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Comparison of Two Pathways Linking Agriculture to Child Health: Dietary Diversity and Micronutrient Intake in the Malagasy Highlands

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Rising micronutrient deficiencies threaten the well-being of preschool-aged children, as is the case for disadvantaged farmers in Madagascar. However, effective interventions to improve their nutritional status are still unknown. This study investigates the disjointed link between agriculture – food/nutrition security and food/nutrition security - nutritional status through a dual approach. Using a panel dataset, our result supports the link between production diversity – dietary diversity, and dietary diversity - improvement in children's wasting. Importantly, the finding highlights an association of own production of pulse with energy/micronutrient intake and that of energy/zinc intake with the reduction of undernourished and stunted child, respectively.

Key words: dietary diversity, micronutrient, child undernutrition

1. Introduction

"Hidden hunger" or "micronutrient malnutrition" has exacerbated the problem of food security in sub-Saharan Africa and has remained a silent obstacle for preschool children. In particular, micronutrient deficiency is a major contributor to premature death and cognitive disablement. This deficiency is prevalent among children in the central highlands of Madagascar, with a high prevalence of stunting (59.9%), wasting (6.0%) and underweight (40.1%) (INSTAT and UNICEF, 2019).[1)] However, effective interventions to address their micronutrient status are still unclear (Campos *et al*., 2019). Hence, understanding the link between agriculture and improved nutritional outcomes for children is of strategic importance.

Research linking agriculture and nutrition has recently gained much attention for its global importance. Specifically, agricultural diversification is often recommended for its contribution to dietary diversification, which in turn is associated with improved nutritional status of individuals. However, no common understanding has been reached regarding its impact on dietary diversity (Sibhatu and Qaim, 2018). At the same time, supporting evidence indicating a link between dietary diversity and nutrient adequacy among children in developing countries has so far been inconclusive (Arimond and Ruel, 2004; Sié *et al*., 2018). More recent studies have analyzed the relationship between agricultural diversification - household diets - and child nutritional outcomes (Bühler *et al*., 2018; Chegere and Stage, 2020). Their findings suggest that production diversification significantly increases dietary diversity; yet, the latter explains only to a negligible extent the state of malnutrition among children.

To date, nearly all studies in this area contend that dietary diversity score can serve as a reliable proxy of dietary quality containing a range of micronutrients essential to the body (Arimond and Ruel, 2004). However, as a summary indicator, its appropriateness is of concern (Jones, 2017). That is, a diverse diet could: (i) be devoid of important micronutrients (Chegere and Stage, 2020); (ii) hide important variations in nutrient intakes (Jones, 2017); (iii) mask the heterogeneous effect of each food group; (iv) obscure underlying pathways with limited understanding of the influence of subsistence and market-based production; and (v) conceal the role of micronutrient intakes in improving a child's nutritional status.

With respect to (i) and (ii), the burden of collecting data on every micronutrient consumed leaves this area unexplored. Only one study has addressed the agriculture - food security - nutrition nexus from the perspective of micronutrient intake (Sekabira and Nalunga, 2020). However, the study does not investigate the role of food groups and their importance to

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1) These figures are of Vakinankaratra region, one of the regions belonging to the central highlands of Madagascar. Our study site is located in this region. Note that stunting rate is the highest in this region among 22 regions in Madagascar, whose average rate of child stunting is 41.6% (INSTAT and UNICEF, 2019). This is one of the reasons why we choose this study site.

human health. About (iii), only one study has analyzed the estimation of nutrient intakes by specifying food groups (Chegere and Stage, 2020). Yet, the study fails to assess the extensive role of each food group on micronutrient intake. As for (iv), although a handful of studies have distinguished the subsistence and income-generating pathways, they have not explicitly differentiated the impact of each food group (Muthini *et al*., 2020; Sekabira and Nalunga, 2020). Finally (v) implies the use of dietary diversity scores obscures the important role of caloric and micronutrient intake on child growth. Yet, limited studies have used the calorie and micronutrient intake measurements to assess the nutritional status of children thus far. Hence, there is an overall lack of empirical analyses to elucidate mediating pathways between the agriculture - food security - nutrition nexus. The present study aims to address these important gaps. The purpose is to unravel the link between agriculture, food/nutrition security, and child nutrition to formulate an effective intervention to address micronutrient deficiencies in children.

This study offers a more comprehensive contribution to the growing literature on agriculture - food security and food security - nutrition by taking three novel approaches. First, we use a twofold approach (the dietary diversity and the micronutrient intake approach) to trace the micronutrient intake pathway. Second, we single out the contribution of each food group on both dietary diversity and micronutrient intake to uncover their specific roles and to capture the heterogeneous linkage through both subsistence and market pathways. Third, we explore the association of diet quality in terms of calorie and micronutrient intake with child nutritional status.

2. Data and Analytical Framework

1) Data

This study uses an original panel dataset produced from household surveys conducted in January 2019 and in January/February 2020 as part of SATREPS project in which the authors participated. Each survey covers a total of 600 lowland rice producing households randomly selected from 60 villages in 3 out of 7 districts of the Vakinankaratra region in Madagascar. The surveys were implemented in the middle of rainy season, or the leanest season, and collected detailed information about agricultural activities and income in the previous dry season as well as household current situation at the time of interview including household-level food consumption (24-hour recall) from home production and market purchases, household characteristics and individual-level anthropometric measures and characteristics. It is worth noting that the stock of produced food is the lowest in the lean season, and it concerns most of the food groups. After eliminating the cases with incomplete data, we construct a balanced panel dataset of 510 households, which includes a pooled data of 395 anthropometric measurements of children under the age of 5 years from the two waves.[2)]

Two categories of outcomes are evaluated in this study: household diet quality and child nutritional status.

The household dietary quality is assessed by household dietary diversification and micronutrient components in the diet. We use two indicators for household dietary diversification: Household Dietary Richness Score (HDRS) from 24-h recall, and Household Dietary Diversity Score (HDDS) from 24-h recall. HDRS is a raw count of any food crops and animal products consumed by the household, while HDDS is constructed on the basis of 12 food groups. Micronutrient components (Iron and Zinc) and calorie intake are calculated from the 24-h recall using food composition tables (FAO, 2020).

The indicators of child nutritional status are based on the anthropometric measurements as follows: (1) stunted, (2) wasted, (3) underweight, and (4) undernourishment (defined as either stunted, wasted, or underweight).[3)]

Two explanatory variables are used as indicators of production diversity within a household: first, Agricultural Richness Score (ARS), which is the count of different food crops and animal products produced by a household; and second, Agricultural Diversity Score (ADS), which is the count of different food groups produced by a household, constructed using the 12 food groups of the HDDS.[4)]

2) Since only children available at the time of the survey were measured, there are a lot of missing measurements. Hence, at the child level, the data are unbalanced very much and cannot be a good panel.

3) Stunted is the case where height-for-age Z-score (HAZ) is less than -2 standard deviations (SD), wasted is the case where weight-for-height Z-score (WHZ) is less than -2 SD, and underweight is the case where weight-for-age Z-score (WAZ) is less than -2 SD. The Z-score was calculated according to the WHO Child Growth Standard 2006.

4) During both surveys, 54% of sample households produced at least one of the 7 food groups: cereals (20%), tubers (23%), pulses (6%), vegetables (11%), milk (5%), egg (3%), and meat (5%). There was no household producing 5 food groups, namely fish, fruit, sugar, oil, or other miscellaneous foods such as tea and coffee. Therefore, we consider only 7 food groups for ADS. Also please note that 46% of sample households produced nothing because it is in the dry season.

2) Analytical framework

First, we examine the linkage of production diversity (ARS and ADS respectively) with household dietary quality (diversification as well as micronutrient components) and child nutritional status using household fixed effects (FE) model. Then, as a robustness check, we estimate a pooled Ordinary Least Square (OLS) model with village-level fixed effects and time fixed effects.

Second, using the same model, we disaggregate foods produced into food groups and investigate the linkage of the production of each food group with household dietary quality. In this analysis, we consider two sources of foods for consumption, market purchase and self-production, and respectively investigate their association with dietary diversity as well as micronutrient intakes.[5)]

Third analysis is for the latter half of the linkage, namely between food consumption and child nutritional status, where using the household dietary quality variables as explanatory variables, its association with child nutritional status is estimated by a pooled OLS model.

3. Descriptive Statistics

Table 1 presents the summary statistics of outcome variables for the full sample. On a daily basis, a household consumes 4.6 food items and 4.0 food groups out of the 12 maximum possible food groups, which implies a shortage of 8 food groups. We also show results depicting the qualitative household food security, including energy and essential micronutrients (daily consumption per adult-male equivalent). We observe that the average intakes of energy and zinc are below the amount required for an adult male body, while that of iron seems to be sufficient.[6)] Our second set of outcome variables consists of the nutritional status of children. Nearly 40 percent of children from our sampled household are stunted, approximately 20 percent are wasted, and more than 25 percent are underweight.[7)] The percentage of undernourished children reaches about 57 percent.

Table 1. Summary statistics of outcome variables

	Mean	S.D.
Household Level Outcomes (N=510*2)		
Household Dietary Richness Score (24-h)	4.55	1.95
Household Dietary Diversity Score (24-h)	3.97	1.44
Energy (Kcal/per adult-male equivalent)	1977	1546
Iron (mg/per adult-male equivalent)	22.6	16.5
Zinc (mg/per adult-male equivalent)	9.59	6.92
Child Level Outcomes (N=373)		
Stunted (HAZ<-2)	0.39	0.49
Wasted (WHZ<-2)	0.20	0.40
Underweight (WAZ<-2)	0.29	0.46
Undernourished (at least one of the above three)	0.57	0.50

As for household characteristics, the descriptive statistics is given in Appendix Table.

4. Results and Discussions

1) Production diversity and dietary diversity

The results of the FE and pooled OLS models showing the influence of household agricultural production diversity on household dietary quality are presented in Table 2. As expected, we observe that ARS and ADS have positive and significant relationship with HDRS and HDDS collected from 24-h recall. However, neither ARS nor ADS has a significant relationship with energy and micronutrient intakes. The insignificant results imply that heterogeneity as to how to diversify food production may mask the contribution of specific food groups to the intake of micronutrients.

In addition, we regress agricultural diversity on child nutritional status. We observe insignificant associations except for ARS, which is positively and significantly associated with WHZ-score. These results may not imply the existence of a direct pathway linking agricultural diversity and child nutritional status but rather justify the two non-unified analyses of agricultural diversity – food diversity and food diversity – nutritional status.

Moreover, the results from disaggregating food crops and animal products into groups are presented in Table 3. With respect to the dietary diversification through the market, tuber, egg, and meat production tend to increase the 24-h dietary scores. Since these products are sold in the market to earn

5) Within the same food group, a household can consume both self-produced foods and market-purchased foods. We treat them as different kinds of foods and analyze their contributions to dietary quality separately.

6) They are 2000 Kcal/day, 17.5 mg/day for iron, and 12 mg/day for zinc. We choose iron and zinc for our study since they, in addition to vitamin A, consist of micronutrient deficiency index for preschool children (Muthayya *et al.*, 2013). But vitamin A is not included in our study since it is distributed by the government in the study site in a program.

7) These figures are not the same as those from INSTAT and UNICEF (2019) given in Section 1, particularly about the wasting. Although we cannot provide evidence, we consider that the difference should come from the fact that the INSTAT and UNICEF data covered the whole Vakinankaratra region including urban area and were collected after harvest period, while our data were only from rural area and collected during lean period. Since wasting reflects acute malnutrition in a short period, seasonality matters.

Table 2. Relationship of agricultural production diversity with household dietary diversity, energy and micronutrient intake and children nutritional status[1)]

Dependent Variable	HDRS (24-h)		HDDS (24-h)		Energy Intake		Iron Intake		Zinc Intake		HAZ[2)]	WHZ[2)]	WAZ[2)]	Undernourish[2)]
Expl. variables	F.E.	Pooled	F.E.	Pooled	F.E.	Pooled	F.E.	Pooled	F.E.	Pooled	Pooled	Pooled	Pooled	Pooled
ARS (Agricultural	0.28**	0.14**	0.22***	0.15***	71.2	-69.3	0.73	-0.91	0.46	-0.26	-0.37	0.37*	-0.06	-0.04
Richness Score)	(0.11)	(0.06)	(0.07)	(0.04)	(105)	(58.7)	(1.38)	(0.63)	(0.56)	(0.31)	(0.27)	(0.22)	(0.18)	(0.04)
ADS (Agricultural	0.27**	0.17**	0.20**	0.17***	12.58	-70.7	0.28	-0.97	0.11	-0.39	-0.23	0.22	-0.05	-0.04
Diversity Score)	(0.13)	(0.07)	(0.09)	(0.05)	(124)	(65.5)	(1.57)	(0.72)	(0.59)	(0.34)	(0.32)	(0.25)	(0.18)	(0.05)
Control Variables[3)]	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes
Observations	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	1,020 1,020	393 393	370 370	389 389	370 370

Note: 1) Household Fixed Effects (F.E.) and pooled OLS model (Pooled) are used. Clustered standard errors at village level for F.E. and robust standard errors for Pooled are in parentheses; * p<0.10 ** p<0.05 *** p<0.01.
2) The dependent variables for nutritional status are HAZ-score, WHZ-score, WAZ-score, and binary dummy for at least one of stunting, wasting, and underweight.
3) Control variables are those shown in Appendix Table and a year dummy. For pooled OLS, Change of HH head dummy is replaced by variables referring to 4) and village fixed-effects are added.

Table 3. Relationship of each food group with household dietary quality[1)]

Dependent Variable	HDRS (24-h)		HDDS (24-h)		Energy Intake		Iron Intake		Zinc Intake	
Explanatory variables	Foods bought in the market	Foods own produced	Foods bought in the market	Foods own produced	Foods bought in the market	Foods own produced	Foods bought in the market	Foods own produced	Foods bought in the market	Foods own produced
Cereal[2)]	-0.15	-0.17	-0.16	-0.09	-82.1	-166.9	0.28	-2.47	0.10	-0.97
	(0.20)	(0.14)	(0.16)	(0.13)	(110.2)	(146.0)	(1.02)	(2.03)	(0.76)	(0.64)
Tuber[2)]	0.44**	0.06	0.31**	0.07	155.2	-337.0	1.21	-1.45	1.04	-0.85
	(0.18)	(0.14)	(0.13)	(0.12)	(137.1)	(224.1)	(1.47)	(2.62)	(0.75)	(0.83)
Pulse[2)]	-0.10	0.44**	-0.19	0.40**	-73.3	616.3***	0.52	8.03***	0.84	2.15**
	(0.24)	(0.17)	(0.19)	(0.16)	(105.7)	(227.0)	(1.52)	(2.71)	(1.18)	(0.84)
Vegetable[2)]	-0.21	0.58***	-0.16	0.36**	87.2	93.5	0.40	0.94	-0.49	-0.29
	(0.34)	(0.21)	(0.25)	(0.18)	(119.8)	(264.7)	(1.43)	(2.91)	(0.87)	(0.80)
Milk[2)]	0.33	-0.02	0.25	0.10	-78.9	127.5	-3.36*	-1.05	-1.45	0.64
	(0.32)	(0.25)	(0.25)	(0.21)	(147.1)	(164.5)	(1.79)	(1.95)	(1.25)	(1.01)
Egg[2)]	0.86***	-0.17	0.87***	-0.07	23.9	165.0	0.60	-4.51	-0.00	-1.28
	(0.34)	(0.24)	(0.25)	(0.24)	(119.2)	(317.6)	(1.52)	(3.96)	(1.33)	(0.99)
Meat[2)]	0.46	-0.19	0.49**	-0.17	-27.1	--193.5	3.32*	0.054	0.93	-0.11
	(0.29)	(0.19)	(0.24)	(0.16)	(192.2)	(297.1)	(1.84)	(3.13)	(1.12)	(0.91)
Control Variables[3)]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020

Note: 1) Household Fixed Effects model is used. Clustered standard errors at village level are in parentheses; * p<0.10 ** p<0.05 *** p<0.01.
2) Dummy for household producing any food in this food group during the last dry season.
3) Control variables are socio-economic characteristics of the household shown in Appendix Table excluding those indicated as only for pooled OLS in note 4) and a year dummy.
4) Pooled OLS models give qualitatively similar results, but significance levels change in some cases. They are not in the table.

Appendix Table. Descriptive statistics

	mean	S.D.
Change of HH head in 2 years[1), 2)]	0.01	0.09
--Male HH head[1), 2), 4)]	0.89	0.32
--Age of HH head (years)[2), 4)]	46.48	13.98
--Years in education of HH head[2), 4)]	5.19	3.69
--Ability in French[1), 4)]	0.63	0.48
--HH with two parents[1), 2), 4)]	0.86	0.35
HH size[2)]	4.85	1.94
Share of children	0.37	0.22
Share of old members (≧60)	0.15	0.31
Share of working woman	0.26	0.14
HH member in off-farm activities[1), 2)]	0.29	0.22
# of plots used for lowland rice	1.64	0.96
# of plots used for upland rice	0.68	0.71
# of other plots	0.88	1.18
Home value per capita (ln MGA)[3)]	2.78	1.56
Farm value per capita (ln MGA)[3)]	2.76	1.55
Water available in dry season[1)]	0.35	0.48
Crop sales in the market[1)]	0.33	0.47
# of Observations (HHs)[2)]	1,020	

Note: 1) A binary dummy variable.
2) HH stands for household.
3) Natural logarithm of Malagasy Ariary. 1 USD was about 3,780 MGA in April 2021.
4) Variables used only for pooled OLS.

cash income, their contribution to food consumption diversity is naturally through the market, or indirect linkage. On the other hand, as for dietary diversification through own-production, or direct linkage, pulse and vegetable production significantly increase HDRS and HDDS from the 24-h recall. However, the significant association is confirmed by pooled OLS regressions only in the case of pulse.

The second half of Table 3 is for the results on micronutrient intakes. We find that pulse production only has a significant positive association with the intake of calories, iron and zinc through own production pathway. The results are robust since they are confirmed by pooled OLS regressions. However, there is no other significant linkage with micronutrient intake.[8)]

The insignificant association between vegetable production and energy or micronutrient intake might reveal the negligible amount of micronutrients (iron and zinc) contained in the consumed vegetables. In the case of tuber and egg, households tend to sell them and diversify their diets primarily through the purchase of sugar, coffee, and cereal, but the purchased food does not appear to increase the overall energy and micronutrient intake.

Hence, the findings imply that dietary diversity indicators may (i) miss out on important micronutrients; (ii) mask important variations in nutrient intakes; (iii) conceal the heterogeneous linkage of specific food groups; and (iv) mask the underlying pathway of micronutrient sources.

2) Diet quality and child nutrition outcomes

Table 4 presents the results of pooled OLS model regarding the association of household dietary diversification and child's nutritional outcomes. The table shows a positive association between HDDS recalled over a 24-h period with WHZ-score, suggesting that a diversified diet lowers the level of wasting in children. However, since small children do not necessarily consume the same food as adults, the observed associations are considered to be due to the household's awareness about nutrition, but may be partially attributed to pulse production.

We also analyze the relationship between energy and micronutrient intake either sourced from market or from own production (zinc and iron) on child's nutritional status in the same regression. The results show that the dummy of an adequate zinc obtained from own produced foods is positively and significantly associated with HAZ-score. Hence, the finding (v) displays the role of micronutrient intakes, in this case zinc, in improving stunting in children.

Table 4. Relationship of household dietary quality with child's nutritional status[1)]

Explanatory variables	HAZ[2)]		WHZ[2)]		WAZ[2)]		Undernourished[2)]	
HDRS (24-h recall)	-0.10		0.26		0.08		-0.02	
	(0.17)		(0.18)		(0.08)		(0.02)	
HDDS (24-h recall)		-0.19		0.40*		0.09		-0.03
		(0.22)		(0.22)		(0.11)		(0.03)
Energy (market)[3)]	0.93	0.96	-1.12	-1.13	-0.20	-0.18	-0.05	-0.06
	(0.74)	(0.75)	(0.77)	(0.78)	(0.31)	(0.31)	(0.10)	(0.10)
Energy (subsistence)[3)]	-0.75	-0.71	0.61	0.54	-0.07	-0.08	-0.15*	-0.15*
	(0.48)	(0.48)	(0.55)	(0.55)	(0.25)	(0.26)	(0.08)	(0.08)
Zinc (market)[3)]	-1.04	-0.96	0.87	0.73	-0.03	-0.05	-0.02	-0.02
	(0.69)	(0.70)	(0.62)	(0.64)	(0.31)	(0.32)	(0.10)	(0.11)
Zinc (subsistence)[3)]	1.24*	1.28*	-0.52	-0.56	0.32	0.32	0.06	0.06
	(0.71)	(0.72)	(0.58)	(0.64)	(0.32)	(0.33)	(0.09)	(0.09)
Iron (market)[3)]	0.40	0.40	-0.58	-0.54	-0.04	-0.02	-0.07	-0.07
	(0.64)	(0.62)	(0.62)	(0.60)	(0.27)	(0.27)	(0.08)	(0.08)
Iron (subsistence)[3)]	0.29	0.28	-0.72	-0.70	-0.03	-0.02	0.07	0.07
	(0.60)	(0.60)	(0.63)	(0.63)	(0.33)	(0.33)	(0.08)	(0.08)
Village dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variables[4)]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations[5)]	393	393	370	370	389	389	370	370

Note: 1) Pooled OLS model is used. Robust standard errors in parentheses; * p<0.10 ** p<0.05 *** p<0.01.
2) The dependent variables for nutritional status are HAZ-score, WHZ-score, WAZ-score, and binary dummy for undernutrition (1 if at least one of stunting, wasting, and underweight).
3) Dummy variables representing an adequate energy and micronutrient for children, sourced either from market or subsistence.
4) They include a year dummy and the variables shown in Appendix Table excluding the change of household head dummy. In addition, characteristics of child (sex, age in months, etc.), mother's education, and sanitation characteristics are included.
5) Due to missing values, the number of observations differ for each regression analysis.

8) The significant estimates for milk and meat in the case of iron intake are not significant by pooled OLS regressions.

In addition, the result shows that (v) an adequate energy from the direct pathway significantly reduces the probability of being undernourished in children.

Therefore, even though we acknowledge that the two linkages are not joined, the result tends to seemingly show the associative link between pulse production – energy and micronutrient intake – and child nutritional status.

5. Conclusion

This study explores the association between farm production diversity and food diversity (micronutrient) as well as that of food diversity (micronutrient) and child nutritional status. The panel regression models show evidence of a positive linkage between production diversity and dietary diversity through both direct (own consumption) and indirect (market purchase) linkages. This study also supports a positive and significant association between household pulse production and calorie and micronutrient intake through the subsistence route. Both findings indicate the importance of assessing the micronutrient intake pathway and the disaggregation of production diversity into food groups. The pooled OLS model, on the other hand, highlights the importance of consuming self-produced caloric and micronutrient-rich food, particularly zinc, to improve overall child nutritional status and stunting in children, respectively. Thus, to enhance nutritional outcomes for children, policies should focus on promoting the production of micronutrient-rich crops such as pulses, particularly during the dry season.

A few limitations, however, remain in this study. First, the number of children under 5 years of age is limited in the sample, hence generalization of the results may belie the regional figure. Second, the food consumption data are from a household consumption survey and are not based on an individual level. Further research is encouraged to account for seasonal differences in household diets and to answer the question of whether off or on farm activities are more beneficial during the dry season.

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