micronutrient intakes

Correlation analysis is used to examine the association between calorie and bioavailable micronutrient intakes. Total household intakes per AE are correlated sample-wise for reasons of inter-regional comparison. The results are shown in Table 3. They suggest highly significant and positive relationships between the intakes of all nutrients under consideration. Yet the strength of the association differs by nutrient. Since staple foods are the key providers of iron and zinc, the correlation between calorie, bioavailable iron and bioavailable zinc is close. The risk of iron and zinc deficiency is thus especially high in calorie-deficient households.

Table 3: Correlation of calorie and bioavailable micronutrient intakes

		Calories	Vitamin A	Iron[a]	Zinc[a]
Vitamin A	Rwanda	0.116*	1.000		
	Uganda	0.377***	1.000		
	Tanzania	0.137***	1.000		
Iron[a]	Rwanda	0.605***	0.425***	*0.884***	
	Uganda	0.852***	0.533***	*0.887***	
	Tanzania	0.539***	0.142***	*0.655***	
Zinc[a]	Rwanda	0.813***	0.231***	0.765***	*0.997***
	Uganda	0.789***	0.274***	0.773***	*0.999***
	Tanzania	0.815***	0.102***	0.675***	*0.997***

Note: *,**,*** Coefficients are statistically significant at the 10%, 5% and 1% level, respectively.
[a] Correlation coefficients in italics report the correlation between bioavailable intakes and gross intakes.

The correlation of vitamin A intakes with calorie and mineral intakes is much weaker in all three samples as a result of different food sources. In Uganda, plantains are an important staple food, so that there is still a relatively close association between vitamin A and calorie

intakes. This is different in the other two countries, where the main staple foods are less important sources of vitamin A. Particularly in Tanzania, (carotenoid-free) cereals are the most important source of calories and minerals. In spite of these differences, the positive correlation between all nutrient intakes indicates that the risk of multiple nutritional deficiencies is high.

For iron and zinc, Table 3 also shows correlation coefficients between gross intakes and bioavailable intakes. As expected, the coefficients are relatively high, but lower than one, especially for iron. This underlines the importance of taking issues of bioavailability into account.

4.4 Determinants of calorie and bioavailable micronutrient intakes

Table 4 shows the estimation results of the calorie and bioavailable micronutrient intake models for the Rwandan, Ugandan and Tanzanian sample populations. Food expenditures are highly significant and positive in all models, implying that the nutritional status improves with rising household income. However, coefficient magnitudes vary remarkably by nutrient. The relatively high calorie elasticities suggest that a substantial share of increasing expenditures is allocated to calorie-dense staple foods. This is not surprising given the generally poor food security in all three sample populations. Since staple crops are important sources of minerals, expenditure elasticities are also high for iron and zinc. In addition, rising incomes lead to higher consumption of meat and fish, which has a double effect for the intake of bioavailable iron in particular: on the one hand, meat and fish contain significant iron amounts themselves; on the other hand, the heme iron from animal products also improves the bioavailability of iron from the rest of the diet, including that from staple foods. The expenditure elasticities for calories, iron and zinc are relatively similar in magnitude across the three samples. This implies consistent nutritional effects associated with income growth.

Olivier Ecker, Katinka Weinberger and Matin Qaim

Table 4: Determinants of calorie and bioavailable micronutrient intakes

	Rwanda				Uganda				Tanzania			
	Calories	Vitamin A	Iron	Zinc	Calories	Vitamin A	Iron	Zinc	Calories	Vitamin A	Iron	Zinc
Per-capita food expenditure (US$)	0.646***	0.634***	0.782***	0.763***	0.680***	1.249***	0.836***	0.687***	0.587***	0.407***	0.830***	0.737***
	(0.051)	(0.139)	(0.055)	(0.050)	(0.046)	(0.140)	(0.055)	(0.077)	(0.043)	(0.141)	(0.072)	(0.093)
Household size (heads)	0.029	-0.238	-0.097*	-0.041	-0.015	-0.292*	-0.024	0.091	-0.077*	-0.277*	-0.053	0.020
	(0.046)	(0.188)	(0.052)	(0.038)	(0.050)	(0.163)	(0.065)	(0.091)	(0.044)	(0.153)	(0.084)	(0.117)
Female[a]	-0.034	0.653***	0.013	-0.006	-0.045	0.421***	0.027	-0.109	-	-	-	-
	(0.051)	(0.186)	(0.062)	(0.044)	(0.048)	(0.162)	(0.056)	(0.082)				
Age (years)	0.030	0.243	0.052	0.037	-0.025	0.271	-0.098	-0.217**	-0.101*	-0.088	-0.230*	-0.282*
	(0.061)	(0.233)	(0.086)	(0.060)	(0.064)	(0.219)	(0.066)	(0.103)	(0.059)	(0.242)	(0.124)	(0.158)
Primary school[b]	-0.001	0.334*	0.023	0.033	0.074	0.277*	-0.013	0.018	-0.069	-0.119	-0.097	0.043
	(0.047)	(0.199)	(0.066)	(0.056)	(0.050)	(0.166)	(0.063)	(0.086)	(0.052)	(0.190)	(0.079)	(0.110)
Secondary school and higher[b]	-0.005	-0.032	-0.247***	-0.003	0.044	0.287	-0.016	-0.024	-0.144	0.377	-0.279	0.112
	(0.065)	(0.267)	(0.088)	(0.065)	(0.083)	(0.222)	(0.076)	(0.120)	(0.097)	(0.327)	(0.167)	(0.182)
Home garden	0.039	1.102***	0.181***	0.065	-0.193***	0.965***	0.076	-0.219**	-0.014	0.330**	-0.056	-0.164
	(0.050)	(0.248)	(0.066)	(0.045)	(0.058)	(0.158)	(0.067)	(0.096)	(0.040)	(0.157)	(0.066)	(0.101)
Market distance (km)	0.047**	-0.083	0.026	-0.007	-0.122	-0.755**	0.149	-0.177	-0.004	0.044	-0.009	0.096
	(0.023)	(0.095)	(0.028)	(0.029)	(0.097)	(0.347)	(0.104)	(0.146)	(0.040)	(0.100)	(0.051)	(0.093)
District 1[c] (Bicumbi/Mayuge/Kongwa)	-0.004	-0.362	-0.029	-0.133*	-0.190**	-0.079	-0.518***	-0.607***	0.385***	-0.541**	0.557***	0.360***
	(0.061)	(0.317)	(0.084)	(0.068)	(0.083)	(0.315)	(0.086)	(0.118)	(0.073)	(0.212)	(0.107)	(0.118)
District 2[c] (Gikonko/Mbale/Singida rural)	0.009	-0.116	0.036	-0.085	-0.070	-0.012	-0.582***	-0.316**	0.170*	-0.269	0.498***	0.014
	(0.075)	(0.317)	(0.093)	(0.075)	(0.079)	(0.324)	(0.100)	(0.129)	(0.086)	(0.193)	(0.116)	(0.193)
District 3[c] (Maraba/Rakai/Muheza)	-0.007	-0.066	0.048	-0.103	-0.152**	0.006	-0.546***	-0.547***	0.157**	-0.347	0.423***	0.154*
	(0.062)	(0.330)	(0.084)	(0.081)	(0.075)	(0.314)	(0.092)	(0.118)	(0.053)	(0.221)	(0.073)	(0.081)
District 4[c] (Cyanzarwe/Kasese)	0.432***	-0.041	0.232**	0.398***	-0.112	0.108	-0.533***	-0.419***	-	-	-	-
	(0.056)	(0.335)	(0.099)	(0.075)	(0.078)	(0.305)	(0.088)	(0.115)				
District 5[c] (Nyamyumba/Soroti)	0.130	0.564*	0.181*	0.096	-0.027	0.560	-0.234*	-0.025	-	-	-	-
	(0.080)	(0.327)	(0.107)	(0.089)	(0.121)	(0.451)	(0.132)	(0.170)				
Constant	8.228***	3.954***	1.343***	1.795***	8.783***	5.609***	1.516***	2.938***	9.035***	5.956***	2.153***	2.579***
	(0.240)	(0.992)	(0.361)	(0.242)	(0.275)	(1.023)	(0.280)	(0.414)	(0.226)	(0.878)	(0.404)	(0.454)
F-value	32.55	10.21	21.00	34.93	32.68	20.13	42.87	12.92	70.22	9.87	21.11	23.54
R-squared	0.623	0.264	0.551	0.722	0.621	0.504	0.668	0.393	0.537	0.125	0.381	0.351
Observations	235	222	235	235	278	235	278	278	375	370	375	375

Note: All continuous variables enter the models in logarithmic terms, so that the coefficients can be interpreted as elasticities. Regression estimations control for potential intra-village correlation through a cluster correction approach. Robust standard errors are reported in parentheses.
*, **, *** Coefficients are statistically significant at the 10%, 5% and 1% level, respectively

[a] For Tanzania, we dropped one observation that represented the sole household with a male meal preparer.
[b] The reference variable is no education level completed.
[c] The reference variable is Rulindo, Kisoro and Arumeru District, respectively.

188

The situation is different for vitamin A, where the expenditure elasticities vary much more across the three sample populations. In the Rwandan and Tanzanian samples, the elasticities for vitamin A are lower than for iron and zinc, because vitamin A intakes are closely associated with vegetable and fruit consumption, which is less in the local contexts. Only in the Ugandan sample is the elasticity higher for vitamin A than for the other nutrients. This is largely due to the important role of plantains, which are consumed as a staple food here. Moreover, the consumption of vegetables and fruits is considerably higher among richer than among poorer households in Uganda. However, caution is warranted with respect to simple generalizations, because vitamin A intakes are often subject to seasonality effects.

In conformity with Engel's law, our expenditure elasticities are somewhat higher than those reported in previous studies for East African countries, because we use food expenditures, whereas other studies have used total household expenditures. For instance, Braun et al. (1991) reported a calorie elasticity of 0.48 for rural households in northwest Rwanda that spent an average 79% of their total expenditure on food. For rural and urban areas in the Dar-es-Salaam and Mbeya regions of Tanzania, where the mean food expenditure share is 52%, Abdulai and Aubert (2004b) estimated elasticities of 0.43, 0.38, 0.31 and 0.47 for calories, vitamin A, iron and zinc, respectively.

Our estimation results indicate that the number of persons in a household has a statistically significant and negative effect on calorie and vitamin A intakes in the Tanzanian, vitamin A intakes in the Ugandan, and bioavailable iron intakes in the Rwandan sample population. Reverse economies of scale of household size have also been found for calorie and micronutrient consumption in other studies in sub-Saharan Africa (Rose & Tschirley, 2003, Abdulai & Aubert, 2004b). The gender of the meal preparer matters mainly for vitamin A intakes in our samples. The positive coefficients of the female dummy suggest that women tend to include higher amounts of vitamin A-rich foods in the diets. In Rwanda, households with female meal planners have 92% higher intakes of bioavailable vitamin A than households with male meal planners, while in Uganda the difference accounts for 52%. Age is significant and negatively related to calorie and bioavailable iron and zinc intakes in Tanzania as well as to bioavailable zinc intakes in Uganda. This might possibly be explained by dietary preferences gradually changing over time. For instance, the consumption of calorie-dense and mineral-rich cereals is lower in Tanzanian households with older meal preparers. The education level of the meal preparer shows no clear influence on calorie and bioavailable mineral intakes. Strikingly, however, the impact of primary school completion on vitamin A intakes is positive and significant in Rwanda and Uganda, suggesting that basic education contributes to dietary diversity and quality.

Home gardens have a considerable, positive effect on household vitamin A intakes in all samples. Our data confirm that households with a home garden consume more vegetables and fruits. A positive relationship between households' vitamin A consumption and the existence of home gardens has also been found by Weinberger (2001) for rural India. The effects of home gardens on calorie and mineral intakes are more diverse. They can partly be attributed to substitution effects in staple food consumption. For instance, Ugandan households with home gardens consume significantly lower amounts of cereals but higher amounts of roots, tubers and pulses, resulting in different nutritional compositions of diets. These findings indicate that nutritional impacts of programs and policies should not be evaluated by looking at the intake of a single nutrient, because interventions can have divergent effects with respect to different nutrients. It is likely that the overall nutrition effects of home gardens could be

further improved if promotion programs were accompanied by nutritional awareness campaigns.

The effect of market distance on nutrient intakes is mostly insignificant. Exceptions include calorie intakes in Rwanda, which increase slightly with market distance, and vitamin A intakes in Uganda, which decrease towards remote areas. In addition, many of the district dummies are significant, and some of the coefficients are relatively large. The coefficients suggest that location-specific factors such as agro-ecological conditions and infrastructural endowments affect calorie and bioavailable iron and zinc intakes in particular. Overall, these findings underline the important role of local conditions for household food and nutrition security in East Africa.

5. Conclusion

Against the background of high prevalence rates of micronutrient deficiencies in developing countries, this study has analyzed dietary patterns and socioeconomic determinants of nutrient intakes in rural households of three East African countries, Rwanda, Uganda and Tanzania. Using data from 24-hour dietary recall surveys, intakes of calories, vitamin A, iron and zinc were examined, taking particular account of micronutrient bioavailability. Since there is seasonal variation in food supply, data from one-time surveys, as used here, can only present a snapshot of the nutrition situation. Therefore, caution is warranted with respect to simple generalizations.

Overall, during the time of our surveys, the majority of the households sampled in all three countries were affected by food and nutrition insecurity. The diets were characterized by very low food variety and a heavy reliance on staple foods, mainly starchy root and tuber crops in Rwanda and Uganda and cereals in Tanzania. The consumption of vegetables and fruits was low, and animal-source foods were hardly consumed, so that the risk of micronutrient malnutrition was high. Both calorie and micronutrient inadequacies were rampant. In all three sample populations, around 80% of the households suffered from vitamin A deficiency in their diets. Dietary iron deficiency was equally high in Rwanda and Uganda, and dietary zinc deficiency affected about 50% of the households sampled in these two countries. In Tanzania, deficiencies in dietary iron and zinc were somewhat less pronounced, but still worrisome.

Analysis of the correlation between different nutrient intakes shows a very close association between calories, bioavailable iron and bioavailable zinc. This is because most of the iron and zinc in East Africa is provided by staple foods and pulses. The correlation between calorie and vitamin A intakes is also positive and significant, but lower in magnitude, because the most important source of vitamin A is vegetables, which are less calorie-dense. In spite of these differences, the positive correlation between all nutrient intakes indicates that the risk of multiple nutritional deficiencies is high.

Econometric models of bioavailable nutrient intakes show that rising household incomes will lead to an improved nutrition situation. However, there are again differences between the individual nutrients. The effect is stronger for calories, iron and zinc than it is for vitamin A. Additional income among the poor seems to be spent primarily on staple foods to reduce hunger. Associated increases in mineral intakes can be seen as a positive externality. This suggests that calorie and mineral deficiencies will shrink in the course of poverty reduction and economic development. While the same holds true for vitamin A deficiency, the effect is

weaker, so that more targeted interventions are additionally required, especially in rural Rwanda and Tanzania. One option would be to biofortify typical staple foods with carotenoids, as is done in the HarvestPlus Challenge Program of the Consultative Group on International Agricultural Research, and in several of the projects of the Grand Challenges in Global Health Initiative supported by the Gates Foundation. Interestingly, the situation in Uganda is slightly different: the positive effect of rising incomes on vitamin A intakes is much larger there, because the demand for vegetables and fruits is more income-responsive, and plantains, which contain notable amounts of carotenoids, are consumed as a staple food.

The gender of the meal preparer has an important influence on household nutrient intakes. Where women are responsible for food choices, the vitamin A status is significantly better. Furthermore, primary education and home gardens for vegetable and fruit production lead to significant increases in household vitamin A intakes in particular. Hence, women empowerment, basic education and the promotion of home gardens seem to be effective avenues to reduce vitamin A deficiency. However, the estimation results also suggest that such policies might have differential net impacts across nutrients, so that partial impact measures need to be interpreted cautiously. Specific interventions should be accompanied by nutrition efforts, promoting balanced and more diverse diets. Spatial differences between but also within regions indicate that detailed knowledge of local dietary patterns and local agricultural production and living conditions is a key prerequisite for designing and targeting effective food and nutrition policies in rural East Africa. More research is needed to provide such knowledge.

Acknowledgements

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