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Multiple cropping alone does not improve year-round food security among smallholders in rural India

Pinki Mondal[1,2,*], Ruth DeFries[3], Jessica Clark[1], Nicole Flowerhill[1], Md. Arif[4,10], Aurelie Harou[5], Shauna Downs[6] and Jessica Fanzo[7,8,9]

1 Department of Geography and Spatial Sciences, University of Delaware, Newark, DE, United States of America
2 Department of Plant and Soil Sciences, University of Delaware, Newark, DE, United States of America
3 Department of Ecology, Evolution,and Environmental Biology, Columbia University, New York, NY, United States of America
4 Foundation for Ecological Security, Mandla, Madhya Pradesh, India
5 Department of Natural Resource Sciences, Agricultural Economics, McGill University, Québec, Canada
6 Department of Urban-Global Health, Rutgers School of Public Health, Newark, NJ, United States of America
7 The Nitze School of Advanced International Studies, Johns Hopkins University, Washington, DC, United States of America
8 The Bloomberg School of Public Health, Johns Hopkins University, Washington, DC, United States of America
9 The Berman Institute of Bioethics, Johns Hopkins University, Washington, DC, United States of America
10 Current affiliation: Deshpande Foundation India, Hubballi, Karnataka, India
* Author to whom any correspondence should be addressed.

E-mail: mondalp@udel.edu

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Abstract

Achieving and maintaining food and nutrition security is an important Sustainable Development Goal, especially in countries with largely vulnerable population with high occurrence of hunger and malnutrition. By studying a small-scale agricultural system in India, we aim to understand the current state of dietary diversity and food insecurity among the farmer communities. The study landscape has witnessed a steady rise in multiple cropping (i.e. harvesting more than once a year) along with irrigation over the last two decades. Whether this multiple cropping can be expected to improve year-round food security is not well understood. We specifically examine if planting multiple food crops within a year is associated with dietary diversity and food security. We collected information on demographic and economic variables, farming activities and livelihood choices, from 200 unique households for three seasons (monsoon/rainy, winter, summer) during 2016–2018 ($n = 600$). Based on both a 24 h and a 30 days recall, we calculated several indicators, including the household dietary diversity score, the minimum dietary diversity for women, and household food insecurity access scale. At least 43% of the sample population experiences moderate to severe food insecurity in all seasons. Cereals (mainly rice) remain the most important food item irrespective of the season, with negligible consumption of other nutrient-rich food such as tubers, fish, eggs, and meats. Around 81% of women in all seasons do not consume a minimally diverse diet. Multiple cropping is associated with higher food security only during monsoon, while selling monsoon crops is associated with winter food security. Households practicing multiple cropping consume more pulses (a plant-based protein source) compared to single-cropping or non-farming households ($p < 0.05$). We find that multiple cropping cannot be used as a cure-all strategy. Rather a combination of income and nutrition strategies, including more diverse home garden, diverse income portfolio, and access to clean cooking fuel, is required to achieve year-round dietary diversity or food security.

1. Introduction

Approximately 690 million people worldwide were still undernourished in 2019 (FAO, IFAD, UNICEF, WFP and WHO 2020) leading to a setback to achieving the Sustainable Development Goal (SDG) target 2.1 (ensuring access to safe, nutritious and sufficient food for all people all year round), or SDG target

2.2 (eradicating all forms of malnutrition). In 2019, two billion people did not have access to sufficient and nutritious food, likely to be further impacted by the COVID-19 pandemic. 'Hidden hunger'—chronic deficiency of micronutrients (vitamins and minerals, such as iron, vitamin A, and zinc)—affects about one quarter of the world's population (HarvestPlus and FAO 2019), with alarmingly high prevalence in sub-Saharan Africa and south Asia (Muthayya *et al* 2013). While smallholder farmers produce a substantial share of global food supply, including about 80% of food consumed in Asia and sub-Saharan Africa (IFAD 2011), they are paradoxically the most vulnerable to food insecurity (Sanchez and Swaminathan 2005).

Sustainable agricultural intensification (i.e. growing multiple crops sequentially in a year, improved high yielding crop varieties, and sustainable use of irrigation and fertilizers) is one of the ways to meet future food demand while ensuring minimum environmental degradation (Burney *et al* 2010, Foley *et al* 2011, Tilman *et al* 2011, ELD Initiative 2015). Multiple cropping practices may take different forms, such as similar crops growing simultaneously and sequentially or agroforestry with coexistence of diverse vegetation types. In addition to the direct benefits of increased diversity in crop production and potential land sparing, multiple cropping might reduce the environmental consequences of single-species cropping systems by reducing soil erosion and associated nutrient loss, preserving the quality of ground and drinking water, and improving pest regulation (Gaba *et al* 2015). Multiple cropping is widespread in the Global South, particularly on small farms, where farmers plant two or more crops sequentially on the same piece of land (Francis and Porter 2017). Winter crops (or the 'second' crop) thus play a critical role in increasing food production, especially in low- and middle-income countries where ~1 billion ha of land could be cleared by 2050 if the current agricultural land expansion were to continue (Tilman *et al* 2011). The assumed positive connection between multiple cropping and food security (Abraham *et al* 2014, ELD Initiative 2015) has motivated global level studies on identifying potential lands available for multiple cropping (Waha *et al* 2020). As such, most of these studies use dietary diversity or food production as proxies for food security (Remans *et al* 2011, Burlingame and Dernini 2012, Jones *et al* 2014, Pellegrini and Tasciotti 2014). More comprehensive food security indicators, however, are frequently examined in terms of socio-economic, political and demographic factors (Dev and Sharma 2010, Chowdhury *et al* 2016, Cafiero *et al* 2018, Isaura *et al* 2019), and rarely in the context of multiple cropping.

While the overall agriculture-diet-nutrition dynamics is complex, the most direct linkages between agriculture and nutrition are: (a) agriculture as a source of food and (b) agriculture as a source of income (Gillespie and Kadiyala 2011, Bhagowalia *et al* 2012, Sibhatu *et al* 2015, Sibhatu and Qaim 2018). In a semi-subsistence agricultural system (producing both subsistence food crops and food/non-food cash crops for market transaction), a shift towards increasing cash crop production has been known to increase local market dependence, and intensify vulnerability to changes in food prices (Von Braun and Kennedy 1986, Maxwell and Fernando 1989, Fafchamps 1992). Cash crop production is also known to have both positive and negative correlations with food availability (Immink and Alarcon 1993, Komarek 2010), food access (Terry and Ryder 2005, 2007, Komarek 2010), food utilization (Leonard *et al* 1994, Von Braun 1995), and overall food/nutrition security (Anderman *et al* 2014) in countries across the globe.

India faces particular challenges in achieving food and nutrition security due to its increasing population and rapid economic growth resulting in changing diet (Pingali 2004, Popkin 2006). Area for winter ('*Rabi*') cropping in India increased from 46 Mha to 56 Mha (+22%) between 2000–2001 and 2016–2017 (Government of India 2017). Yet, existing literature suggests increased consumption of refined cereals such as rice and wheat, decline in coarse cereals (sorghum/millet) and pulses (edible seeds from leguminous crops), and increases in fat and animal-source food (Gillespie and Kadiyala 2011, Popkin *et al* 2012, DeFries *et al* 2018). Especially in India, policies have played a critical role in driving relative price changes, leading to skewed staple food consumption. An existing policy bias toward wheat and rice is reflected in the inclusion of these staple crops in the targeted public distribution system (TPDS), the large allocation of research-and-development funds, and fertilizer and water subsidies, which has probably led to a lower dietary diversity, along with decline of pulse production/consumption in India. The recently implemented National Food Security Act, 2013 aims to provide further subsidized staples to 75% of the rural and 50% of the urban Indian population (OECD/ICRIER 2018). In such a cereal-heavy diet, vegetarian or non-vegetarian protein sources become more important in achieving nutrition security.

In this study, we specifically examine if planting multiple crops within a single year is associated with improved food and nutrition security in a semi-subsistence farming community in the state of Madhya Pradesh. This central Indian state has witnessed an increase in area under multiple cropping from 5.2 Mha to 9.9 Mha (+90%) between 2004–2005 and 2017–2018 (Directorate of Economics and Statistics 2017). The net area under irrigation increased about 45% since 2008–2009, covering 9.5 Mha in 2013–2014

(Ministry of Statistics and Programme Implementation India 2017). Whether such aggressive investment in multiple cropping and irrigation infrastructure could result in year-round food security among smallholder communities is yet to be examined. Using primary survey data from 200 households over three seasons ($n = 600$) from five districts in Madhya Pradesh, we investigate the following questions:

(a) how do dietary diversity and food security vary across seasons for smallholder farmers?
(b) are multiple cropping practices associated with dietary diversity and improved food security?
(c) is agriculture as a source of income, i.e. income from crop sale, associated with dietary diversity and food security?

We adopted the FAO definition of food security, i.e. all individuals, at all times, have reliable physical and economic access to sufficient, safe, and nutritious food (FAO 1996). Such definition relies upon four dimensions of food security: availability, access, utilization and stability. We used multiple indicators of dietary diversity and nutritional adequacy to capture the different components of food security.

2. Methods

2.1. Study region

We selected central India as the focus area since there is a mix of single-cropping and double-cropping practices, and the smallholder farmers in this region represent some of the most vulnerable communities in India, with people predominantly belonging to socially excluded tribal communities (UKAID 2014). Agricultural intensification in this region is achieved via different pathways—by using high-yield crop variety during monsoon/rainy season resulting in higher income, by planting multiple crops sequentially in a year, or by increasing production with better agricultural inputs (better coverage and year-round access to irrigation, more fertilizer). This is also a landscape with limited infrastructure, e.g. refrigeration and transportation, with traditional weekly markets (*bazaar*) serving as the primary food distribution system in addition to local shops and TPDS.

We focused on 40 villages in five districts in the state of Madhya Pradesh—Balaghat, Chhindwara, Dindori, Mandla and Seoni—to understand the agriculture-diet-nutrition dynamics across agricultural households from various socio-economic settings (SI table 1; figure 1 (available online at stacks.iop.org/ERL/16/065017/mmedia)). All of these districts fall within the 'hot moist sub-humid' agro-ecological subregion that covers Satpura range and Wainganga valley (Gajbhiye and Mandal 2000). The primary crops planted during monsoon are paddy rice and maize (mostly in Chhindwara), with some pulses (pigeon pea, black gram). During winter, smallholders in this region predominantly plant wheat and pulses (chickpea, grass pea, pea, lentil), with occasional paddy rice and linseed. They also produce vegetables, e.g. spinach, okra, ridge gourd, cauliflower, onion, in home gardens during winter. Summer is not a common cropping season, with occasional home gardening for vegetables (tomato, bottle gourd, eggplant) and some paddy rice. Agriculture in this region is mostly rain-fed with more winter cropping expected with suitable soil and access to irrigation. All five districts have witnessed an increase in multiple cropping, along with area under wheat and pulses, since 2004–2005 (SI figure 1). Our prior work has shown a temporally fluctuating pattern in winter cropping in this landscape (Mondal *et al* 2016) driven mostly by access to irrigation, with a possibility for losing 20%–68% of winter crops based on the current groundwater depletion (Jain *et al* 2021). This landscape thus gives us a unique opportunity to test if, and how, multiple cropping is associated with seasonal changes in dietary diversity and food security, if any.

2.2. Sampling strategy for surveys

We used a stratified random sampling strategy to identify study villages *a-priori* using a satellite-derived winter cropped area dataset (Jain *et al* 2017a, 2017b) as the base map (figure 1). First, we created a stratum based on agricultural practices (predominantly single cropping vs. double cropping) in the five study districts. Then we randomly selected eight villages from each of the five districts to represent each of the agricultural practice categories. Within each village five households were randomly selected (household $n = 200$) by the interviewer based on location within the village and availability of the respondents. The same individual in each household (male or female adult, based on availability) was interviewed for each of the three seasons (summer, monsoon/rainy season, winter/dry season), resulting in 600 surveys. A list of the survey questions has been provided in SI tables 2–4.

We utilized the food and nutrition technical assistance (FANTA) project recommendations for the questionnaire surveys for food security and diversity indicators (SI tables 3, 4), namely the household food insecurity access scale (HFIAS) (Coates *et al* 2007) and household dietary diversity score (HDDS) (FAO 2011). We collected food availability data through a 30 days recall and food consumption data (FAO 2011) through a 24 h recall. The interviewer avoided visiting a village right after the weekly market days, whenever possible, to avoid misrepresentation of dietary diversity. The interviewer administered the questionnaires three times a year for monsoon (June–October), winter (November–February), and summer (March–May) seasons. Although the study region has negligible triple cropping, inclusion of

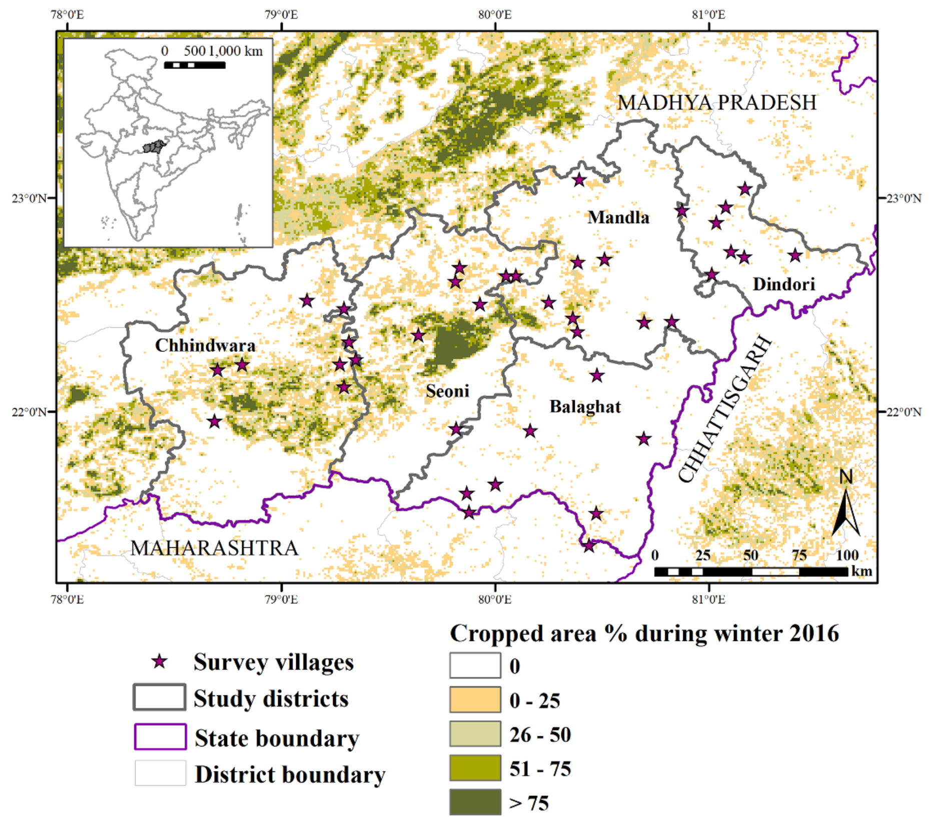

Figure 1. Map of study area showing location of the 40 study villages within the five study districts at the boundary of the Indian states of Madhya Pradesh, Maharashtra and Chhattisgarh, along with the spatial distribution of winter cropping (the second crop) in 2016 (cropped area data source: Jain *et al* 2017b).

summer season (the season of greatest food shortage) enabled us to develop a baseline to identify seasonal changes in diet (FAO 2011). Approvals from the Institutional Review Boards were obtained from both Columbia University and the University of Delaware.

2.3. Dietary diversity and food insecurity indicators

Using the data collected on 16 individual foods or food groups consumed over the last 24 h, we calculated HDDS by aggregating food items into 12 groups (SI table 3): cereals, white tubers/roots, vegetables, fruits, meat, eggs, fish/seafood, pulses/nuts/seeds, milk/milk products, oils/fats, sweets, spices/condiments/beverages e.g. tea and alcoholic beverage such as *Mahua*. The respondents were first asked about the dietary consumption at the household level over the last 24 h (breakfast/snack, morning meal, lunch, dinner). Based on the qualitative responses, the interviewer assigned a value of 'yes' (1) or 'no' (0) to each of the food groups (SI table 3). While we made every effort to interview the women for the dietary diversity questionnaire, it was not always possible. HDDS ranges between 0 and 12; the higher the score the higher is the dietary diversity (SI figure 2).

To document nutritional adequacy among smallholder farmer families, we further focused on the women 15–49 years of age ($n = 413$). We calculated the minimum dietary diversity for women (MDD-W) for each eligible respondent (FANTA 2014, FAO 2016). It is a dichotomous indicator for women consuming at least five out of ten defined food groups (grains/tubers, pulses, nuts/-seeds, dairy, meat/fish, egg, dark green leafy vegetable, other vitamin-A enriched vegetables, other vegetables, and other fruits) over the last 24 h (SI figure 2). We report proportion of women respondents who had MDD-W, i.e. consumed at least five food groups.

We further calculated proportion of women respondents, as the percent of total women respondents, who consumed food groups that are good sources for micronutrients such as vitamin A or iron (FAO 2011) over the last 24 h. A value of 1 was assigned to the following three categories if the respondent consumed any of the food groups listed for each of these categories.

(a) Plant-based vitamin A: vitamin a rich vegetables and tubers, dark green leafy vegetables, vitamin a rich fruits
(b) Animal-based vitamin A: organ meat, eggs, milk or milk products
(c) Iron: organ meat, flesh meat, fish and seafood.

Low percentages of sub-population consuming the micronutrient-rich food groups can be used as an indicator of severely inadequate diets, especially relevant for ongoing monitoring and intervention assessments (FAO 2011). For this study, we only consider vitamin A and iron as the dietary diversity data explicitly highlights both iron and vitamin A rich food groups, given that many populations (including in India) are at risk of under-consuming these key nutrients (Bailey *et al* 2015, Gonmei and Toteja 2018). Due to the nature of the data collected, we were not able to consider other important nutrients such as protein or calcium.

We used the food availability surveys (SI table 4) to construct HFIAS that represents varying levels of food insecurity over the past 30 days based on responses to nine occurrence and nine frequency-of-occurrence questions (Coates *et al* 2007). The range for HFIAS is 0–27; the higher the score, the more food insecure is the household (SI figure 2). This indicator reflects three domains perceived as central to the experience of food insecurity: (a) anxiety about household food supply (b) insufficient quality, including variety, preferences and social acceptability and (c) insufficient food supply and intake and their physical consequences. Furthermore, we report the Household Food Insecurity Access Prevalence (HFIAP) status of the study population by categorizing the households into four groups: food secure (HFIA 1) and mild (HFIA 2), moderately (HFIA 3) or severely food insecure (HFIA 4). For this indicator, a HFIA category variable was first assigned to each household using the following set of criteria (see SI table 4 for questions).

(a) HFIA category = 1 if [(Q1a = 0 or Q1a = 1) and Q2 = 0 and Q3 = 0 and Q4 = 0 and Q5 = 0 and Q6 = 0 and Q7 = 0 and Q8 = 0 and Q9 = 0]
(b) HFIA category = 2 if [(Q1a = 2 or Q1a = 3 or Q2a = 1 or Q2a = 2 or Q2a = 3 or Q3a = 1 or Q4a = 1) and Q5 = 0 and Q6 = 0 and Q7 = 0 and Q8 = 0 and Q9 = 0]
(c) HFIA category = 3 if [(Q3a = 2 or Q3a = 3 or Q4a = 2 or Q4a = 3 or Q5a = 1 or Q5a = 2 or Q6a = 1 or Q6a = 2) and Q7 = 0 and Q8 = 0 and Q9 = 0]
(d) HFIA category = 4 if [Q5a = 3 or Q6a = 3 or Q7a = 1 or Q7a = 2 or Q7a = 3 or Q8a = 1 or Q8a = 2 or Q8a = 3 or Q9a = 1 or Q9a = 2 or Q9a = 3]

2.4. Regression models

Using HDDS and HFIAS as response variables, we ran eight regression models to identify the most important associations of different factors including demographic, economic, farming activities and livelihood choices (table 1). We ran two full models (pooling data from all three seasons) and six season-specific models.

All continuous predictor variables were centered on the mean values and were tested for collinearity. Standard errors were clustered by villages. We considered only full records with no missing values for any of the variables, resulting in a sample size of 573 for the full models. In these models, we used fixed effects (season, district and village) to minimize any time-invariant unobservable component that might otherwise bias our estimates.

In order to identify significant associations within each season, we also developed three sets of regression models, each for HFIAS and HDDS. The sample sizes for summer, monsoon and winter models are 196, 188 and 189, respectively. These regression models enabled us to identify the season-specific importance of multiple cropping in a year and source of income (farm vs. non-farm) in achieving food security and dietary diversity. District and village variables were used as fixed effects in these season-specific models.

Table 1 provides details on all the variables used in the regression models. Based on the survey data, we developed an asset index using data collected on several asset indicators, such as household ownership of consumer durables (livestock, television, radio, refrigerator, bicycle, phone) and characteristics of the household's dwelling (building materials). Such an indicator can be used as a proxy for wealth/assets as they provide advantages over other common measures of well-being, e.g. consumption, income and expenditures. Assets are accumulated over a longer time period and tend to last longer, making them a strong indicator of a household's permanent wealth compared to a household's income, for example, which suffers from seasonal variation and/or non-remunerated self-employment (Sahn and Stifel 2000, Filmer and Pritchett 2001, Moser and Felton 2007). Here, we use factor analysis to create an asset index as it offers more flexibility by not forcing all the components to explain the correlation structure between the assets (see Sahn and Stifel 2000 for details). Data cleaning, visualization and regression analysis were performed using MS Excel, ArcMap 10.5.1 and R 4.0.2 packages tidyverse, sandwich, and lmtest.

3. Results

3.1. How do dietary diversity and food security vary across seasons for smallholder farmers?

The food groups most consumed (>96% households) around the year are cereals, oils and spices (figure 2), while consumption of other food groups vary across seasons. The other most consumed food group is vegetables, reported by 90%–95% of households, with the lowest consumption in monsoon. Pulse consumption is at its most during summer (76%) with 62% each during monsoon and winter. White tuber consumption fluctuates considerably between 20% in

Table 1. Description of variables used in this study.

Demographic	Economic	Farming activities	Livelihood choices
HHM: number of household members (who eat together) EDUHH: highest education level in the household. High-school and beyond = 1, other = 0	OCU_F: primary occupation. Over 6 months farming = 1, other = 0 Asset_index: a weighted variable based on a range of asset indicators, e.g. livestock, bicycle, radio, television, refrigerator, bicycle, phone, building materials	Crop_no: number of cropping seasons within a year PLLS: Farming activities last season. Yes = 1, no = 0	COKS: primary fuel source for cooking. LPG = 1, fuelwood /both = 0 FPDC: food purchase decision maker. Female = 1, male/both = 0.
	HHSS_R: money spent on food items purchased from subsidized shop/public distribution system in last month.	LSSL: crops sold last season. Yes = 1, no = 0	FCDC: cooking decision maker. Female = 1, male/both = 0.
	MON: money spent on food items purchased from market/shop in last month.	IRLS: access to irrigation last season. Yes = 1, no = 0 HGAG: food grown in home garden this season. Yes = 1, no = 0	MFRQ: number of market visits per month for food purchase. FPS_FI: % of the total cash income from farm produce (crop + livestock) spent on food items. NFAS_FI: % of the total cash income from non-farm activities (wage, salary) spent on food items.

monsoon and 69% in winter. People in this landscape rarely consume any other food groups, except for milk and sweets. Over 70% of the households lack milk in their diet (figure 2), with the rest of the households consuming negligible amount of milk in tea. While the ethnic groups (such as *Gond, Baiga, Pardhan*) in this region are predominantly non-vegetarian, egg/fish/meat is not a common food item in their diet due to the lack of affordability (Mondal, personal communication). About 0.5%–2% of the respondents consume animal-sourced protein.

The diets of the women of 15–49 years of age ($n = 413$) are highly inadequate from a nutritional point of view (figure 2). During summer, only about 19% of women consumed a minimally diverse diet. That number drops to 16% and 13% during monsoon and winter, respectively, leaving a vast majority of the women consuming poor quality diets. The diets of the majority of women (96%–98%) lack iron-sourced food, such as organ/flesh meat, fish, or seafood. Animal-source vitamin-A rich foods are also lacking in the diets of 70%–80% of the women respondents. Between 21% (monsoon) and 54% (summer) women lack plant-based vitamin-A rich foods in their diets.

In the study region, summer is the least food secure season with 28% of the households reporting severe food insecurity while about one-fifth of the population are severely food insecure during winter (figure 2). Approximately 28% of households are food secure during summer, while 40% and 44% households are food secure during monsoon and winter, respectively. A considerable fraction of the households is moderately or mildly food insecure throughout the year, ranging from 36% in winter to 44% in summer.

3.2. Are multiple cropping practices associated with dietary diversity and improved food security?

About 53% of the surveyed households practice multiple cropping, i.e. 2 or 3 cropping seasons within a year. Yet, a higher number of crops throughout the year (crop_no) shows a positive association with higher dietary diversity only during monsoon, with a variable estimate of 0.550 (table 2 a). Having a home garden (HGAG) helps with dietary diversity during winter (estimate = 0.400; table 2(a)), but not during monsoon or summer, even though 66% respondents had a home garden during monsoon compared to 49% and 6.5% in winter and summer, respectively. We also find that liquefied petroleum gas (LPG) as primary or additional fuel source for cooking (COKS)

Figure 2. Top panel: seasonal variations in consumption of different food groups plotted by the percentage of respondents. A full circle denotes 100% respondents consumed that particular food group. Middle panel: the status of nutritional inadequacy among women population. Numbers denote proportion of women respondents with nutritional inadequacy. Bottom panel: the household food insecurity access (HFIA) prevalence status where HFIA 1 is the food secure group and HFIA 2–4 are mildly, moderately and severely food insecure groups.

is positively associated with higher dietary diversity during summer with an estimate of 0.412 (table 2(a)).

In the study region, pulses can be an excellent source of protein that could be available (as a second crop), accessible and affordable to the local communities. Agricultural census data suggest an increase in cropped area under different types of pulses over the last two decades (SI figure 1), although existing literature suggests a decrease in pulse consumption (Headey *et al* 2012). Bhagowalia *et al* (2012) reported a positive association between number of crops grown by a household and share of pulses. Similarly, we find that pulse consumption in households practicing multiple cropping is significantly higher ($p < 0.05$) in summer and monsoon compared to the single-cropping households or non-farming households (figure 3). Among the multiple cropping households (53% of all households), between 63% and 86% consume pulses, whereas only 29%–37% single-cropping households have pulses in their diets (not significantly different from non-farming households).

Multiple cropping throughout a year (Crop_no) is associated with higher food security in monsoon with a variable estimate of −0.907 (table 2(b)), i.e. the higher the crop number the lower is the food insecurity score. Such association was absent during summer and winter. However, planting crops (PLLS) during monsoon is associated with improved food security during winter with an estimate of −1.288 (table 2(b)). Assets appear to be the only factor that can keep households food secure throughout the year, with the estimates ranging between −0.731 in summer and −0.778 in monsoon (table 2(b)).

3.3. Is agriculture as a source of income, i.e. income from crop sale, associated with dietary diversity and food security?

About one-fifth of this sample population sell a portion of the crops throughout the year. We find that households depending more on income from farming to purchase food items (FPS_FI) have a less diverse diet during monsoon (estimate = − 0.276; table 2(a)) and winter (estimate = − 0.397; table 2(a)). More dependence on income from farming for food purchase is also associated with higher food insecurity during monsoon (estimate = 1.015; table 2(b)). Dependence on non-farm income (NFAS_FI) for food purchase is associated with higher food insecurity during monsoon (estimate = 0.544; table 2(b)), although the association is less significant compared to the one with income from farming. This shows that

Table 2. Variable estimates and standard errors clustered by villages (within parentheses) from eight regression models constructed for (a) the household dietary diversity score (HDDS) and (b) the household food insecurity access scale (HFIAS). All continuous independent variables are centered on mean. Full model with data from all three seasons have district, village and season fixed effects. Season-specific models have village and district fixed effects. Statistically significant associations are in bold.

(a) Household dietary diversity score (HDDS)

Variables	Full model ($n = 573$)	Summer ($n = 196$)	Monsoon ($n = 188$)	Winter ($n = 189$)
HHM	−0.083 (0.069*)	−0.118 (0.074)	−0.166 (0.092**)	−0.027 (0.117)
EDUHH	0.030 (0.092)	0.015 (0.138)	−0.043 (0.110)	0.094 (0.110)
OCU_F	0.095 (0.169)	−0.036 (0.210)	−0.388 (0.305)	0.284 (0.345)
Asset_index	**0.115** (0.061*)	0.133 (0.098)	**0.274** (0.082****)	0.055 (0.100)
HHSS_R	−0.055 (0.053)	−0.034 (0.087)	−0.030 (0.100)	0.027 (0.091)
MON	**0.131** (0.042***)	0.050 (0.097)	**0.246** (0.105**)	0.119 (0.121)
Crop_no	0.150 (0.128)	0.087 (0.187)	**0.550** (0.230**)	0.043 (0.144)
PLLS	0.180 (0.125)	0.278 (0.253)	**−0.908** (0.510*)	0.578 (0.425)
LSSL	−0.061 (0.084)	0.011 (0.136)	0.024 (0.167)	−0.211 (0.135)
IRLS	−0.135 (0.111)	**−0.384** (0.167**)	0.386 (0.398)	0.155 (0.132)
HGAG	−0.007 (0.082)	−0.168 (0.171)	−0.149 (0.187)	**0.400** (0.112****)
COKS	**0.195** (0.082**)	**0.412** (0.137***)	0.078 (0.142)	−0.002 (0.139)
FPDC	**−0.158** (0.077**)	−0.168 (0.140)	−0.196 (0.138)	**−0.216** (0.114*)
FCDC	0.121 (0.251)	−0.409 (0.336)	0.707 (0.526)	**0.457** (0.157***)
MFRQ	−0.005 (0.080)	−0.079 (0.069)	0.035 (0.100)	0.004 (0.069)
FPS_FI	**−0.189** (0.065***)	−0.122 (0.119)	**−0.276** (0.120**)	**−0.397** (0.159**)
NFAS_FI	**−0.082** (0.042*)	−0.124 (0.077)	0.026 (0.100)	−0.103 (0.068)

(b) Household food insecurity access scale (HFIAS)

Variables	Full model ($n = 573$)	Summer ($n = 196$)	Monsoon ($n = 188$)	Winter ($n = 189$)
HHM	**0.459** (0.184**)	0.109 (0.215)	**0.809** (0.293***)	**0.409** (0.176**)
EDUHH	−0.023 (0.260)	−0.026 (0.252)	0.070 (0.404)	0.094 (0.327)
OCU_F	−0.163 (0.394)	−0.824 (0.549)	0.523 (0.633)	0.208 (0.840)
Asset_index	**−0.694** (0.208****)	**−0.731** (0.264***)	**−0.778** (0.279***)	**−0.752** (0.288***)
HHSS_R	0.205 (0.145)	0.380 (0.287)	−0.014 (0.286)	**0.425** (0.154***)
MON	**−0.248** (0.107**)	−0.209 (0.235)	−0.202 (0.263)	−0.295 (0.179)
Crop_no	**−0.522** (0.275*)	−0.420 (0.555)	**−0.907** (0.379**)	−0.161 (0.343)
PLLS	−0.430 (0.332)	0.300 (0.612)	0.182 (0.812)	**−1.288** (0.728*)
LSSL	**−0.402** (0.208*)	0.177 (0.401)	−0.648 (0.475)	**−0.650** (0.351*)
IRLS	0.168 (0.317)	−0.862 (0.725)	0.205 (0.714)	0.272 (0.401)
HGAG	−0.247 (0.248)	0.096 (0.742)	−0.776 (0.585)	−0.343 (0.403)
COKS	0.029 (0.241)	0.412 (0.429)	−0.453 (0.316)	0.156 (0.330)
FPDC	0.224 (0.171)	−0.490 (0.321)	0.351 (0.383)	**0.780** (0.231****)
FCDC	−0.547 (.661)	−0.581 (0.728)	−0.607 (1.177)	**−1.802** (0.611***)
MFRQ	−0.071 (0.084)	−0.266 (0.214)	0.018 (0.194)	−0.037 (0.260)
FPS_FI	0.240 (0.160)	0.306 (0.299)	**1.015** (0.429**)	0.140 (0.285)
NFAS_FI	**0.308** (0.143**)	0.390 (0.276)	**0.544** (0.295*)	0.122 (0.222)

*Significance codes: '****' 0.001, '***' 0.01, '**' 0.05, '*' 0.1*

smallholders are food insecure during monsoon, irrespective of the source of income for food purchase. We also find that households that could sell crops during monsoon (LSSL) are more food secure in winter (estimate = − 0.650; table 2(b)).

4. Discussion

In a market-oriented agricultural system with cash crop production, poorer food and/or nutrition security is not uncommon (Anderman *et al* 2014, Dewey 1981, 1989). This might be an outcome in a system where cash crop sale gives the farmers more purchasing power, but the local market itself depends on the local food production with low diversity of food crops available to purchase (Ickowitz *et al* 2019). We find that even in a semi-subsistence system such as the study region, where smallholders produce food crops multiple times a year, improved food security can be elusive. No single approach can secure year-round dietary diversity and food security. This finding provides important evidence against the narrative that equates multiple cropping with improved food security (ELD Initiative 2015). Our results rather show that there is no panacea for achieving year-round food security and place-based realities must be interweaved into national-level narratives.

We find that notable variations in dietary diversity and food security exist across seasons. Moreover, irrespective of the season or cropping strategies,

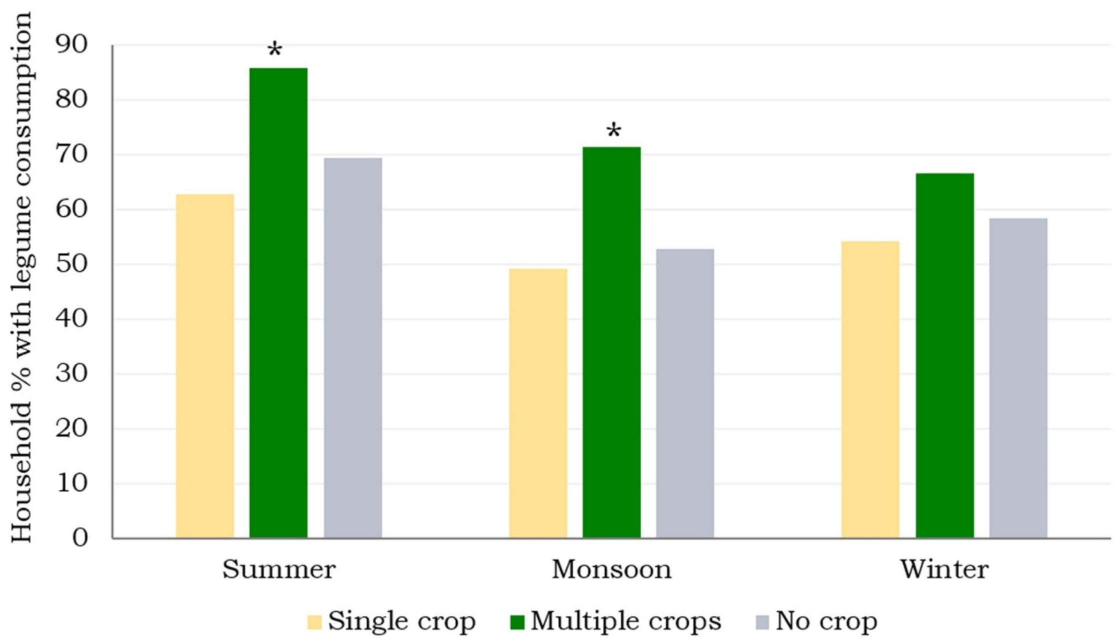

Figure 3. Seasonal variations in legume consumption among single-cropping, multiple-cropping and non-farming households. Statistically significant difference ($p < 0.05$) according to a two-population z score test is denoted by asterisk (*).

women in the study landscape have minimally diverse diet and are likely at risk of nutritional inadequacy (figure 2). This finding is in line with a recent study that finds dietary discrimination faced by women in India (Gupta *et al* 2020). A low-technology mechanism, i.e. increasing production diversity at the home gardens, might be an effective tool to address this issue of nutritional inadequacy among women. Diverse cropping and home gardens have been positively associated with dietary diversity (Rowe 2009, Dame and Nüsser 2011, Bhagowalia *et al* 2012, Islam *et al* 2018, Bellon *et al* 2020). Increased production at the local level can thus lead to improved nutrition, especially when leafy vegetables and fruits are directly consumed (Benson 2015). However, our results show that home garden is positively associated with dietary diversity only during winter. Two-thirds of the respondents grow vegetables in home gardens during monsoon as well. Yet, we do not see the same positive association between home garden and dietary diversity. This is likely because households grow the same group of vegetables during monsoon. By diversifying the home gardens, such as planting green leafy vegetables, vitamin-A enriched fruits or other fruits and vegetables, it is possible to achieve a more diverse diet among women. Regular access to a variety of food groups through home gardens could be particularly effective for this landscape where refrigeration at household-level is not common, thus purchasing perishable vegetables/fruits at the weekly markets for consumption might not be feasible.

About a third of the respondents use LPG for cooking in this landscape with wider adoption to be expected (Khanwilkar *et al* 2021) because of the flagship clean cooking policy '*Pradhan Mantri Ujjwala Yojana*' launched in 2016. We find that LPG use has a positive association with dietary diversity during summer, also found in the full model. This finding aligns with another study from India where alternative cook stoves (biogas) were found to be associated with diverse household diets (Anderman *et al* 2015). However, LPG is expensive and inconvenient for the households (require refilling), in addition to high dependence on imports and sensitivity to market fluctuations (Hameed 2020). While LPG might have direct health benefits, and potential environmental benefits through reduced use of forest products (fuelwood) for cooking, a direct link to improved food security, and not only dietary diversity, is yet to be established in the study landscape.

Our findings indicate that seasonal agricultural income does not improve year-round dietary diversity or food security. Since monsoon crop sale is positively associated with higher food security in winter, similar market transaction opportunities for winter/summer crops might help alleviate farmer concerns related to overall food security. Pulses, one of the major winter crops in this landscape, are among the higher-priced food items in India. It would not be surprising if farmers who grow pulses sell it to cover non-food household expenses, which is an economic strategy as opposed to a nutritional one (Birthal *et al* 2007). However, growing pulses during winter, whenever feasible, can also be promoted as a nutritional strategy in this landscape. Since single-cropping households will have to depend on either market or TPDS (where pulses are not generally available at a subsidized rate) for food items during summer and winter, affordability is likely to play a crucial role in pulse consumption status in these households. Creating a local market structure, where pulses are locally grown and sold at local markets, might help with increased availability and reduced price of this nutritionally important food group (Sibhatu *et al* 2015, Ickowitz *et al* 2019).

There are several pathways to improve food security and dietary diversity. One such approach argues that off-farm employment increases incomes and the ability to purchase food, and thus can reduce dependence on income from agriculture (IAASTD 2009, Babatunde and Qaim 2010). While we do not find a direct evidence supporting this argument, we find that lower dietary diversity is associated with more dependence on income from farming for food purchase, especially during monsoon and winter. We also find that food security declines with more dependence on non-farm income for food purchase. With more household members engaged in off-farm activities, lack of labor availability might contribute to some sense of anxiety around food security in these smallholder communities. These seasonal variations reveal the complex interplay of farm and off-farm activities, further complicated by existing household assets. Since the asset index is consistently associated with improved food security and diverse diet, we can conclude that a better economic baseline for these households can result in an improved food and nutrition security. Our findings highlight that even in a landscape experiencing rapid agricultural intensification through multiple cropping and irrigation, a suite of additional strategies must be in place to ensure food security in smallholder communities.

Data Availability Statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5061/dryad.tdz08kq07.

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ORCID iDs

Pinki Mondal https://orcid.org/0000-0002-7323-6335
Ruth DeFries https://orcid.org/0000-0002-3332-4621

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