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Abstract

It has been widely recognized that agriculture has the potential to contribute to rural household food security and nutrition in developing countries. However, studies that directly explore the link between agricultural productivity and farmers' nutrition are scarce. In this study, we examine how households' rice yield could affect their calories and micronutrients intake. To achieve this, we used three-years panel data of farm households collected in the Vakinankaratra region, one of the most important rice-producing regions of Madagascar. First, the results suggest that higher rice yield is significantly associated with an increase in calorie and micronutrients intake. Moreover, the results suggest that households with higher rice yield purchase more nutritious foods. Secondly, the results show that raising rice yield is a positive significant association with an increase in the share of the output sold and the cash revenue from rice sales. Therefore, we conclude that the market represents the channel through which increased staple foods production translates into improved nutritional outcomes. The findings of this study imply that interventions that improve rice yield and market access by farmers would contribute to improving households' nutritional outcomes.

Keywords: Rice, Agricultural productivity, Nutrition, Market access, Commercialization, Madagascar

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1 Introduction

It has been established that the growth of agricultural productivity and food production has helped to reduce hunger (Gödecke et al., 2018; Khoury et al., 2014; Pingali, 2012). Nevertheless, nutritional deficiencies, which are less related to general food shortages than to low dietary quality and diversity deficiencies, remain a major concern especially in Sub-Saharan Africa (SSA) and South Asia (FAO et al., 2021; Headey and Ecker, 2013; IFPRI, 2017). Furthermore, malnutrition is still among the major causes of premature deaths, infectious diseases, physical and mental growth retardation in children, and other types of health problems in developing countries (IFPRI, 2017).

Agriculture and nutrition are closely linked because the majority of undernourished people live in rural areas and many of them are smallholder farmers (Pinstrup-Andersen, 2007; Sibhatu et al., 2015). Recent literature has pointed the role of agriculture in improving nutritional outcomes. More specifically, it supports that increase in agriculture production, either from higher productivity (Darko et al., 2018; Kim et al., 2019; Slavchevska, 2015) or from increased commercialization (Carletto et al., 2017; Ogutu et al., 2019; Ruel et al., 2018; von Braun, 1995), is linked with improved nutrition.

At the macro-level several studies have shed light on the potential that increased productivity in agriculture should improve farm household's nutrition (Devkota and Upadhyay, 2013; Ogubdari and Awokuse, 2016). For example, Ogubdari & Awokuse (2016) examined the case of 41 countries in Sub-Saharan Africa (SSA) and found that an increase in agricultural value-added per hectare and cereal production per hectare contributes positively and significantly to food availability per capita in terms of weight, calorie, as well as protein supply.

At the household level, a systematic literature review of studies in South Asia by Shankar, Poole, & Bird (2019) found evidence that higher agricultural production per unit of land is significantly associated with improved household nutritional outcomes. For example, Morioka and Kondo (2017) suggested that the growth in productivity of agriculture in real terms has a positive impact on household food security in Nepal. Moreover, they found that the impact is stronger at the lowest levels of income. For a specific case of rice, Headey and Hoddinott (2016) found a significant association between rice productivity growth and child nutritional outcomes in Bangladesh. More specifically, they found evidence that rice yields predict the earlier introduction of complementary foods to infants after 6 months old as well as increases in their weight-for-height, but no improvements in their dietary diversity or height-for-age.

Studies in SSA that examine empirically the link between agricultural productivity and farm household nutrition, and in particular, the micronutrients intake are scarce. A study by Dzanku (2015) in Ghana found that the productivity of agriculture affects positively food expenditure. In the same vine, Darko et al. (2018) found that increase in maize yield per hectare has a positive impact on the household caloric intake in Malawi, though in terms of economic magnitude both the direct effect and economy-wide spillover effect of a percentage increase in agricultural productivity on the poverty and food security measures are small.

In general, although the potential of agricultural productivity and dietary diversity in improving food consumption has been recognized, there is little empirical evidence that they improve key measures of nutritional outcomes, such as micronutrients intake. More specifically, despite that a lot of effort has been done to induce a green revolution in rice production in SSA, empirical works that focus on the direct impact of household rice productivity on micronutrients intake at the household level are scarce. This paper seeks to fill this knowledge gap by exploring the nutritional impacts of lowland rice yield in the Vakinankaratra region of Madagascar.

The contribution of the paper is threefold: First, in Madagascar, rice is not one of the staple foods, but the only one, the most important staple food. This is different from other SSA countries, where there are several staple foods. As a result, many projects are aiming at the enhancement of rice productivity in Madagascar, and rice yield is relatively high compared with the cases of other SSA countries. However, its consequences on rice producers' nutritional status are poorly examined. Moreover, it is known that the nutritional status of farm household members is low in Madagascar (FAO et al., 2021). For example, in terms of the prevalence of stunting among children under 5 years old, Madagascar is one of the worst ten countries in the world according to the World Bank (World Bank, 2019). To the best of our knowledge, however, no study examines the relationship between rice productivity and nutritional status in the Malagasy context. The dearth of nutritional and agricultural data in Madagascar has undoubtedly been a constraint to exploring such a relationship. Second, one of the major limitations in most studies that use a seven-day recall questionnaire to capture rural households' consumption is that they are not free from seasonality effect. Seasonality in the reported data may lead to an overestimation or underestimation of the effects of the variables of interest. The data used in this paper is collected both during lean season and just after the harvest. Therefore, we used the weighted average of both seasons. This allows us to reduce the effect of the seasonal patterns of consumption on our estimates. Third, as opposed to the previous studies, we used panel data which allows us to remove the endogeneity due to unobserved time-invariant factors that can be correlated with both rice productivity and nutritional outcomes.

The remainder of this paper is organized as follows: Section 2 provides an overview of agriculture and nutrition in Madagascar. Section 3 lays out the conceptual link between agriculture and nutrition at the farm level and develops concrete research hypotheses. Section 4 describes the data used in this paper and the econometric approach used to test the hypotheses. Section 5 presents and discusses the results, and Section 6 concludes the paper.

2 Background on agriculture and nutrition in Madagascar

2.1 Agricultural production in Madagascar

Agriculture employed 74% of Madagascar's population and accounted for almost 23% of GDP in 2019 (FAO, 2019). It is characterized by extensive agricultural production and is very susceptible to climate hazards (Harvey et al., 2014). The production is carried out by small family farms, with approximately 85% of farmers cultivating rice (GRiSP[1], 2013). In Madagascar rice is produced mainly in rain-fed lowland plots where water can be retained during the rainy season[2], consequently, rice production is highly seasonal, with the vast majority of production taking place in the rainy season, and production in the dry season constrained by lack of water.

Figure 1 uses FAO production data to show the trends in rice yields and chemical fertilizers used in agriculture in Madagascar between 1961 and 2020. Before 2000 rice yield in Madagascar was stagnated like other African countries, but since 2000 Madagascar has experienced rapid growth of rice yield to catch up with Asia (Figure 1a). As shown in Figure 1b, the quantity of nitrogen used in agriculture began to be increasing exponentially since 2000, which interestingly

[1] GRiSP: Global Rice Science Partnership

[2] Rice production has been extended to upland plots since the early 2000s with the introduction of new varieties that are cold and drought tolerant (Raboin et al., 2014). More than half of lowland rice producers grow upland rice recently in the study site (Ozaki and Sakurai, 2020).

corresponds to the high growth in rice yield in Figure (1a) although we do not have any evidence of their causal relationship. In fact, the use of chemical fertilizers for rice is still limited. For example, according to the world bank data, fertilizer consumption in agriculture is approximately only 12.6 kg/ha of arable land in Madagascar. This application rate is much lower than in Asian countries, such as 149 kg/ha for Thailand, 318 kg/ha for Indonesia, 236 kg/ha for Bangladesh, and about 415 kg/ha for Vietnam in 2018 (World Bank, 2019). For the case of rice production, a previous study in our study site shows that almost 75% of lowland rice plots received no chemical fertilizer at all, and even if they use some, the application rate is less than 40 kg/ha (Ozaki and Sakurai, 2021).

2.2 Dietary and nutrition trends in Madagascar

Like other countries of sub-Sahara Africa, Madagascar is permanently threatened by food insecurity. Figure 2 uses FAO Food Balance Sheets to plot trends in food supply and nutritional status of households in Madagascar. This figure needs to be treated with caution because there may be systematic errors in FAO Food Balance Sheets, particularly misreporting of production for foods that are traded little (Headey and Hoddinott, 2016). Though the prevalence of undernourished people is declining over time, it remains high with more than 40% of the total population in 2020 (Figure 2a). The daily energy supply though higher than the minimum requirement remains lower than the dietary energy requirement defined by FAO (Figure 2b). Also, there are some malnutrition problems in Madagascar. For example, Figure 2a shows that since 2015, the prevalence of anemia among women of reproductive age is higher than 37% while the proportion of children under 5 years old who are stunted is more than 42% approximately.

Rice is the main staple food in Madagascar: the per-capita annual rice consumption was estimated to be 157kg in 2018, making it one of the highest in the world for rice consumption per capita (FAO, 2018). This implies that rice represents an important source of calorie intake. For example, in 2018 rice's contribution to the daily calorie supply was 1075 kcal/per capita, which represents 56% of the total calorie consumption (FAO, 2018). Furthermore, rice is also known as one of most important income sources for most farm households in Madagascar (World Bank, 2016). Therefore, we expect that the increase of household cash revenue that would follow the increase of rice yield will be translated into an enhanced purchase of food unproduced by the household, specifically highly nutritious food.

3 Conceptualizing the linkages between rice productivity household nutritional outcomes

The linkage between agriculture production and nutrition, in general, is quite complex and highly context-specific. Moreover, there are many interactions among the different pathways that connect agricultural production to nutritional outcomes. A review by Gillespie et al.(2019) identified six routes of this linkage that can be summarized into three main channels: (a) food production, which can affect the food available for household consumption as well the price of diverse foods; (b) agricultural income for expenditure on food and non-food items; and (c) women's empowerment, which affects income, caring capacity and practices, and female energy expenditure.

In general, the literature suggests that the effect of income on nutrition is very heterogeneous. Some studies found that the income elasticity of nutrition is declining or tend close to zero (Colen et al., 2018; Ogundari and Abdulai, 2013; Salois et al., 2012; Skoufias et al., 2011), while other recent studies in low- and middle-income countries demonstrate that agricultural income growth contributes effectively to improved nutrition (Carletto et al., 2015; Gillespie et al., 2019; Pingali and Sunder, 2017).

Figure 3 provides a simplified picture of how an increase in rice production per unit would improve the farmers' nutritional outcomes in Madagascar. Rice production may have a direct effect on the farm household calory intake through the Pathway (1). However, while an increase in food production increases food availability, it does not guarantee that the quality, variety, or nutritional value of the food will increase. To achieve this, it is necessary that the growth in rice production induces an increase in cash revenue (Pathway 2). More specifically, this would imply that higher rice productivity via farmers' adoption of improved inputs and management practices may improve the nutritional status of nutritionally vulnerable households by enhancing their cash revenue, which provides better access to more diverse or nutritious foods through the market.

However, there is another possibility. The increase in rice productivity may free up additional land for the production of other crops, which could improve the nutrition directly through dietary diversification and indirectly through higher cash income (Pathway 3). This would contribute to improving the farm household either through direct consumption or increased cash revenue.

From this conceptual framework we postulate the following hypotheses:

(1) Increased households' rice yield is associated with higher energy intake by households.
(2) Increased households' rice yield is associated with higher micronutrients intake by households.

With respect to the mechanism through which increased households' rice productivity improves the households' micronutrients intake, we postulate two additional hypotheses:

(3.1) Increased households' rice yield is associated with larger purchases of highly nutritious foods.

(3.2) Increased households' rice yield is associated with a higher households' cash revenue.

4 Method and data

4.1 Method

In order to test the hypotheses postulated above, we model the relationship between nutritional outcomes and rice yield as:

$$N_{ivt} = \delta_0 + \delta_1 y_{ivt} + \delta_2' X_{ivt} + \delta_3' T_t + \delta_4' T_t * V_v + \mu_i + \varepsilon_{ivt} \quad (1)$$

where N_{ivt} refers to nutritional outcome for household i in village *v* of year t and y_{it} to household i*'s* rice yield in natural logarithm. The parameter of interest is δ_1, representing the effect of rice yield on the household's nutritional outcomes. *X* is a vector of time-variant household and farm characteristics, including household socio-demographics, and asset variables. T_t is a vector of time dummies for the years 2018, 2019, and 2020, which captures all structural changes such as economic growth, improvements of communication and transportation infrastructure, and climate shocks. Interaction terms between year dummies (T_t) and village dummies (V_v) are also added to control for time varying village specific effects such as drought and low temperature. μ_i is household fixed effect, which is to control for time-invariant factors that can be correlated with both yields and nutritional outcomes (e.g. water availability, soil quality, climate, household preferences, and cultural practices). While Equation (1) controls for a wide range of observable factors, we acknowledge that empirical estimates of the effects of rice yield on nutrition could still be biased by unobservable time-variant factors that simultaneously influence rice yields and nutrition outcomes. Also, an important concern is that the relationship between agricultural productivity and nutritional status may not run in one direction. On the contrary, individuals in better nutritional status and health are likely to be able to perform more strenuous activities with fewer breaks, and hence have higher productivity (Egbetokun et al., 2012; Gkiza and Nastis, 2017). This means that we must treat the results below as suggestive rather than definitive evidence on the linkages between rice productivity and nutritional outcomes at the household level.

4.2 Data

This study used data collected by the FertilitY sensing and Variety Amelioration for Rice Yield (FyVary) Project led jointly by the Japan International Research Center for Agricultural Sciences and the Malagasy Ministry for Agriculture, Livestock and Fishing (MINAE). One of the major goals of this project is to increase the rice yield under low fertility conditions through rapid diagnosis of soil fertility and the development of nutrient-use-efficient breeding lines. The project site is the Vakinankaratra region in central Madagascar, one of the most important rice-producing regions of this island country in terms of volume. The sample households were chosen following two steps: First, a census survey was conducted in 60 villages across 3 out of the 6 districts of the Vakinankaratra region from December 2017 to January 2018. The villages were selected proportionally to the size of each district. Second, from the households listed in the census, 10 lowland rice-growing households were randomly selected in each of 60 villages. This yielded an initial sample size of 600 households.

The data collected includes demography, agricultural input and output, monthly rice purchases and sales, monthly expenditure of food and non-food items, 7-day and 24-hour recall questionnaire about food consumption, and non-agricultural/off-farm activities. To capture the dry season activities as well as the seasonality in food consumption, farmers were interviewed at least twice every year: the first round after the harvest and the second during the lean season. The data covers three rice productions in years of 2018, 2019, and 2020. We kept households that appear at least twice during the three years, then additional exclusion of households with missing values yielded to an unbalanced panel of 1587 observations including 487 households that appear in each of the three years. Since total number of observations should have been 1800 in three years, the attrition rate is 11.8%, or less than 4% per year on average, which suggests a moderate attrition.

4.3 Variables and summary statistics

Table 1 shows the summary statistics of the key variables and some control variables. The lowland rice yield (kg/ha) is the variable of interest of this study. Since some farmers have several plots, we computed the average yield weighted by the plot size. On average, the yield of lowland rice for our sample is 3363.4 kg/ha, which is close to the regional average yield of 3000-3500 kg per ha during the period of study (WFP, 2019). Moreover, Table 1 shows that more than 54% of households in our sample sell rice, which suggests that a large number of farmers in the study site obtain cash revenue from lowland rice production. Also, Table 1 shows that only 20% of the total output is sold. However, it is worth noting that selling rice does not mean that those farmers produce sufficient rice for self-consumption. In fact, many farmers purchase rice during the lean season in Madagascar (Minten et al., 2006). In this study, we found that more than 43 % of the sample is at the simultaneously seller and buyer rice (Table 1). We also controlled for some farming characteristics variables including the number of other crops, the income from other farming activities such as dry season farming, non-rice crops, and upland rice cultivation.

As for household wealth, the summary statistics in Table 1 show that the average size of total land cultivated is 0.88 hectares and the average livestock holding is 2.75 TLU, which suggests that our sample is composed of smallholder farmers. Household socio-demographic variables include the age of the household head, number of children under 5 years old, number of children between 6-15 years old, and the number of adult members. In addition, when we analyze household food consumption and expenditure, we include two more control variables: one is the identity of the respondent to reduce the effect of a possible measurement error, taking 1 if the respondent is different from the person who knows better about household food consumption; the other is a binary variable to control for unordinary food consumption in the 24 hours before the interview (for example a day of ceremony or feast).

The summary statistics of the outcome variables are shown in Table 2. In total, we have 7 survey rounds during the three years for the consumption data. Therefore, we calculated the average value of outcome variables weighted by the household size in AE (Adult Equivalent). First, monthly the food consumption and rice purchases are presented the panel A of Table 2. It shows that the food consumption is 48583.4 MGA per AE, which is equivalent to USD 0.42 per/AE/ day. The food consumption of non-purchased is converted into MGA. The market plays an important role in food consumption, with an average food purchase of 30769.6 MGA per AE, which is equivalent to 63% of the total food consumption. On average, households in this sample purchase 5.43 kg/AE of rice per month, which increases approximately 6% during the lean season. Additionally, the panel B of Table 2 shows that a large share of the of household budget is allocated to staple foods group, follows by meat and fish.

Panel C of Table 2 presents households' calories and micronutrients intake calculated based on 24-hour dietary recall. On average, the sample calories intake is 2640 kcal/day/AE, which is approximately equivalent to the standard requirement for an appropriate active life for an adult. However, the prevalence of calorie deficiency is 45%, which suggests that a high number of undernourished people should be included this sample. In terms of micronutrients, we concentrate on iron, zinc, and vitamin A, for which deficiencies are particularly widespread in Sub-Saharan Africa (Mason et al., 2015). For this sample the average iron intake is 14.32 mg/day/AE, which is closed to the recommended[3] amount while zinc intake is lower than the recommended level of 11 mg/day/AE WHO (2005). A striking observation in Table 2 is that on average the vitamin A intake is 221 μg RAE/day/AE, which is far below the standard requirement of 800 μg RAE/day/AE defined the WHO (2005).

5 Results and Discussion

The effects of rice productivity on the calorie and micronutrients intake are shown in Table 3. First, the results show that raising rice yield has a positive and significant impact on household energy intake (Column 1 of Table 3). For instance, an increase of rice productivity by 1% is associated with an increase of the calorie intake per AE by 0.18 % approximately. This result supports our Hypothesis (1) that higher households' rice yield is associated with higher energy intake. Additionally, the results in columns (1) and (2) of Table A1 in the appendix show that there is a significant impact of household's rice yield on food consumption per AE, and more specifically rice consumption per AE. Furthermore, the results in column (5) of Table A1 of the appendix shows households with higher rice yield purchase less rice during the lean season. Consistent with the Pathway (1) in Figure 3, higher rice productivity contributes to the increase of the amount of food that is available for households.

Second, columns (2)-(4) of Table 3 show that the rice productivity elasticities of micronutrients intake are positive and significant across all the micronutrients of interest. For example, an increase of rice productivity by 1% is associated with an increase of zinc intake by

[3] WHO (2005) recommend a daily amount of iron of 8.7mg/day for men over 18 years old and 14.8mg/day for women aged 19 to 50.

0.11%, iron intake by 0.75%, and vitamin A intake by 0.19%. These results support our Hypothesis (2) that an increase in lowland rice productivity improves farm households' nutritional outcomes. Not only does higher productivity increases calorie intake, but it also improves the household micronutrient intake. However, the effect size of the observed effects remains low. For instance,(Ozaki and Sakurai, 2021) found in this study site that farmers who adopt chemical fertilizers increase their rice yield by 30%, which is interestingly close to one standard deviation of rice in this study. The increase in rice yield that follows this adoption would increase the households' zinc intake and Vitamin A intake by 0.3 mg/day/AE and 12.54 μg RAE/day/AE respectively, which is still not enough to satisfy their daily standard requirements.

Furthermore, consistent with this result, column (5) suggests that increased household rice yield is associated with a higher household dietary diversity score. For example, a coefficient of 0.7 in column (5) of Table 3 suggests that an increase of the rice yield by 10% will increase the Household dietary diversity score (HDDS) by 0.067 ($0.7 \times \ln [1.1]$) food groups. A hypothetical increase of rice yield by one standard deviation- approximately a 38 % increase relative to the sample mean- would increase the HDDS by only 4.26 % relative to the sample mean. This low effect size is consistent with the low elasticities in most of the micronutrient intake.

To understand the transmission channel of the observed effects, we estimate the impact of rice yield on the monthly food expenditure per AE. The results are shown in Table 4. Columns (1) and (2) of Table 4 show that rice yield does not significantly affect the purchase of staple foods (e.g., rice and maize), tuber, and pulses. However, and interestingly, we observe a positive and significant effect on the purchase of micronutrient-rich food groups such as vegetables, fruits, and meat/fish (columns (3)-(6). For example, an increase of rice yield per ha by 1% is associated with an increase of the purchase of vegetables by 0.45%, fruits by 0.57%, and meat/fish by 0.65 %.

Consistent with columns (3)-(6), the results in column (3) of Table A1 shows that there is a positive association between rice yield and the total consumption from purchased foods. These results support our our Hypothesis (3.1) that an increase in the households' rice yield is associated with more purchases of highly nutritious foods.

As discussed in the previous section (3), for a higher yield to be translated into more purchases of highly nutritious foods, it is necessary that the increase in yield induces higher cash revenue. Therefore, to deepen our analysis, we estimate the effect of rice yield on the household level of commercialization and the cash revenue from lowland rice sales. The results of the econometric estimation are presented in Table 5. First, columns (1)-(3) of Table 5 show that the coefficients of rice yield on the decision to sell as well as on the share of rice that is sold are positive and significant. For example, a coefficient of 31.14 in column (2) suggests that an increase of household's rice yield by 10% is associated with an increase of the share of rice sold by 3 points percentage. The magnitude of the observed impact is quite high. For instance, a hypothetical increase in the rice yield by one standard deviation- approximately 38% relative to the sample mean - would be associated with an increase of the share of the rice sold by 50%. Moreover, columns (4) and (5) show that the increase in rice sales is translated into higher cash revenue. Consistent with the effect size of columns (2) and (3), there is a strong association between household's rice yield and cash revenue obtained from rice sales. For example, an increase in rice yield by 1% is associated with an increase in cash revenue by 4.75%. The strong effect of rice productivity on the income seems surprising but consistent with the low level of commercialization shown in the descriptive statistics: If we assume that local demand for rice is fixed, low commercialization - 20% in this sample - implies low pressure on prices, and then higher revenues for farmers who sell rice.

Moreover, we investigate the effect of market access on rice sales. To do so, we used the household location to the main road, more specifically the distance. Since location is time-invariant, we used the interaction term between the distance and household rice yield. The results in Table 5 suggest that distance from the main road affect negatively the rice commercialization and the cash revenue from sales at the highest level of rice yield. This result suggests that market access remains a significant constraint to rice commercialization for households in this sample.

Furthermore, to check the validity of Pathway (3) shown in Figure 3, we estimated the effect of rice yield on the other sources of income. The results are shown in column (1) of Table A2 of the appendix. It suggests that raising lowland rice yield does not significantly associated with the income from the production of the other crops. One possible explanation is that lowland plots are generally small and rice production is far below the self-sufficient quantity in the study site. Furthermore, household's rice yield does not significantly affect off-farm income (column (1) of Table A2 in the appendix).

Overall, the results of this study are consistent with previous studies that agriculture production contributes to the farm household nutritional outcome through crop commercialization (Ogutu et al., 2019). However, this study goes further by showing that commercialization could be enhanced by boosting crop yield. More specifically, the positive effects on calories and nutrients suggest that the additional cash revenue that follows the increase in rice yield improves households' economic access to food and dietary quality. Households with higher rice productivity do not only access to energy-dense foods (including rice itself), but also purchase foods that contribute to improved micronutrients intake, such as vegetables, fruits, meat, and fish.

6 Conclusion and policy implications

Nutritional deficiencies remain the main cause of several health problems in Sub-Sahara Africa. Improving agricultural productivity has a prominent role to play in alleviating malnutrition among the poorest in this part of the world. This has motivated the academics, practitioners, and policy communities to gear up to improve the productivity of major staple food crops such as rice in this region. However, how the increase of staple crop productivity translates into more micronutrients intake at the household level is not well investigated. In this study, we aim to fill this gap by exploring the association between lowland rice yield and energy and micronutrients intake. To achieve this, we used three-years panel data of smallholder farmers collected in the Vakinankaratra region of Madagascar. Moreover, we have used a household fixed-effect model to control for unobservable time-invariant factors that may correlate with both nutritional outcomes and rice yield. Additionally, we controlled for several time-variant variables including the other sources of income, household asset, and socio-demographic, year-village dummy variables.

First, the results suggest that an increase in rice yield is significantly associated with an increase in calorie and micronutrients intake. Second, our regression supports that the linkage between rice productivity and nutritional outcomes is through the market in the following way: (i) higher rice yield is significantly associated with higher commercialization of rice in the market, (ii) rice yield is positively and significantly associated with household cash revenue, and (iii) higher rice yield is significantly associated with a higher purchase of nutritious food.

The findings of this study have important policy implications. First, though the effect size of rice yield on the micronutrients intake is low, significantly raising the productivity of rice, which is the most important crop for farm households, would benefit nutrition policies in rural Madagascar in the short run. Second, local strategies to improve farm household market participation are likely to benefit rural households' nutrition. In particular, market-related infrastructures would be important to this by facilitating farmers' commercialization of the additional production that follows the increase in yield.

References

Carletto, C., Corral, P., Guelfi, A., 2017. Agricultural commercialization and nutrition revisited: Empirical evidence from three African countries. Food Policy 67, 106–118. https://doi.org/10.1016/j.foodpol.2016.09.020

Carletto, G., Ruel, M., Winters, P., Zezza, A., 2015. Farm-Level Pathways to Improved Nutritional Status: Introduction to the Special Issue. J. Dev. Stud. 51, 945–957. https://doi.org/10.1080/00220388.2015.1018908

Colen, L., Melo, P.C., Abdul-Salam, Y., Roberts, D., Mary, S., Gomez Y Paloma, S., 2018. Income elasticities for food, calories and nutrients across Africa: A meta-analysis. Food Policy 77, 116–132. https://doi.org/10.1016/j.foodpol.2018.04.002

Darko, F.A., Palacios-Lopez, A., Kilic, T., Ricker-Gilbert, J., 2018. Micro-Level Welfare Impacts of Agricultural Productivity: Evidence from Rural Malawi. J. Dev. Stud. 54, 915–932. https://doi.org/10.1080/00220388.2018.1430771

Devkota, S., Upadhyay, M., 2013. Agricultural Productivity and Poverty Reduction in Nepal. Rev. Dev. Econ. 17, 732–746. https://doi.org/10.1111/rode.12062

Dzanku, F.M., 2015. Household Welfare Effects of Agricultural Productivity: A Multidimensional Perspective from Ghana. J. Dev. Stud. 51, 1139–1154. https://doi.org/10.1080/00220388.2015.1010153

Egbetokun, O.A., Ajijola, S., Omonona, B.T., Omidele, M.A., State, O., 2012. Farmers' Health And Technical Efficiency In Osun State, Nigeria 1, 13–30.

FAO, 2019. FAOSTAT: Employment Indicators [WWW Document]. URL http://www.fao.org/faostat/en/#data/OE (accessed 8.5.21).

FAO, 2018. Food Balance Sheet [WWW Document]. URL http://www.fao.org/faostat/en/#data/FBS/report (accessed 7.25.21).

FAO, IFAD, UNICEF, WFP, WHO, 2021. The State of Food Security and Nutrition in the World 2020, the State of the World. FAO, IFAD, UNICEF, WFP and WHO, Rome, FAO. https://doi.org/10.4060/ca9692en

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, 3–12. https://doi.org/10.1016/j.foodpol.2018.10.012

Gkiza, I.G., Nastis, S.A., 2017. Health and women's role in agricultural production efficiency.

Appl. Econ. Perspect. Policy 39, 428–440. https://doi.org/10.1093/aepp/ppw025

Gödecke, T., Stein, A.J., Qaim, M., 2018. The global burden of chronic and hidden hunger: Trends and determinants. Glob. Food Sec. 17, 21–29. https://doi.org/10.1016/j.gfs.2018.03.004

GRiSP, 2013. Rice Almanac, 4th ed. Los Baños (Philippines): International Rice Research Institute. 283 p.

Harvey, C.A., Rakotobe, Z.L., Rao, N.S., Dave, R., Razafimahatratra, H., Rabarijohn, R.H., Rajaofara, H., MacKinnon, J.L., 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. Philos. Trans. R. Soc. B Biol. Sci. 369. https://doi.org/10.1098/rstb.2013.0089

Headey, D., Ecker, O., 2013. Rethinking the measurement of food security: From first principles to best practice. Food Secur. 5, 327–343. https://doi.org/10.1007/s12571-013-0253-0

Headey, D., Hoddinott, J., 2016. Agriculture, nutrition and the green revolution in Bangladesh. Agric. Syst. 149, 122–131. https://doi.org/10.1016/j.agsy.2016.09.001

IFPRI, 2017. Global Food Policy Report. Washington, DC.

Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H., Struik, P.C., 2014. Increasing homogeneity in global food supplies and the implications for food security. Proc. Natl. Acad. Sci. U. S. A. 111, 4001–4006. https://doi.org/10.1073/pnas.1313490111

Kim, J., Mason, N.M., Snapp, S., Wu, F., 2019. Does sustainable intensification of maize production enhance child nutrition? Evidence from rural Tanzania. Agric. Econ. (United Kingdom) 50, 723–734. https://doi.org/10.1111/agec.12520

Mason, N.M., Jayne, T.S., Myers, R.J., 2015. Smallholder Supply Response to Marketing Board Activities in a Dual Channel Marketing System: The Case of Zambia. J. Agric. Econ. 66, 36–65. https://doi.org/10.1111/1477-9552.12066

Minten, B., Dorosh, P., Jenn-treyer, O., Magnay, J., Razafintsalama, Z., 2006. Rice Markets in Madagascar in Disarray : Policy Options for Increased Efficiency and Price Stabilization. World Bank Africa Reg. Work. Pap. Ser. 73.

Morioka, M., Kondo, T., 2017. Agricultural Productivity Growth and Household Food Security Improvement in Nepal. Rev. Dev. Econ. 21, e220–e240. https://doi.org/10.1111/rode.12325

Ogubdari, K., Awokuse, T., 2016. Assessing the Contribution of Agricultural Productivity to

Food Security levels in Sub-Saharan African countries 26.
Ogundari, K., Abdulai, A., 2013. Examining the heterogeneity in calorie-income elasticities: A meta-analysis. Food Policy 40, 119–128. https://doi.org/10.1016/j.foodpol.2013.03.001
Ogutu, S.O., Gödecke, T., Qaim, M., 2019. Agricultural Commercialisation and Nutrition in Smallholder Farm Households. J. Agric. Econ. 71, 534–555. https://doi.org/10.1111/1477-9552.12359
Ozaki, R., Sakurai, T., 2021. Profitability of Chemical Fertilizer Application：Comparison of Lowland and Upland Rice Cultivation in Madagascar. Japanese J. Agric. Econ. 23, 119–124. https://doi.org/10.18480/jjae.23.0_119
Ozaki, R., Sakurai, T., 2020. The Adoption of Upland Rice by Lowland Rice Farmers and Its Impacts on Their Food Security and Welfare in Madagascar. Japanese J. Agric. Econ. 22, 106–111. https://doi.org/10.18480/jjae.22.0_106
Pingali, P., Sunder, N., 2017. Transitioning Toward Nutrition-Sensitive Food Systems in Developing Countries. Annu. Rev. Resour. Econ. 9, 439–459. https://doi.org/10.1146/annurev-resource-100516-053552
Pingali, P.L., 2012. Green revolution: Impacts, limits, andthe path ahead. Proc. Natl. Acad. Sci. U. S. A. 109, 12302–12308. https://doi.org/10.1073/pnas.0912953109
Pinstrup-Andersen, P., 2007. Agricultural research and policy for better health and nutrition in developing countries: A food systems approach. Agric. Econ. 37, 187–198. https://doi.org/10.1111/j.1574-0862.2007.00244.x
Raboin, L.-M., Randriambololona, T., Radanielina, T., Ramanantsoanirina, A., Ahmadi, N., Dusserre, J., 2014. Upland rice varieties for smallholder farming in the cold conditions in Madagascar's tropical highlands. F. Crop. Res. 169, 11–20. https://doi.org/10.1016/j.fcr.2014.09.006
Ruel, M.T., Quisumbing, A.R., Balagamwala, M., 2018. Nutrition-sensitive agriculture: What have we learned so far? Glob. Food Sec. 17, 128–153. https://doi.org/10.1016/j.gfs.2018.01.002
Salois, M.J., Tiffin, R., Balcombe, K.G., 2012. Impact of Income on Nutrient Intakes: Implications for Undernourishment and Obesity. J. Dev. Stud. 48, 1716–1730. https://doi.org/10.1080/00220388.2012.658376
Shankar, B., Poole, N., Bird, F.A., 2019. Agricultural inputs and nutrition in South Asia. Food

Policy 82, 28–38. https://doi.org/10.1016/j.foodpol.2018.10.011

Sibhatu, K.T., Krishna, V. V., Qaim, M., 2015. Production diversity and dietary diversity in smallholder farm households. Proc. Natl. Acad. Sci. U. S. A. 112, 10657–10662. https://doi.org/10.1073/pnas.1510982112

Skoufias, E., Di Maro, V., González-Cossío, T., Ramirez, S.R., 2011. Food quality, calories and household income. Appl. Econ. 43, 4331–4342. https://doi.org/10.1080/00036846.2010.491454

Slavchevska, V., 2015. Agricultural Production and the Nutritional Status of Family Members in Tanzania. J. Dev. Stud. 51, 1016–1033. https://doi.org/10.1080/00220388.2015.1018906

von Braun, J., 1995. Agricultural commercialization: impacts on income and nutrition and implications for policy. Food Policy 20, 187–202. https://doi.org/10.1016/0306-9192(95)00013-5

WFP, 2019. La filière riz à Madagascar face à la fortification. Rome, Italy: WFP.

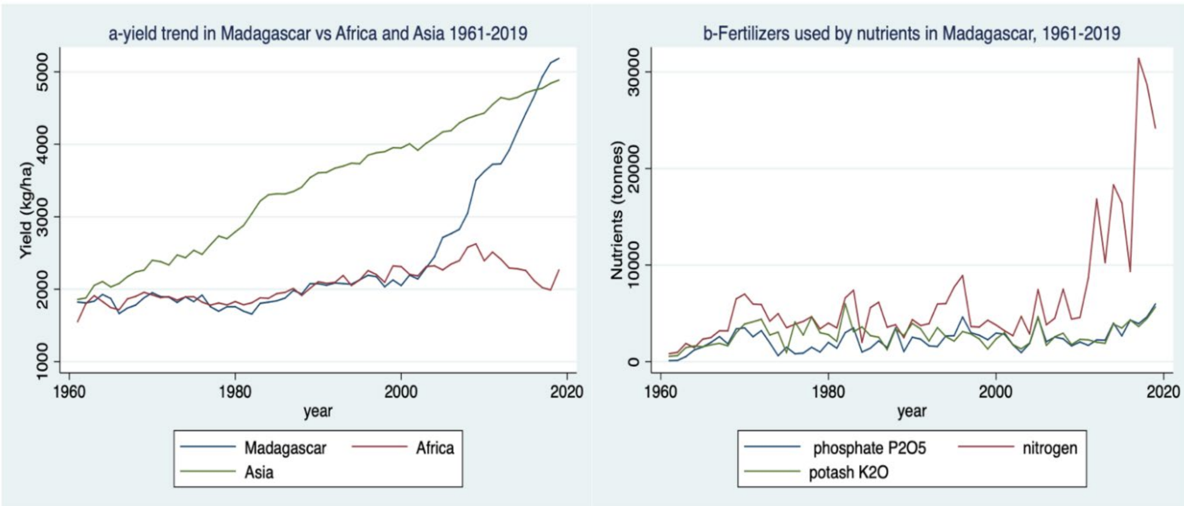
WHO, 2005. Human Vitamin and Mineral Requirements, 2nd ed, World Health Organization.

World Bank, 2019. World Bank. World Development Indicators [WWW Document]. URL https://data.worldbank.org/indicator/AG.CON.FERT.ZS?view=chart&locations=MG (accessed 8.11.21).

World Bank, 2016. Madagascar Economic Update, Madagascar Economic Update. Washington, DC: World Bank. https://doi.org/10.1596/27824

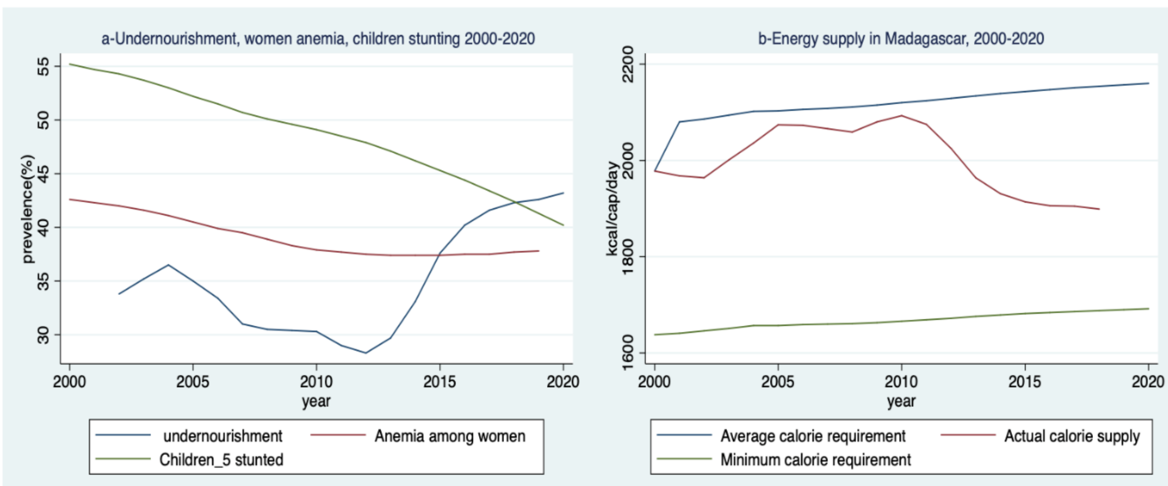
Tables and Figures

Figure 1: Trends in rice yields and chemical fertilizers used in agriculture in Madagascar, 1961–2020



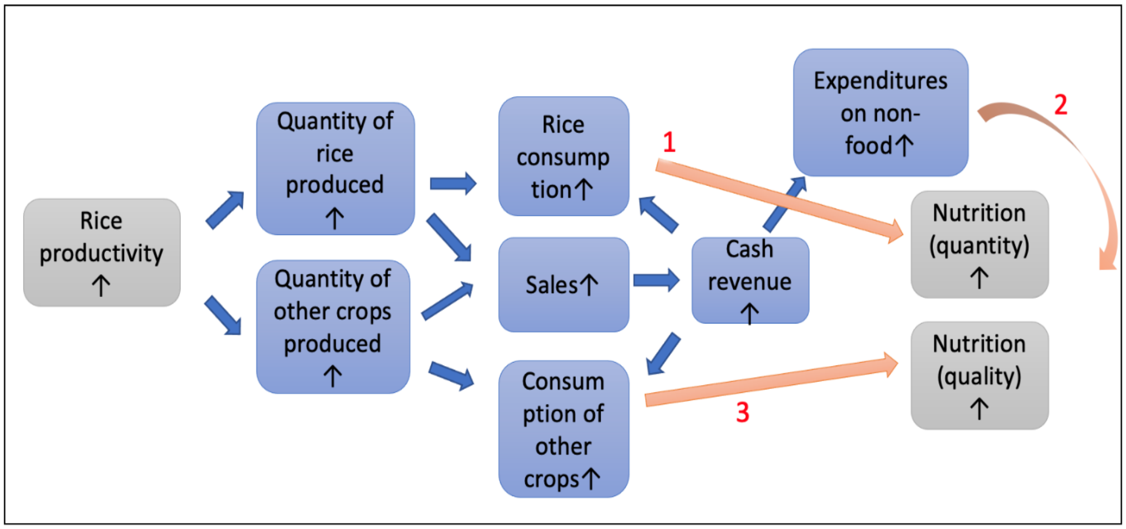
Source: Constructed by authors based on the FAO data, 2021.

Figure 2: Trends in the Average dietary energy requirement and nutritional status in Madagascar, 2000-2020



Source: Constructed by authors based on the FAO food balance sheets, 2021.

Figure 3: Linkage between rice yield and farm household nutrition outcomes



Source: Constructed by authors

Table 1: Summary statistics rice production and households' characteristics

	2018	2019	2020	All	
Variables	mean	mean	mean	mean	Standard deviation
	(1)	(2)	(3)	(4)	(5)
Lowland rice yield (kg/ha)	3432	3203.6	3455.7	3363.4	1294.17
Lowland production (kg/AE)	230.46	236.2	247.3	237.8	454.79
Total land size for lowland rice (ha)	0.32	0.29	0.28	0.3	0.57
Number of lowland rice plots	1.7	1.62	1.72	1.68	0.92
Commercialization of lowland rice (1/0)	0.57	0.58	0.48	0.54	0.49
Share of the lowland rice production sold (%)	20.88	18.94	20.67	20.17	27.44
Cash revenue from lowland rice sales (1000 MGA/AE)	45.20	30.90	61.26	45.57	173.95
Household buys rice (1/0)	0.88	0.84	0.79	0.84	0.36
Household buys and sells rice in a year (1/0)	0.48	0.46	0.34	0.43	0.49
Crop diversification [a]	1.52	1.74	2.13	1.79	1.58
Income from other farm activities (1000 MGA/AE)	232.0	143.22	178.47	185.51	382.91
Off-farm income (1000 MGA/AE) [b]	227.57	336.22	360.32	306.30	406.80
Age of the household's head	53.16	46.66	47.45	49.19	69.79
Number of children under 5 years old	0.67	0.61	0.54	0.61	0.76
Number of children between 6-15 years old	1.4	1.32	1.29	1.34	1.22
Number of adult members	2.92	2.91	2.91	2.91	1.24
Household size (in AE)	3.69	3.55	3.63	3.62	1.41
Consumption questionnaire respondent [c] (1/0)	0.35	0.52	0.39	0.42	0.49
Yesterday was a special day (1/0)	0.04	0.05	0.00	0.03	0.18
Total size of land cultivated (ha)	0.87	0.9	0.88	0.88	3.57
Livestock holdings (Tropical Livestock Unit, TLU)	2.77	2.74	2.74	2.75	3.21
Distance to the main road (km)	5.37	5.44	5.40	5.40	5.09
Value of total asset (1000 MGA/AE)	144	149.22	162.42	151.6	296.0
Number of Observations	550	529	508	1587	

Note: AE is Adult Equivalent. MGA: Malagasy Ariary is Malagasy currency (1 MGA = US$ 0.00026 as of July 27th, 2021).

a) Crop diversification is the number of other crops cultivated.

b) The income from other farming activities includes income from dry season farming, non-rice crops, and upland rice cultivation.

c) Consumption questionnaire respondent takes 1 if the respondent is different from the person who knows better about household consumption and 0 otherwise.

Table 2: Summary statistics of consumption and micronutrients supply

	2018	2019	2020	All	
Variables	mean	mean	mean	mean	Standard deviation
	(1)	(2)	(3)	(4)	(5)
A. Food consumption					
Consumption of purchased food (1000 MGA/month/AE)	33.96	23.45	34.74	30.77	20.75
Consumption of non-purchased food (1000 MGA/month/AE)	13.96	19.77	19.99	17.81	14.27
Total food consumption (1000 MGA/month/AE)	47.92	43.23	54.73	48.58	23.98
Total rice consumption (1000 MGA/month/AE)	24.50	24.02	28.31	25.55	11.20
Monthly rice purchased rice (kg/month/AE)	6.54	5.82	3.83	5.43	9.37
Monthly (average) rice purchased rice during lean season (kg/month/AE)	7.07	6.70	3.40	5.78	7.58
B. Purchase of different food groups					
Staple foods (1000 MGA/month/AE)	13.35	6.30	14.33	11.31	11.98
Pulses (1000 MGA/month /AE)	1.27	1.43	1.06	1.26	1.47
Tubers and Roots (1000 MGA/month/AE)	0.40	1.02	1.24	0.87	1.61
Vegetables (1000 MGA/month/AE)	1.92	2.25	2.17	2.20	8.8
Fruits (1000 MGA/month/AE)	0.53	1.06	0.53	0.71	3.81
Meat and Fish (1000 MGA/month/AE)	5.80	3.81	4.53	4.73	6.75
C. Diet quality, Energy, and micronutrients intake					
Household Dietary Diversity Score (HDDS)[a)]	5.030	5.213	5.643	5.290	1.114
Calorie intake (kcal/day/AE)	2639.1	2567.2	2783.5	2661.9	834.9
Prevalence of undernourishment (%)[b)]	50.6	46.3	38.3	45.2	49.8
Iron intake (mg/day/AE)	14.27	13.84	14.89	14.32	8.89
Zinc intake (mg/day/AE)	9.60	7.60	9.20	8.81	4.53
Vitamin A intake (µg RAE/day/AE)	236.90	166.70	258.60	220.70	190.0
Number of Observations	550	529	508	1587	

Note: AE is Adult Equivalent. MGA: Malagasy Ariary is Malagasy currency (1,000MGA = US$ 0.026 as of July 27th, 2021). RAE is retinol activity equivalents

[a)] HDDS is number of different food groups consumed during the 24 hours preceding the survey [0-12]

[b)] The percentage of the household with calorie consumption lower that 2,500kcal/day/AE.

Table 3: Impact of household's rice yield on the calories and micronutrients intake (Household fixed effects)

VARIABLES	Energy	Zinc	Iron	Vitamin A	HDDS
	(1)	(2)	(3)	(4)	(5)
Lowland rice yield (Ln)	0.183***	0.115***	0.750***	0.190***	0.697***
	(0.026)	(0.034)	(0.039)	(0.043)	(0.074)
Age of the household's head	-0.000	0.000***	-0.000**	-0.000***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of children under 5 years old	-0.074***	-0.027	0.044	-0.015	-0.023
	(0.026)	(0.035)	(0.038)	(0.036)	(0.081)
Number of children between 6-15 years old	-0.057***	-0.051**	-0.025	0.004	-0.023
	(0.019)	(0.025)	(0.030)	(0.017)	(0.064)
Number of adult members	-0.041**	-0.056***	-0.052**	-0.014	0.022
	(0.017)	(0.019)	(0.025)	(0.017)	(0.057)
Consumption questionnaire respondent [a] (1/0)	0.011	0.024	0.013	0.001	-0.104
	(0.023)	(0.027)	(0.033)	(0.025)	(0.073)
Yesterday was a special day (1/0)	0.015	-0.017	0.136	0.063	0.074
	(0.069)	(0.075)	(0.082)	(0.051)	(0.201)
Value of farm asset per AE (ln)	0.048	-0.032	0.066*	0.042	0.049
	(0.032)	(0.025)	(0.039)	(0.025)	(0.073)
Livestock holdings (TLU)	0.006	0.0020	-0.0010	-0.002	0.018
	(0.003)	(0.003)	(0.007)	(0.007)	(0.016)
Total off-farm income per AE (ln)	-0.001	-0.007	0.006	0.003	0.012
	(0.003)	(0.004)	(0.009)	(0.004)	(0.012)
Total size of land cultivated (ln)	0.000	0.018	0.034	-0.022	-0.019
	(0.024)	(0.027)	(0.041)	(0.022)	(0.087)
Total plot size for lowland rice (ln)	0.007	0.005	0.016	0.014	0.070
	(0.020)	(0.018)	(0.025)	(0.020)	(0.064)
Crop diversification	0.007	-0.013	0.015	0.005	0.091
	(0.016)	(0.014)	(0.018)	(0.014)	(0.062)
R-squared	0.236	0.215	0.408	0.405	0.325
Observations	1,587	1,587	1,587	1,587	1,587

Note: From columns (1) to (4) the dependent variables are in logarithm.

[a)] Consumption questionnaire respondent takes 1 if the respondent is different from the person who knows better about household consumption and 0 otherwise.

[b)] Crop diversification is number of other crops cultivated.

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the village level in parentheses. Number of households in the panel is 550.

Table 4: The impact of rice yield on the purchase of different food groups(Household fixed effects)

VARIABLES	Staple food	Pulse	Tuber	Vegetables	Fruits	Meat and Fish
	(1)	(2)	(3)	(4)	(5)	(6)
Lowland rice yield (Ln)	-0.024	0.374	0.288	0.456***	0.575**	0.658***
	(0.245)	(0.239)	(0.249)	(0.171)	(0.253)	(0.139)
Age of the household's head	-0.002***	-0.000	-0.002	0.000	0.001***	0.000
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.001)
Number of children under 5 years old	-0.232	0.246	0.005	-0.022	0.407*	-0.141
	(0.225)	(0.255)	(0.233)	(0.124)	(0.220)	(0.121)
Number of children between 6-15 years old	0.238	-0.118	-0.095	-0.267***	0.280*	-0.114
	(0.180)	(0.138)	(0.216)	(0.082)	(0.161)	(0.098)
Number of adult members	-0.099	-0.163	-0.020	-0.064	-0.115	-0.019
	(0.149)	(0.202)	(0.133)	(0.072)	(0.157)	(0.084)
Value of farm asset per AE (ln)	-0.030	0.401	-0.159	0.233	0.226	0.467***
	(0.278)	(0.286)	(0.236)	(0.167)	(0.263)	(0.138)
Livestock holdings (TLU)	-0.052	0.026	-0.029	-0.028	0.019	-0.002
	(0.037)	(0.045)	(0.054)	(0.023)	(0.045)	(0.021)
Total off-farm income per AE (ln)	0.052	-0.012	-0.007	-0.021	0.008	0.014
	(0.045)	(0.031)	(0.043)	(0.016)	(0.029)	(0.030)
Total size of land cultivated (ln)	-0.588***	-0.204	-0.611**	-0.150	-0.027	0.154*
	(0.211)	(0.230)	(0.243)	(0.114)	(0.222)	(0.088)
Total plot size for lowland rice (ln)	0.157	0.186	0.229	0.070	0.105	0.085
	(0.165)	(0.185)	(0.212)	(0.090)	(0.202)	(0.087)
Crop diversification [a]	0.163	-0.197	-0.086	-0.106*	-0.238*	-0.094
	(0.146)	(0.134)	(0.151)	(0.055)	(0.139)	(0.067)
R-squared	0.443	0.289	0.481	0.233	0.232	0.210
Observations	1,355	1,103	807	1,587	1,587	1,587
Number of households in the panel	532	517	450	550	550	550

Note: Dependent variables are natural logarithm of the expenditure on the purchased food.
[a)] Crop diversification is number of other crops cultivated.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the village level in parentheses.

Table 5: The effect of rice yield on rice commercialization and households' cash revenue (Household fixed effects)

VARIABLES	Commercialization (1/0)	The share of the rice sold (%)	Conditional share of the rice sold (%)	Cash revenue from rice sales (ln)	Conditional cash revenue from rice sales (ln)
	(1)	(2)	(3)	(4)	(5)
Lowland rice yield (ln)	0.405**	31.141***	47.253***	4.753***	2.981**
	(0.165)	(9.083)	(16.962)	(1.692)	(1.120)
Age of the household's head	-0.000***	-0.011*	0.246*	-0.002***	0.002
	(0.000)	(0.007)	(0.140)	(0.001)	(0.014)
Number of children under 5 years old	-0.044	0.910	0.487	-0.446	-0.106
	(0.028)	(1.623)	(2.282)	(0.274)	(0.114)
Number of children between 6-15	0.005	0.472	0.617	-0.101	-0.233**
years old	(0.026)	(1.260)	(2.567)	(0.259)	(0.099)
Number of adult members	-0.006	-0.341	1.465	-0.152	-0.017
	(0.022)	(1.343)	(1.873)	(0.240)	(0.082)
Value of farm asset per AE (ln)	0.014	0.608	1.815	0.281	0.261**
	(0.037)	(2.546)	(3.272)	(0.404)	(0.128)
Livestock holdings (TLU)	-0.007	-0.079	-0.175	-0.049	0.009
	(0.008)	(0.303)	(0.745)	(0.078)	(0.028)
Distance to main road*Rice yield (ln)	-0.054**	-3.331***	-4.633**	-0.575***	-0.277**
	(0.021)	(1.146)	(2.121)	(0.214)	(0.137)
Total size of land cultivated (ln)	0.016	-1.071	-0.374	0.124	0.023
	(0.039)	(1.802)	(2.997)	(0.376)	(0.085)
Total off-farm income per AE (ln)	-0.002	0.412	0.376	0.000	0.016
	(0.004)	(0.384)	(0.452)	(0.050)	(0.026)
Total plot size for lowland rice (ln)	0.037	-0.914	-5.892**	0.549*	0.297**
	(0.029)	(1.279)	(2.905)	(0.277)	(0.136)
Crop diversification [a]	0.017	1.088	1.986	0.160	0.098
	(0.019)	(1.132)	(2.469)	(0.191)	(0.073)
R-squared	0.214	0.216	0.356	0.220	0.401
Observations	1,587	1,587	865	1,587	865
The number of households in the panel	550	550	386	550	386

Note: [a)] Crop diversification is number of other crops cultivated.
The dependent variable in columns (3) and (5) are conditioned on commercialization =1.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the village level in parentheses.

Appendix

Table A 1: The effect of rice yield on food consumption and rice purchases (Household fixed effects)

VARIABLES	Total food consumption per AE	Total rice consumption per AE	Consumption on purchased food per AE	Total rice purchase per AE	Rice purchase during lean season
	(1)	(2)	(3)	(4)	(5)
Lowland rice yield (Ln)	0.117***	0.123***	0.183***	-0.071	-0.678***
	(0.038)	(0.028)	(0.064)	(0.068)	(0.077)
Age of the household's head	0.000***	-0.000	-0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of children under 5 years old	-0.030	-0.056*	-0.082	0.055	-0.042
	(0.030)	(0.031)	(0.052)	(0.056)	(0.116)
Number of children between 6-15 years old	-0.093***	-0.087***	-0.075**	0.009	0.029
	(0.023)	(0.024)	(0.035)	(0.046)	(0.081)
Number of adult members	-0.091***	-0.090***	-0.092***	-0.045	-0.065
	(0.015)	(0.020)	(0.022)	(0.039)	(0.047)
Value of farm asset per AE (ln)	0.095***	0.009	0.091**	0.113*	0.054
	(0.029)	(0.030)	(0.035)	(0.059)	(0.112)
Livestock holdings (TLU)	0.010*	0.006	0.004	-0.002	-0.005
	(0.006)	(0.005)	(0.007)	(0.009)	(0.017)
Total off-farm income per AE (ln)	0.009	0.003	0.013	0.007	-0.004
	(0.006)	(0.005)	(0.008)	(0.009)	(0.012)
Total size of land cultivated (ln)	0.047**	0.013	-0.034	-0.062***	-0.033
	(0.023)	(0.024)	(0.040)	(0.023)	(0.030)
Total plot size for lowland rice (ln)	-0.008	0.014	0.017	0.030	0.006
	(0.017)	(0.017)	(0.029)	(0.035)	(0.037)
Crop diversification [a)]	0.010	0.008	0.032	0.001	-0.006
	(0.014)	(0.017)	(0.020)	(0.033)	(0.041)
R-squared	0.291	0.247	0.317	0.310	0.361
Observations	1,587	1,587	1,587	1,587	1,587
Number of households in the panel	550	550	550	550	550

Note: The dependent variables are in in natural logarithm.
[a)] Crop diversification is number of other crops cultivated.
*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the village level in parentheses.

Table A 2: The impact of household's rice yield on the rice availability, other sources of income (Household fixed effects)

VARIABLES	Off-farm income per AE	Income from other farm activities	Income from other crops
	(1)	(2)	(3)
Lowland rice yield (Ln)	-0.116	-0.151	-0.250
	(0.156)	(0.281)	(0.299)
Age of the household's head	-0.000	0.005***	0.004***
	(0.000)	(0.001)	(0.001)
Number of children under 5 years old	0.256	0.430	0.395
	(0.174)	(0.306)	(0.298)
Number of children between 6-15 years old	0.040	-0.080	0.061
	(0.110)	(0.289)	(0.182)
Number of adult members	0.191	0.049	-0.416*
	(0.156)	(0.179)	(0.215)
Value of farm asset per AE (ln)	0.333	0.360	-0.333
	(0.249)	(0.239)	(0.256)
Livestock holdings (TLU)	0.053	0.078	0.075*
	(0.039)	(0.056)	(0.040)
Total size of land cultivated (ln)	-0.122	0.228	0.201
	(0.164)	(0.405)	(0.252)
Total plot size for lowland rice (ln)	-0.072	0.042	0.175
	(0.112)	(0.242)	(0.225)
Crop diversification [a)]	-0.102	-0.211	0.757***
	(0.101)	(0.149)	(0.189)
R-squared	0.275	0.340	0.634
Observations	1,587	1,587	1,587

Note: The dependent variables are in in natural logarithm. Income from other farm activities include income from dry season cropping, other crops in the main season, upland production. Income from other crops include income from all other crops excluding rice.

[a)] Crop diversification is number of other crops cultivated.

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered a t the village level in parentheses. The number of households in the panel is 550