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ORIGINAL PAPER

The association between crop and income diversity and farmer intra-household dietary diversity in India

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Abstract

This paper investigates the associations between crop and income diversity and dietary diversity among men, women, adolescents, and children of farmer households in India. We examine crop, income, and dietary data collected from 1106 farmer households across Gujarat and Haryana, two states that represent different livelihood transition pathways in India. Regression results suggest that crop diversity had a positive association with dietary diversity among adults (both men and women) in both states, and among adolescents and children in Haryana. Higher family education and annual income were the two most important factors associated with higher dietary diversity score (DDS) in Gujarat whereas, higher family education, greater crop diversity, and increased distance traveled to markets were the most important factors associated with higher individual DDS in Haryana. Specifically, for children, crop diversity emerged as one of the most important factors associated with dietary diversity in both states. Interestingly, we find that even in these two relatively prosperous states, the pathways to dietary diversity vary across sites and within households, suggesting that policies to improve dietary diversity should be tailored to a given location and context.

Keywords Agriculture · Nutrition · Farmer livelihoods · Farm income · India

1 Introduction

Malnutrition, ranging from undernourishment to obesity, is one of the biggest public health challenges as it affects one in three people worldwide. Globally, 88% of countries face a burden of at least two forms of malnutrition, ranging from stunting, anemia, to being overweight. Over 150 million children are stunted or wasted, while nearly 40 million children and 2 billion adults are overweight (Development Initiatives 2017). Further, over 2 billion people lack key micronutrients such as iron and vitamin A (IFPRI 2014; Elliott 2015). Although malnutrition is a worldwide phenomenon, it is especially chronic in South Asia, where one-third of the global malnourished population resides (Elliott 2015). Malnutrition is particularly widespread in India, where approximately 35% of children are stunted, wasted or underweight, and 20% of men and women are overweight or obese. Simultaneously, over 50% of children and women and 20% of men are anemic (IIPS 2017; Rao et al. 2018). Although trends suggest that the rate of malnutrition in India has decreased over the last decade, it is still a major challenge, especially in rural India (IFPRI 2016; Pingali and Abraham 2018). Malnutrition prevails at multiple levels, across all ages, genders, castes and social groups. However, its prevalence is highest among the rural poor, where there are higher rates of childhood stunting and anemia compared to urban areas (Raykar et al. 2015; Rao et al. 2018). While the causes of rural malnutrition are likely multifaceted and complex, many possible causes have been

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suggested including low incomes, limited access to markets, and limited access to education (Arnold et al. 2009; IFPRI 2014).

In regions such as India, where a majority of the population derives food and employment directly from agriculture, changes in cropping patterns and farmer income portfolios may be affecting farmer household nutrition. Over the past several decades, multiple transitions, related to both cropping patterns and income sources, have begun to occur across farming communities in India. Overall, households have reduced crop diversity by shifting towards planting staple and cash crops (Saha 2013; MoA 2014a). Simultaneously, family members of farming households are opting out of agriculture resulting in more diversified livelihood portfolios for rural families in India (NSSO 2013). Currently, only 60% of an average Indian farming household's income comes directly from agricultural sources (NSSO 2013). To date there is little understanding of the impact that these changes may have on household nutrition. Yet, understanding these effects is important as they may help inform policies to reduce rural malnutrition in India in the face of current transitions.

Considering the changes in cropping patterns and income sources that Indian farming systems are currently facing, previous studies have suggested a significant link between income, crop diversity, and dietary diversity among farmer households. A systematic review examining evidence of the relationship between crop diversity and dietary diversity in low- and middle-income countries concluded that there is a clear and consistent association between agricultural biodiversity and farmer household dietary diversity, however, the magnitude of this association was small (Jones 2017a). On the other hand, other studies, including one meta-analysis, have found that the positive association between crop diversity and dietary diversity is not always present in smallholder farming systems, and when present the magnitude is small (Sibhatu et al. 2015; Sibhatu and Qaim 2018). Higher crop diversity may provide farmer households with access to a wider range of food items produced on their own farm, as well as opportunities to cultivate cash crops, which may indirectly influence dietary diversity through increased income. Although increasing incomes have been shown to improve dietary diversity (Bhagowalia et al. 2012; Doan 2014; Dillon et al. 2014), little work has been done to understand how diversifying farmer household income may influence dietary diversity (Benfica and Kilic 2016). Yet, understanding this relationship is critical given that farmers are increasingly diversifying their income sources across the developing world (Haggblade 2007; Davis et al. 2010; Winters et al. 2010; Davis et al. 2014, 2017).

Thus, to better understand the implications of changes in cropping patterns and income sources on dietary diversity among farmer households, we examine the association between crop and income diversity and intra-household dietary diversity among farmer households in two Indian states, Gujarat and Haryana, which are currently on two different livelihood transition pathways. Farmers in Gujarat have transitioned to planting a large diversity of high value cash crops including castor, tobacco, fennel and cumin. On the other hand, farmers in Haryana specialize in India's main staple crops, rice and wheat. In addition, both regions are better developed than most agricultural regions in India and allow ample opportunities for farmer households to pursue additional income sources including salaried professions and owning small businesses. While these two states are relatively prosperous, they have high rates of malnutrition. Nearly 30% of children in rural Gujarat and Haryana are stunted, wasted, or underweight, and nearly 60% of women are anemic (Raykar et al. 2015; IIPS 2017). Thus, to better understand the association between crop and income diversity and farmer intra-household dietary diversity, Haryana and Gujarat offer an ideal case study as they represent different livelihood transition pathways for farmer households in India where there are still high rates of malnutrition. Specifically, this study investigates the following questions:

1. How are crop and income diversity associated with dietary diversity among men, women, adolescents, and children among farmer households in Gujarat and Haryana?
2. Which agricultural and socio-economic factors (e.g., crop diversity, income diversity, family education, annual income, distance traveled to markets) have the largest associations with individual (male, female, adolescent, and child) dietary diversity?
3. How does intra-household nutritional equity between men and women vary based on these socio-economic factors?

Through this study, we aim to understand how crop and income diversity is associated with intra-household dietary diversity among farmer households in India. While our data are cross-sectional and only examine the associations between crop and income diversity and dietary diversity at one time step, this work has important implications for understanding how crop specialization and increased income diversity may affect intra-household dietary diversity. This is of critical importance given that India has some of the highest malnutrition rates worldwide and these changes are becoming more widespread across the country as farming communities become better integrated with markets (Van de Walle 2002; Hettige 2006; Baquedano et al. 2011). More importantly, two (Bhagowalia et al. 2012; Kavitha et al. 2016) out of total three studies conducted in India to date (Bhagowalia et al. 2012; Chinnadurai et al. 2016; Kavitha et al. 2016) found a positive association between crop diversity and household dietary diversity. However, these studies used household data (Household Dietary Diversity Score-HDDS) whereas our study used intra-household data facilitating investigations at individual levels within a farmer household using Dietary Diversity Scores (DDS). The results from this study can help identify potential strategies and food policy interventions that may improve dietary diversity in a critically malnourished region like India.

In this paper, we found that crop diversity had a positive association with dietary diversity among adults (both men and women) in both states, and among adolescents and children in Haryana. In addition, higher family education and annual income were the two most important factors associated with higher dietary diversity score (DDS) in Gujarat whereas, higher family education, greater crop diversity, and increased distance traveled to markets were the most important factors associated with higher individual DDS in Haryana. To sample farmer households in Gujarat and Haryana, we used a rigorous sampling methodology (Section 2). The results section (Section 3) explains major descriptive statistics on farming systems in both states and outlines major statistical analyses elaborating the regression results related to associations between agricultural and socioeconomic factors and individual dietary diversity scores in Gujarat and Haryana. The discussion section (Section 4) describes our major findings, their relevance to current literature, and outlines the major limitations of this study. Finally, Section 5 concludes the major findings and outlines the relevant policy implications of improving dietary diversity among farmer communities in India.

2 Material and methods

2.1 Study locations and sampling methodology

Two Indian states, Gujarat and Haryana (Fig. 1), were selected because secondary data (Saha 2013; MoA 2014a, b; http://www.esaharyana.gov.in; http://www.dag.gujarat.gov.in) suggested that these states vary in terms of crop, farm, and income diversity. Since we were interested in examining the association between crop and income diversity and farmer intra-household dietary diversity, we sampled farmers across a gradient of low to high crop and income diversity.

To identify appropriate regions across this gradient, we used secondary data on crops grown, livestock owned, income generated, and household education from Indian census statistics. Specifically, we constructed an index that was adapted from Singh and Benbi's (2016) 'Farming Intensity Index.' To capture variation in crop diversity, we calculated the crop diversity index (CDI; Section 2.3) for each district using data on area under each crop type (Table S1). To capture variation in income diversity, we constructed an index that considered crop diversity (e.g., crop diversity index), farm diversity (e.g., per capita livestock and per capita poultry), farm income (e.g., total cropped area divided by percent of total land area, which is a measure of cropland extent), and household education (e.g., rural literacy). Then, we standardized and took a weighted average of each of these five variables by their relative importance to this study, 0.5 (crop diversity), 0.15 (livestock population/person), 0.15 (poultry population/person), 0.10 (% rural literacy), and 0.10 (% cropped area). Based on these indices, three districts were selected in each state (Fig. 1); specifically, we selected one district that had an index value close to the state average, one district that had one of the highest index values, and one district that had one of the lowest index values within each state. Geography of the state was also considered so that the selected districts were spread across the state and were not adjoining one another.

We used the same methodology to select blocks within each of these three districts in Gujarat and Haryana (Tables S3 and S4). As secondary data at the village level were unavailable, we did not select villages a priori and instead three sets of villages within each block were randomly selected in the field. We stratified these sets of villages to include one set that was close to a city, one set that was close to a highway, and one set that was far from both a city and a highway (Fig. 2). We did this to ensure a range in income diversity given that rural households are more likely to take part in non-agricultural livelihoods, such as salaried professions, if they are closer to cities where these jobs are typically offered.

Each village set included two to three adjoining villages. Within each village set, approximately 30 farmer households were selected randomly using purposive sampling. We targeted those farmer households where all three members, one male, one female, and one adolescent or child, were available at the time of survey. We focused on farming families since we were interested in understanding how diversity of crops grown on farm was associated with farmer dietary diversity. These farm families varied in general livelihood portfolio, with some families earning their livelihood solely from farming while others earned income from a wide range of occupations. In the case of large joint families, members engaged directly in farming and their children were preferred to participate over others who did not live within the village or more frequently traveled to cities for work or study. Surveys were conducted by visiting the selected farm households at their home. Within each household, we selected one adult male (head of the household, > 18 years of age), one adult female (the primary food preparer, > 18 years of age), and one adolescent (> 5 and < 18 years of age) or child (< 5 years of age) of any gender. Adolescents and children were selected randomly out of the available family members at the time of survey. This resulted in a total of 3318 respondents across 1106 households in both states.

2.2 Survey data collection

Separate structured survey schedules were prepared for men, women, adolescents, and children, and data were collected

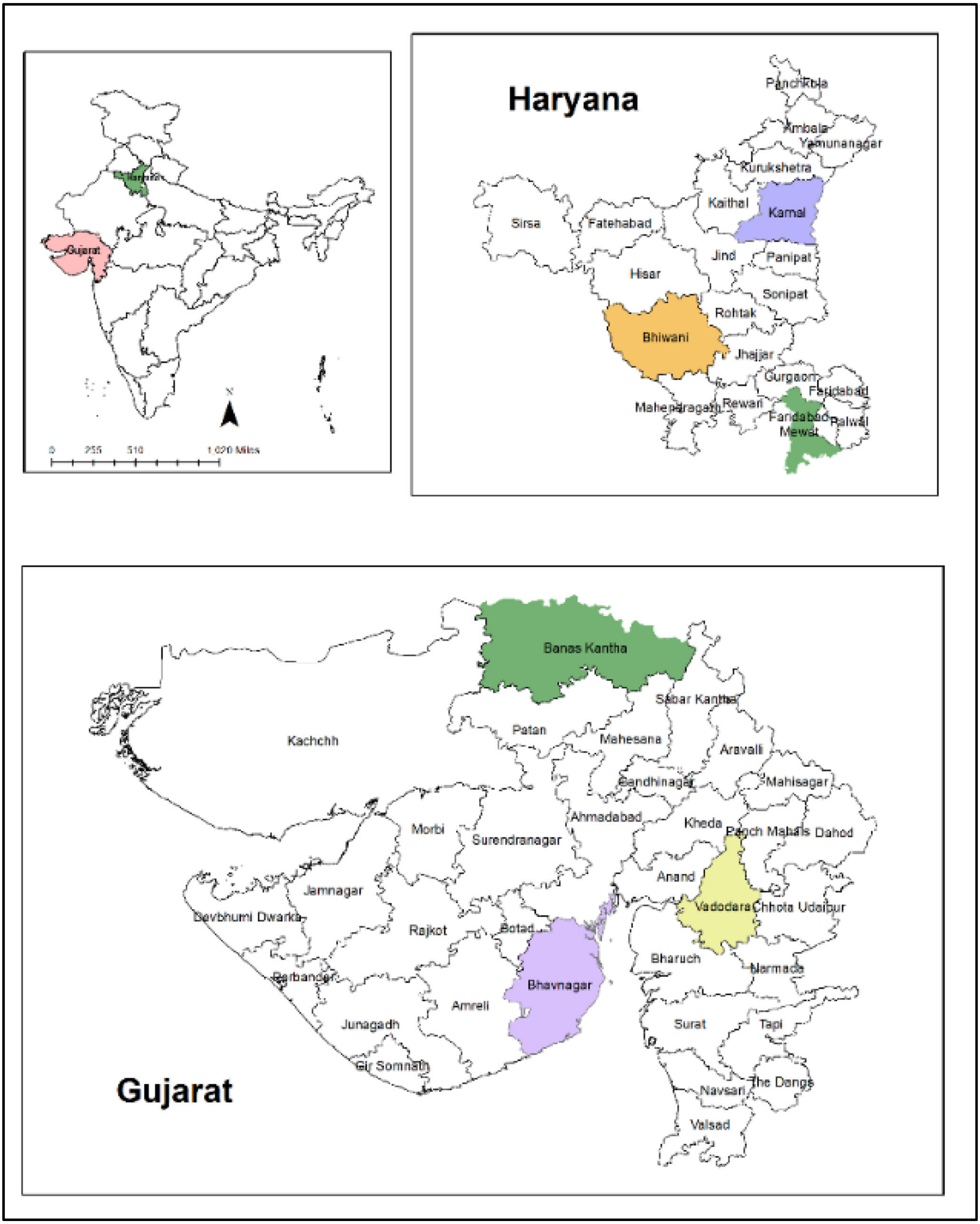

Fig. 1 A map of states, districts and blocks selected for this study in India

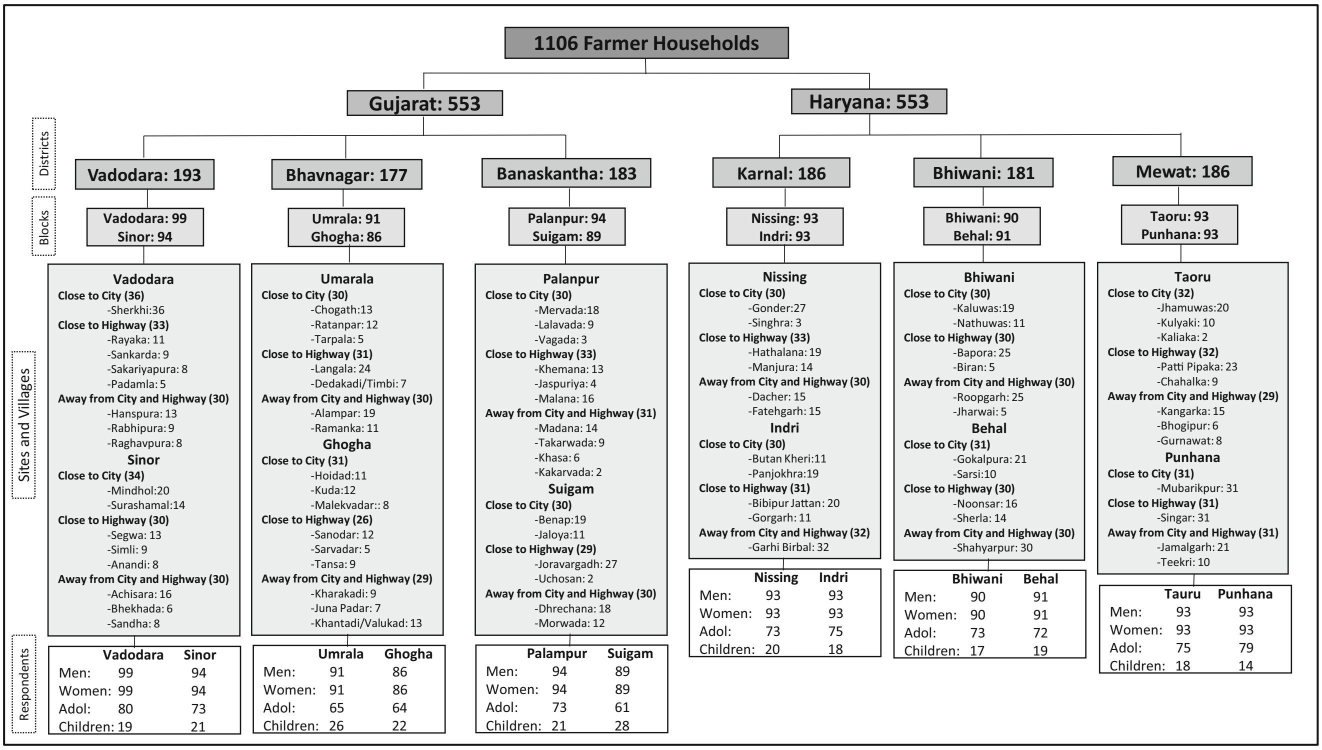

Fig. 2 Sample distribution showing number of farmer households surveyed in each block and district in Gujarat and Haryana

using a mobile-based application. Two separate teams of five female enumerators conducted the surveys in each state during May–June 2017. Data related to crops grown, farm related activities, income sources, demographic information, and food intake (24-h recall) were collected from one male, one female, and one adolescent or child in each household. Visits to villages were not systematically timed in any way, and we surveyed a given village based on availability of the field team. The day of the week that a given village was visited may have influenced dietary information collected using 24-h recall methods if local village markets were not available every day of the week. However, we do not believe that this resulted in any systematic bias in our analyses given that the day of the week in which we visited a village was random relative to the availability of local village markets. This survey was reviewed and approved by the Institution Review Board (IRB Approval Number: IRB00000246).

2.3 Metrics constructed

Below we have included the description and formulas for all metrics considered in this study:

Crop diversification index The Crop Diversification Index (CDI) was calculated for each farmer household surveyed using the 1-H formula, where H is Hirschman-Herfindahl Index (HHI) measured as:

$$H = \sum_{i=1}^{N} S_i^2$$

where

N is the total number of crops during 2016–17,

S_i represents area proportion of the i-th crop in total cropped area.

H takes a value of 1 when there is a monoculture and approaches zero with increasing diversity. Therefore, when using 1-H, a larger number indicates greater crop diversity (Singh and Benbi 2016). The CDI was calculated using all crops grown during the whole year.

Income diversity index The Income Diversity Index (IDI) was calculated using the percentage of family income from different farm and non-farm sources such as crop production, non-crop activities e.g. dairy, poultry, bee-keeping etc., business, government or private employment and the 1-H formula. The households with the most diversified income had the largest IDI. We believe that asking farmers the percent of income that comes from each source, as opposed to total income, leads to more reliable self-reports of income as most farmers do not maintain income and expenditure accounts; furthermore, in some cases, farmers may not want to disclose their non-farming income sources because non-farming income is taxable in India. We base this belief on our in-depth knowledge from the field and from discussions with farmers.

Family education index The Family Education Index (FEI) for each farmer household was calculated by adding the education level of all adults and adolescents in a household and dividing the resulting value by the number of all adults and adolescents. We preferred to take the average level of education of all adults and adolescents, as opposed to the maximum level of education, within a given household because, based on our experience in the field, household diets are influenced by multiple family members and not just the most educated household member.

Dietary Diversity Score (DDS) for adults and adolescents As defined by the FAO (2016), ten food groups reflecting the micronutrient adequacy of women's diets were used to measure individual-level dietary diversity of males, females and adolescents. In the absence of validated indicators of dietary diversity for men or adolescents, we used the food groups underlying the Minimum Dietary Diversity for Women (MDD-W), an indicator specifically recommended for assessing the diversity of diets of women and adolescent girls of reproductive age. Each of the three respondents (male, female, adolescent) were asked if he/she had consumed a food item from each of the listed groups within the last 24 h. These 10 food groups were: 1) grains, white roots and tubers, and plantains; 2) pulses: beans, peas and lentils; 3) nuts and seeds; 4) dairy; 5) meat, poultry and fish; 6) eggs; 7) dark green leafy vegetables; 8) other vitamin A-rich fruits and vegetables; 9) other vegetables; 10) other fruits. The dietary diversity score (DDS) is a continuous score between 0 and 10 for each of the respondents. The DDSs were also converted into categorical variables that represented whether a given respondent was meeting the minimum diversity score (minimum five food groups) as defined by the FAO (2016).

Dietary Diversity Score (DDS) for children The WHO calculates DDS differently for children, considering only seven food groups instead of ten (WHO 2008). The seven groups were: 1) grains, roots and tubers; 2) legumes and nuts; 3) dairy products (milk, yogurt, cheese); 4) flesh foods (meat, fish, poultry and liver/organ meats); 5) eggs; 6) vitamin-A rich fruits and vegetables; 7) other fruits and vegetables. In this case, the DDS was a continuous score between zero and seven for each of the children. The DDSs were also converted into categorical variables that represented whether a given child was meeting the minimum diversity score (a minimum of four food groups) as defined by the WHO (2008).

Difference in male DDS and female DDS (DDDS) We calculated this variable by subtracting the male DDS from the female DDS within the same farmer household to further investigate potential within-household gender disparities in diet quality.

2.4 Framework to examine associations

We ran regressions to examine the associations between various crop, income and socioeconomic factors and dietary diversity among men, women, adolescents and children in a farmer household in India. In our regressions, we included study site type (e.g. close to city, close to highway, away from city and highway) as controls, and district or block fixed effects (Fig. 3).

In these regressions, we used the following independent variables:

Crop Diversity Index (CDI) Crop diversity (CDI) is one of the main variables of interest in our study given that many Indian farmer households are transitioning to lower diversity farms (Saha 2013; MoA 2014a). In addition, many previous studies (Sibhatu et al. 2015; Jones 2017a; Koppmair et al. 2017; Sibhatu and Qaim 2018) have found a significant association between crop diversity and dietary diversity.

Crop groups (presence/absence) To better understand the mechanisms underlying the potential relationship between crop diversity and dietary diversity, we examine which specific crop groups, including cash crops, vegetables, and/or pulses, are associated with dietary diversity. We focus on these three specific crop groups because previous work has shown that cash crop production (Sibhatu et al. 2015), vegetable production (Ochieng et al. 2017), and pulse production (Murendo et al. 2018) are associated with improved dietary diversity.

Income Diversity Index (IDI) and Per Capita Annual Income (PCAI) Income diversity (IDI) is also one of the main factors of interest in our study, given that farming households in India are transitioning to more diverse livelihood portfolios (Haggblade 2007; Davis et al. 2010; Winters et al. 2010; Davis et al. 2014, 2017). As previous studies (Etea et al. 2019; Babatunde and Qaim 2010) have suggested that diversified income portfolios may influence household food security and nutrition, we examined whether IDI was associated with dietary diversity in our study. We also wanted to include household per capita income (in INR) since previous studies have shown that higher incomes are associated with improved dietary diversity (Benfica and Kilic 2016; Bhagowalia et al. 2012; Doan 2014; Dillon et al. 2014).

Family Education Index (FEI) Previous studies have found that household education is one of the most important factors influencing household dietary diversity (Ruel et al. 1992; Kabubo-Mariara et al. 2009; Snapp and Fisher 2015; Alderman and Headey 2017; Ochieng et al. 2017), and we therefore include household education as a control variable in our regressions.

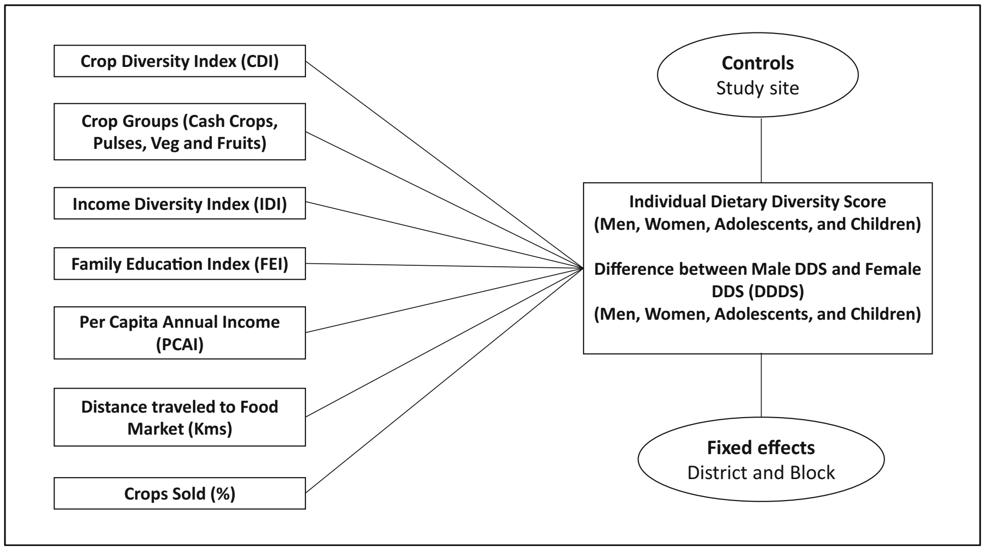

Fig. 3 Framework showing independent variables, controls and fixed effects used in regressions

Distance traveled to Food Markets (Kms) Previous studies have found that improved market access is associated with higher dietary diversity (Jones et al. 2014; Koppmair et al. 2017). We therefore wanted to include market access as a control factor in our study. We used average distance traveled by farmers to markets for vegetables, fruits, and pulses as a proxy for market access.

Crops sold (%) Since most farmers in Gujarat and Haryana sell some part of their agricultural production to markets (Table S5) and this increased income may improve dietary diversity (Benfica and Kilic 2016; Bhagowalia et al. 2012; Doan 2014; Dillon et al. 2014), we included the average percent of crops sold to the market for each farmer in our analysis.

2.5 Statistical models

We first tabulated descriptive statistics of all of our variables of interest across each district and state to understand the variation in our variables across study sites. We then ran a series of regressions to identify the associations between crop and income diversity, socio-economic factors, and dietary diversity. Linear regressions in R Project Software were used for all analyses. All continuous independent variables were normalized by mean and standard deviation to make coefficient values comparable across all independent variables. We calculated variable inflation factors (VIFs) for each regression and found no evidence of multi-collinearity (VIF < 1.2). To reduce the effect of location on our results, we included district fixed effects in all regressions and also included block fixed effects as a robustness check in supplementary tables. The relative importance of all of the independent variables used in each regression was assessed using the relaimpo package in R.

Specifically, we ran five separate linear regressions for each of our dependent variables of interest (Male DDS, Female DDS, Adolescent DDS, Child DDS, and Difference between Male DDS and Female DDS-DDDS). We conducted two regressions for each of the two dependent variables, e.g. Crop Diversity Index (CDI), or growing of crop groups (e.g. cash crops, pulses, vegetables and fruits) as independent factors.

3 Results

3.1 Descriptive results

Socio-economic profile Most male and female respondents did not pass the 10th Standard (secondary school education). In Haryana, 92% of family members in a given household were engaged in farming whereas, in Gujarat, the respective number was only 83%, which suggests that rural households in Gujarat may explore more non-farming career opportunities. More than 60% of farmer households in Gujarat were engaged in dairy farming as compared to only 12% in Haryana. Farmer engagement in other secondary occupations like poultry was negligible. Mean annual self-reported household income from all sources in Gujarat ($2655) was more than 5 times higher than in Haryana ($514). Lower average incomes in Haryana could occur because the crops they grow (e.g. wheat and rice) are largely non-cash crops and are purchased by government agencies at a minimum support price (MSP), which is a government policy that ensures a minimum price for 24 major crops across India (Aditya et al. 2017). These differences may also be due to inaccurate self-reports of income across both states, with more farmers underreporting income in Haryana or overreporting income in Gujarat.

Cropping patterns The majority of farmers (95%) in both states cultivated less than 10 ha (ha) of land, and 65% of farmers in Haryana and 51% of farmers in Gujarat had 2 ha or less of land (Table S5). Although farmers in Haryana (Table S5) cultivated smaller landholding sizes (2.1 ha) than in Gujarat (3 ha), they grew a greater number of crops in a given year (3.6 crops v/s 1.2 crops). Farmers in Haryana had higher CDI when compared to farmers in Gujarat (0.62 v/s 0.49). Farmers were more likely to plant cash crops in Gujarat including castor, cotton, tobacco, fennel, and cumin whereas, farmers in Haryana planted more staple crops, such as wheat and rice, which are supported by the MSP. In terms of income diversity, farmers in Gujarat had more diversified income portfolios than in Haryana (0.36 v/s 0.17). Considering market integration for purchasing food, farmers in Gujarat traveled on average 6 Kms, compared to 3 Kms in Haryana.

Individual dietary diversity scores Individual DDS scores in Gujarat (Table 1) were greater than in Haryana. Considering the standard cutoffs for dietary diversity (FAO 2016; WHO 2008), only one-third of adults and children (male: 34%; female: 33%; adolescent: 36%; child: 40%) surveyed across both states met the minimum dietary diversity score cutoffs. Considering each state independently, only 8–10% of men, women and adolescents, and 21% of children in Haryana met minimum dietary diversity scores. In Gujarat, 57%, 59%, 65%, and 57% of males, females, adolescents and children respectively were able to meet minimum diversity scores.

Consumption of different food groups Considering the consumption of different food groups, all men, women, and adolescents surveyed across both states consumed grains, white roots and tubers, and plantains (Table 1). Around three-fourths of men, women and adolescents in Gujarat ate pulses, beans, peas and lentils while the respective figures were much lower in Haryana (43–44%). Dairy products were equally popular among farmer households in both states. However, nut, meat and egg consumption was limited to 1–5% of the respondents in each state. Only 13–15% of men, women and adolescents in Gujarat ate dark-green leafy vegetables while the percent of people eating leafy greens in Haryana was 7–8%. Nearly two-thirds of men, women and adolescents in Gujarat ate vitamin A-rich fruits and vegetables whereas, in Haryana, only one-fourth of respondents consumed this food group. Similarly, over 80% of men, women and adolescents reported eating other vegetables in Gujarat, whereas that number was only 44–48% in Haryana. Consumption of fruits was also greater in Gujarat (34–42%) than in Haryana (15–20%). With respect to the composition of the daily diet of children, 84% and 95% of children surveyed across both states consumed grains, roots and tubers, and dairy products (such as milk, yogurt, cheese), respectively. Children consumed more legumes and nuts in Gujarat (57%) than in Haryana (29%). Nearly 60% of child diets in Gujarat had some type of fruit and vegetable while only one-third of those in Haryana had meals having fruits and vegetables. However, flesh and eggs were limited to only 1–2% of children across both states. It is important to note that farmer households were selected randomly without stratifying across vegetarian v/s non-vegetarian households.

Intra-household dietary diversity equity When considering intra-household dietary diversity equity between men and women, the average male DDS (Adult) was 2.06 units higher than female DDS across two states. State-wise, this gender-based difference was higher in Haryana (2.76 units) than in Gujarat (1.36 units).

3.2 Statistical analyses

3.2.1 Dietary diversity scores

Male dietary diversity Although income diversity (IDI) had no association with Male DDS in either state (Table 2), farmers growing more crops (i.e. with higher CDI) in a given year had higher DDS in both Gujarat ($p < 0.05$) and Haryana ($p < 0.01$). The proportion of crops sold to markets and annual income were significant drivers of male DDS in Gujarat ($p < 0.05$). Annual income was also associated with male DDS in Haryana though the significance level was low ($p < 0.10$). Considering specific crop groups, farmers households in Gujarat who were growing cash crops ($p < 0.01$), and vegetable and fruits ($p < 0.10$) had a higher male DDS whereas cash crops ($p < 0.5$) and pulses ($p < 0.01$) were significantly associated with male DDS in Haryana. Family education (FEI) was a significant factor affecting male DDS in both states, although these relationships were stronger in Haryana ($p < 0.01$) when compared to Gujarat ($p < 0.5$). Distance traveled to food markets was significantly associated with male DDS in Haryana only ($p < 0.5$).

All regressions were run with block fixed effects as a robustness check (Table S6). In Haryana, the results remained similar across all variables except for distance traveled to food markets where the significance level became smaller ($p < 0.05$) with block fixed effects. In Gujarat, the significance level became smaller for cash crops ($p < 0.05$), and per capita annual income ($p < 0.10$) and the coefficients for family education, and crops sold (%) became insignificant with block fixed effects.

Female dietary diversity Higher crop diversity was associated with higher female DDS in both states (Gujarat: $p < 0.05$; Haryana: $p < 0.01$). Growing cash crops and pulses ($p < 0.01$) in Haryana was associated with higher female DDS whereas, in Gujarat, vegetables and fruits ($p < 0.05$) had a significant association with female DDS. Family education (FEI) and annual income were associated with higher

Table 1 Average Dietary Diversity Score (DDS) among men, women, adolescents and children, distribution of men, women, adolescents, and children (%) meeting the standard DDS cutoffs, different food groups consumed (%) by men, women, adolescents and children (24-h recall) among farmer households surveyed in Gujarat and Haryana

Parameter/State	Gujarat	Haryana	Overall
Average Dietary Diversity Score (DDS)			
Men	4.7	3.4	4.1
Women	4.7	3.3	4.0
Adolescents	4.9	3.4	4.1
Children	3.6	2.7	3.2
Number of individuals (%) meeting the dietary diversity cutoffs			
Men	57	10	34
Women	59	8	33
Adolescents	65	9	36
Children	57	21	40
Food Groups Consumed (%): Men			
Food Group 1: Grains, white roots and tubers, and plantains	100	100	100
Food Group 2: Pulses: beans, peas and lentils	73	42	58
Food Group 3: Nuts and seeds	8	4	6
Food Group 4: Dairy	96	93	95
Food Group 5: Meat, poultry and fish	1	5	3
Food Group 6: Eggs	1	2	1
Food Group 7: Dark green leafy vegetables	15	7	11
Food Group 8: Other Vitamin A-rich fruits and vegetables	62	23	43
Food Group 9: Other vegetables	82	48	65
Food Group 10: Other fruits	34	17	25
Food Groups Consumed (%): Women			
Food Group 1: Grains, white roots and tubers, and plantains	100	100	100
Food Group 2: Pulses: beans, peas and lentils	71	44	57
Food Group 3: Nuts and seeds	8	3	5
Food Group 4: Dairy	97	91	94
Food Group 5: Meat, poultry and fish	0	4	2
Food Group 6: Eggs	1	1	1
Food Group 7: Dark green leafy vegetables	15	8	11
Food Group 8: Other Vitamin A-rich fruits and vegetables	62	22	42
Food Group 9: Other vegetables	84	45	64
Food Group 10: Other fruits	39	15	26
Food Groups consumed (%): Adolescents			
Food Group 1: Grains, white roots and tubers, and plantains	100	100	100
Food Group 2: Pulses: beans, peas and lentils	74	44	58
Food Group 3: Nuts and seeds	9	5	7
Food Group 4: Dairy	96	90	93
Food Group 5: Meat, poultry and fish	1	4	2
Food Group 6: Eggs	1	2	1
Food Group 7: Dark green leafy vegetables	13	7	10
Food Group 8: Other Vitamin A-rich fruits and vegetables	66	23	44
Food Group 9: Other vegetables	88	44	65
Food Group 10: Other fruits	42	20	31
Food Groups consumed (%): Children			
Food Group 1: Grains, roots and tubers	88	79	84
Food Group 2: Legumes and nuts	57	29	45
Food Group 3: Dairy products (milk, yogurt, cheese)	94	95	95
Food Group 4: flesh foods (meat, fish, poultry and liver/organ meats)	2	0	1
Food Group 5: Eggs	2	2	2
Food Group 6: Vitamin-A rich fruits and vegetables	61	33	48
Food Group 7: Other fruits and vegetables	60	32	47
Difference in Mean DDS between Male and Female (DDDS)			
Adult	1.36	2.76	2.06
Adolescent	0.06	0.04	−0.10
Child	0.04	0.11	0.05

female DDS in both states although their significance was relatively stronger in Haryana. Distance traveled to food markets was significantly associated with female DDS in Haryana ($p < 0.05$) whereas proportion of crops sold to the market was important for female DDS in Gujarat ($p < 0.10$). These regressions were run with block fixed effects as a robustness check (Table S7) and the results remained similar across all variables in Haryana. In Gujarat, family education, and per capita

Table 2 Regression results showing the agricultural and socio-economic factors affecting the Dietary Diversity Score (DDS) among Men in Gujarat and Haryana with district fixed-effects

Dietary Diversity Score (Male)				
	Gujarat		Haryana	
	CDI	Crop Groups	CDI	Crop Groups
Crop Diversity Index (CDI)	0.081**		0.225***	
	(0.033)		(0.076)	
Cash Crops#		0.289***		0.195**
		(0.105)		(0.094)
Pulses#		−0.086		0.297***
		(0.080)		(0.091)
Veg and Fruits#		0.143*		0.128
		(0.085)		(0.117)
Income Diversity Index (IDI)	−0.055	−0.037	0.002	−0.009
	(0.045)	(0.045)	(0.035)	(0.035)
Family Education Index (FEI)	0.093**	0.089**	0.100***	0.104***
	(0.044)	(0.044)	(0.036)	(0.035)
Per Capita Annual Income (PCAI)	0.069**	0.065**	0.241*	0.204
	(0.030)	(0.030)	(0.141)	(0.141)
Distance traveled to Food Markets (Kms)	0.043	0.044	0.137**	0.152***
	(0.032)	(0.032)	(0.057)	(0.057)
Crops Sold (%)	0.081**	0.008	−0.031	−0.028
	(0.035)	(0.039)	(0.043)	(0.046)
Site-Close to City	0.009	−0.023	0.090	0.104
	(0.092)	(0.091)	(0.084)	(0.084)
Site-Close to Highway	0.067	0.029	−0.018	−0.002
	(0.091)	(0.092)	(0.082)	(0.082)
Observations	547	547	548	548
R^2	0.147	0.157	0.080	0.096
Adjusted R^2	0.131	0.138	0.063	0.075
Residual Std. Error	0.853	0.850	0.774	0.769
Sample Size (*n*)	537	535	538	536
District Fixed Effects	Y	Y	Y	Y

CDI represents a regression that includes CDI as an independent variable, and Crop Group represents a regression that includes individual crop groups as an independent variable

Significance codes $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

represents crop groups

annual income became insignificant with block fixed effects (Table 3).

Adolescent dietary diversity Dietary diversity among adolescents (Table 4) was strongly and positively associated with crop diversity (CDI) in Haryana ($p < 0.05$). Cash crops ($p < 0.05$) and pulses ($p < 0.10$) had a significant association with adolescent DDS in both states although in the case of pulses in Gujarat, this association was negative ($p < 0.01$). Growing of vegetable and fruits was significantly associated with DDS among adolescents in Haryana ($p < 0.05$). Family education (FEI) was associated with higher adolescent DDS in both the states though with higher significance levels in Gujarat. Farmer households with higher annual income in Gujarat ($p < 0.10$), and those that traveled farther distances to purchase food in Haryana ($p < 0.10$) were associated with higher adolescent DDS. Further, dietary diversity was not associated with gender of the adolescent in either state.

As a robustness check (Table S8), the regressions in Table 4 were run with block fixed effects and the results remained similar across all variables in Haryana, except for crop diversity (CDI) and family education (FEI) where the significance

Table 3 Regression results showing the agricultural and socio-economic factors affecting the Dietary Diversity Score (DDS) among Women in Gujarat and Haryana with district fixed-effects

Dietary Diversity Score (Female)				
	Gujarat		Haryana	
	CDI	Crop Groups	CDI	Crop Groups
Crop Diversity Index (CDI)	0.085**		0.226***	
	(0.034)		(0.067)	
Cash Crops#		0.075		0.274***
		(0.109)		(0.081)
Pulses#		−0.100		0.325***
		(0.082)		(0.079)
Veg and Fruits#		0.183**		0.050
		(0.088)		(0.101)
Income Diversity Index (IDI)	−0.024	−0.014	0.019	0.010
	(0.047)	(0.047)	(0.031)	(0.030)
Family Education Index (FEI)	0.116**	0.127***	0.108***	0.109***
	(0.046)	(0.046)	(0.031)	(0.031)
Per Capita Annual Income (PCAI)	0.059*	0.059*	0.295**	0.245**
	(0.031)	(0.031)	(0.123)	(0.122)
Distance traveled to Food Markets (Kms)	0.029	0.027	0.127**	0.143***
	(0.033)	(0.033)	(0.050)	(0.049)
Crops Sold (%)	0.061*	0.025	−0.029	−0.029
	(0.036)	(0.040)	(0.037)	(0.040)
Site-Close to City	0.0003	−0.035	0.086	0.099
	(0.094)	(0.094)	(0.073)	(0.073)
Site-Close to Highway	−0.083	−0.105	0.083	0.104
	(0.094)	(0.096)	(0.072)	(0.071)
Observations	547	547	548	548
R^2	0.137	0.137	0.082	0.115
Adjusted R^2	0.121	0.118	0.064	0.095
Residual Std. Error	0.877	0.879	0.676	0.665
Sample Size (*n*)	537	535	538	536
District Fixed Effects	Y	Y	Y	Y

CDI represents a regression that includes CDI as an independent variable, and Crop Group represents a regression that includes individual crop groups as an independent variable

Significance codes * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

represents crop groups

level became smaller ($p < 0.05$) with block fixed effects. In Gujarat, the level of significance remained similar except for cash crops ($p < 0.10$) and family education ($p < 0.10$) where the p values became larger.

Child dietary diversity Farmer households with higher crop diversity were associated with higher child DDS in Haryana (Table 5). No specific crops, except cash crops in Haryana, were associated with increased child DDS ($p < 0.05$). Distance traveled to purchase food was positively associated with DDS among children in Haryana. Family education and gender have no significant association with child DDS in either state.

As a robustness check (Table S9), these regressions were run with block fixed effects. The results remained similar across all variables in Haryana though with stronger significance levels for crop diversity and cash crops ($p < 0.01$). In Gujarat, CDI and family education are significantly associated with child DDS ($p < 0.05$). As a robustness check (Table S9), the association between family education and child DDS in Gujarat became negatively significant when regressions were run with block fixed effects. For Haryana, the regression results remained intact with block fixed effects.

Additionally, as the mother is mainly responsible for dietary requirements of their children (adolescents and children),

Table 4 Regression results showing the agricultural and socio-economic factors affecting the Dietary Diversity Score (DDS) among Adolescents in Gujarat and Haryana with district fixed-effects

Dietary Diversity Score (Adolescent)	Gujarat		Haryana	
	CDI	Crop Groups	CDI	Crop Groups
Crop Diversity Index (CDI)	0.046		0.196***	
	(0.038)		(0.074)	
Cash Crops#		0.248**		0.194**
		(0.120)		(0.092)
Pulses#		−0.271***		0.160*
		(0.092)		(0.092)
Veg and Fruits#		0.102		0.244**
		(0.097)		(0.118)
Income Diversity Index (IDI)	0.017	0.033	0.028	0.020
	(0.052)	(0.051)	(0.036)	(0.035)
Family Education Index (FEI)	0.166***	0.154***	0.071**	0.076**
	(0.057)	(0.056)	(0.036)	(0.036)
Gender	−0.039	−0.033	−0.029	−0.018
	(0.085)	(0.084)	(0.069)	(0.068)
Per Capita Annual Income (PCAI)	0.065*	0.063*	0.141	0.138
	(0.033)	(0.033)	(0.131)	(0.131)
Distance traveled to Food Markets (Kms)	0.008	0.015	0.108*	0.125**
	(0.038)	(0.038)	(0.057)	(0.057)
Crops Sold (%)	−0.003	−0.052	−0.067	−0.086*
	(0.040)	(0.045)	(0.042)	(0.047)
Site-Close to City	0.048	−0.007	0.054	0.060
	(0.106)	(0.104)	(0.084)	(0.084)
Site-Close to Highway	0.121	0.046	−0.098	−0.085
	(0.104)	(0.105)	(0.082)	(0.083)
Observations	410	410	442	442
R^2	0.115	0.143	0.070	0.083
Adjusted R^2	0.090	0.115	0.046	0.055
Residual Std. Error	0.850	0.838	0.691	0.688
Sample Size (*n*)	399	397	431	428
District Fixed Effects	Y	Y	Y	Y

CDI represents a regression that includes CDI as an independent variable, and Crop Group represents a regression that includes individual crop groups as an independent variable

Significance codes * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

represents crop groups

additional regressions (Tables S10 and S11) were run including two additional female variables, female DDS and female Age. Results suggest that female DDS had a strong positive association ($p < 0.01$) with both adolescent and child DDS in both states whereas, female age was significantly associated with child DDS in Haryana only ($p < 0.05$). However, inclusion of these female variables made the relationships with CDI and family education (FEI) insignificant, and weakened other associations, particularly those with crop groups.

3.2.2 Difference between male DDS and female DDS (DDDS)

The DDDS is a difference between male DDS and female DDS within the same farmer household investigating potential gender disparities in diet quality. It was not significantly associated with crop diversity in either state (Table 6). Considering the specific crop groups, production of pulses in Gujarat was significantly associated with higher female DDS relative to male DDS within the same farmer household ($p < 0.05$).

Greater family education in Haryana ($p < 0.05$) and distance traveled to food markets in Gujarat ($p < 0.05$) had a significant association with higher male DDS compared to female DDS. In addition, the distance to cities or highways was associated with higher female DDS compared to male DDS in Haryana.

As a robustness check, the above regressions were run with block fixed effects (Table S12). The results are similar with significance levels decreased for pulses in Haryana ($p < 0.10$) and distance traveled to food markets in Gujarat ($p < 0.10$). Growing of cash crops ($p < 0.10$), and vegetables and fruits ($p < 0.05$) in Gujarat became significant with block fixed effects.

3.3 Factor importance

The relative importance of all agricultural and socio-economic independent factors (Fig. 4) associated with individual dietary

Table 5 Regression results showing the agricultural and socio-economic factors affecting the Dietary Diversity Score (DDS) among Children in Gujarat and Haryana with district fixed-effects

Dietary Diversity Score (Child)	Gujarat		Haryana	
	CDI	Crop Groups	CDI	Crop Groups
Crop Diversity Index (CDI)	0.103		0.521**	
	(0.089)		(0.199)	
Cash Crops#		−0.005		0.582**
		(0.275)		(0.236)
Pulses#		0.052		0.036
		(0.204)		(0.228)
Veg and Fruits#		0.034		0.184
		(0.218)		(0.270)
Income Diversity Index (IDI)	−0.091	−0.080	0.011	−0.019
	(0.122)	(0.124)	(0.079)	(0.082)
Family Education Index (FEI)	−0.117	−0.098	−0.031	−0.013
	(0.094)	(0.095)	(0.087)	(0.090)
Gender	−0.097	−0.111	0.088	0.082
	(0.185)	(0.190)	(0.165)	(0.173)
Per Capita Annual Income (PCAI)	0.077	0.078	0.553	0.788
	(0.091)	(0.093)	(0.515)	(0.539)
Distance traveled to Food Markets (Kms)	−0.012	−0.017	0.362***	0.387***
	(0.078)	(0.079)	(0.136)	(0.139)
Crops Sold (%)	0.042	0.008	0.005	−0.064
	(0.093)	(0.097)	(0.098)	(0.105)
Site-Close to City	−0.264	−0.326	0.030	−0.025
	(0.243)	(0.244)	(0.187)	(0.192)
Site-Close to Highway	−0.127	−0.169	0.011	−0.045
	(0.245)	(0.245)	(0.188)	(0.190)
Observations	137	137	106	106
R^2	0.098	0.089	0.183	0.185
Adjusted R^2	0.018	−0.007	0.088	0.070
Residual Std. Error	1.062	1.075	0.758	0.765
Sample Size (*n*)	126	124	95	93
District Fixed Effects	Y	Y	Y	Y

CDI represents a regression that includes CDI as an independent variable, and Crop Group represents a regression that includes individual crop groups as an independent variable

Significance codes * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

represents crop groups

Table 6 Regression results showing the agricultural and socio-economic factors affecting the Difference in Male DDS and Female DDS (DDDS) in Gujarat and Haryana with district fixed-effects

Difference between Male DDS and Female DDS (DDDS)

	Gujarat		Haryana	
	CDI	Crop Groups	CDI	Crop Groups
Crop Diversity Index (CDI)	0.020		0.106	
	(0.032)		(0.084)	
Cash Crops#		0.136		0.025
		(0.102)		(0.104)
Pulses#		0.017		−0.204**
		(0.077)		(0.102)
Veg and Fruits#		−0.129		0.089
		(0.083)		(0.131)
Income Diversity Index (IDI)	0.038	0.047	−0.036	−0.038
	(0.044)	(0.044)	(0.039)	(0.039)
Family Education Index (FEI)	0.007	0.002	0.083**	0.092**
	(0.043)	(0.043)	(0.040)	(0.039)
Per Capita Annual Income (PCAI)	0.026	0.025	−0.146	−0.095
	(0.029)	(0.029)	(0.155)	(0.157)
Distance traveled to Food Markets (Kms)	0.068**	0.074**	0.090	0.094
	(0.031)	(0.031)	(0.063)	(0.063)
Crops Sold (%)	−0.004	−0.030	−0.046	−0.076
	(0.034)	(0.038)	(0.047)	(0.051)
Site-Close to City	0.112	0.095	−0.174*	−0.190**
	(0.089)	(0.089)	(0.093)	(0.093)
Site-Close to Highway	0.126	0.117	−0.212**	−0.241***
	(0.089)	(0.090)	(0.091)	(0.091)
Observations	547	547	548	548
R^2	0.046	0.053	0.234	0.238
Adjusted R^2	0.028	0.031	0.220	0.221
Residual Std. Error	0.827	0.826	0.857	0.856
Sample Size (*n*)	537	535	538	536
District Fixed Effects	Y	Y	Y	Y

CDI represents a regression that includes CDI as an independent variable, and Crop Group represents a regression that includes individual crop groups as an independent variable

Significance codes * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

represents crop groups

diversity (DDS among men, women, adolescents and children) was assessed.

Family education (FEI) was the most important factor affecting dietary diversity among males and females in Gujarat. In Haryana, distance traveled to food markets and crop diversity (CDI) were the most important variables for male DDS, and family education (FEI), and crop diversity (CDI) were the most important variables associated with female DDS. Per capita income (PCAI) and crops sold (CS) were among the top three most important factors associated with male and female DDS in Gujarat whereas in Haryana, they were among the three least important factors associated with dietary diversity among males and females. Considering adolescent DDS, family education (FEI) was the most important factor in both states. Per capita income in Gujarat and distance traveled to food markets in Haryana, respectively, were the second most important factors explaining female DDS. CDI was the lowest ranked variable in Gujarat, yet it was the third most important factor in Haryana. Distance traveled to food markets (DFM) and annual income (PCAI) were less important for adolescent DDS compared to male and female DDS in both states.

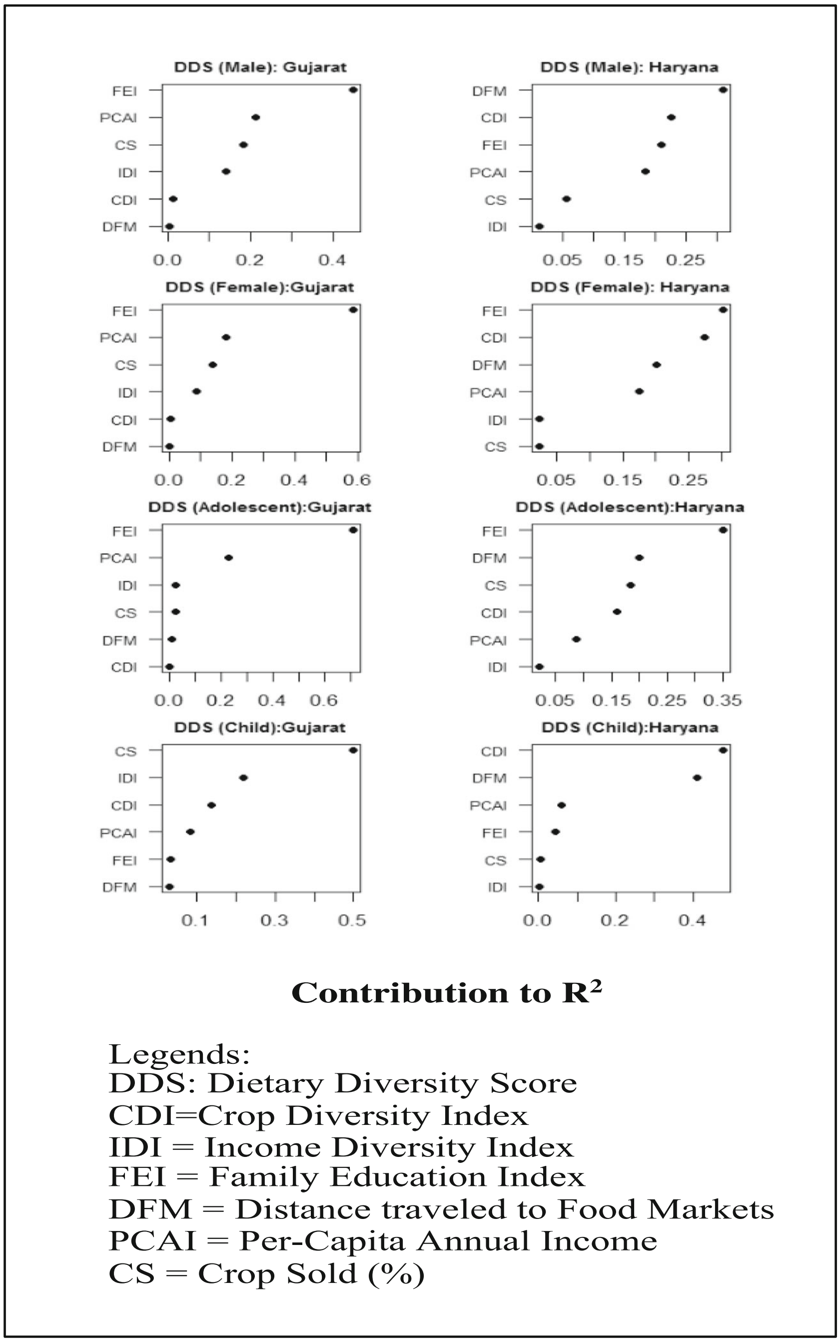

Fig. 4 Relative importance of agricultural and socio-economic factors associated to Dietary Diversity Score (DDS) among men, women, adolescents and children in Gujarat and Haryana

Considering child DDS, variable importance plots are fairly different compared to results for male, female, and adolescent DDS. For instance, family education (FEI), which remained one of the most important factors associated with DDS among male, female and adolescent DDS, is the second least important factor in Gujarat and a mid-ranked factor in Haryana. Crop diversity (CDI) emerged as the first and third most important factor associated with dietary diversity among children in Haryana and Gujarat, respectively. In Gujarat, crop sold (CS) and income diversity (IDI) were the two most important factors explaining child DDS. Distance traveled to food markets (2nd position) and annual income (3rd position) were still important in Haryana.

4 Discussion

In this study, we investigated the association between crop and income diversity and dietary diversity among men, women, adolescents, and children of farmer households using primary data collected from 1106 households across Gujarat and Haryana. We were interested in examining this association to better understand the implications of ongoing agricultural transitions, which include a move towards crop specialization and increased income diversification, on intra-household dietary diversity among farmer households in India. Specifically, we examined whether diversification of cropping systems, as measured as crop diversity (CDI), and income sources, as measured by income diversity (IDI) were associated with intra-household dietary diversity among farmer households. Our results suggest that crop diversity had a positive association with individual dietary diversity among adults (both men and women) in both states, and among adolescents and children in Haryana. In addition, crop diversity was the most and the second most important factor explaining dietary diversity among children and adults, respectively, in Haryana. Overall, we did not find a significant association between IDI and individual DDS in either state, though IDI was the second most important factor explaining variation in child DDS in Gujarat. While our data are cross-sectional and examine the associations between crop and income diversity and dietary diversity at one time step, this work has important implications for understanding how crop specialization and increased income diversity may affect intra-household dietary diversity. Our results broadly suggest that crop specialization in particular may be associated with reduced dietary diversity in farming households of India.

Our finding of a strong and positive association between CDI and individual DDS across both states supports results from the previous literature (Kadiyala et al. 2014; Jones et al. 2014; Kumar et al. 2015; Sibhatu et al. 2015; Snapp and Fisher 2015; Powell et al. 2015; Jones 2017a, b; Powell et al. 2017). A positive association between crop diversity and dietary diversity has been suggested to occur via two possible pathways: (1) by providing a household with a variety of food crops to consume and (2) by providing a variety of crops that can be sold to the market to generate income that is used to purchase a broader variety of foods from markets (Di Falco and Chavas 2009; Njeru 2013; Webb 2013; Makate et al. 2016).

Our results suggest that crop diversity is associated with individual dietary diversity likely through both pathways (Table 7). To better identify how higher CDI may improve dietary diversity via the consumption as well as income pathway, we examined the association between growing different types of crop groups (cash crops, pulses, vegetables and fruits) and dietary diversity. In Haryana, cultivation of pulses was associated with higher male, female, and adolescent DDS. This is particularly interesting given that overall consumption of pulses was much lower in Haryana than in Gujarat (Table 1), and consumption was likely higher for those households that produced pulses on farm. Considering how CDI may influence dietary diversity through the income generation pathway, we found that the cultivation of cash crops was associated with higher dietary diversity among all members of a farmer household in Haryana, and for males and adolescents in Gujarat. It is important to note that farmers who grew cash crops had significantly higher CDI in both the states ($p < 0.0001$). Additionally, selling crops (%) also had a positive association with DDS among men, women in Gujarat. Similar results were found in Indonesia, Kenya, Ethiopia, and Malawi (Sibhatu et al. 2015; Koppmair et al. 2017), where better access to crop selling markets improved diets among farmers. These results suggest that cultivating a variety of crops and being well integrated with markets for selling crops could be catalysts for improving dietary diversity in rural India.

Table 7 A summarized version of four regression tables (Tables 2, 3, 4 and 5) showing independent factors associated with DDS among men, women, adolescents and children, and their level of significance

	DDS (Male)		DDS (Female)		DDS (Adolescent)		DDS (Child)	
	Gujarat	Haryana	Gujarat	Haryana	Gujarat	Haryana	Gujarat	Haryana
Crop Diversity Index (CDI)#	**	***	**	***		***		**
Cash Crops$	***	**		***	**	**		**
Pulses$		***		***	*** (−)	*		
Vegetable and Fruits$	*		**			**		
Family Education Index (FEI)#	**	***	**	***	***	**		
Per Capita Annual Income (PCAI)#	**	*	*	**	*			
Distance traveled to Food Markets#		**		**		*		***
Crops Sold (%)#	**		*					

Significance codes: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$; *** (−) $p < 0.1$ with negative coefficient;

# indicates independent factors having a significant association in the first regression, i.e. with CDI as a dependent factor, in each of the Tables 2, 3, 4, and 5 in Section 3;

$ indicates independent factors having a significant association in the second regression, i.e. with Crop Groups as a dependent factor, in each of the Tables 2, 3, 4, and 5 in Section 3

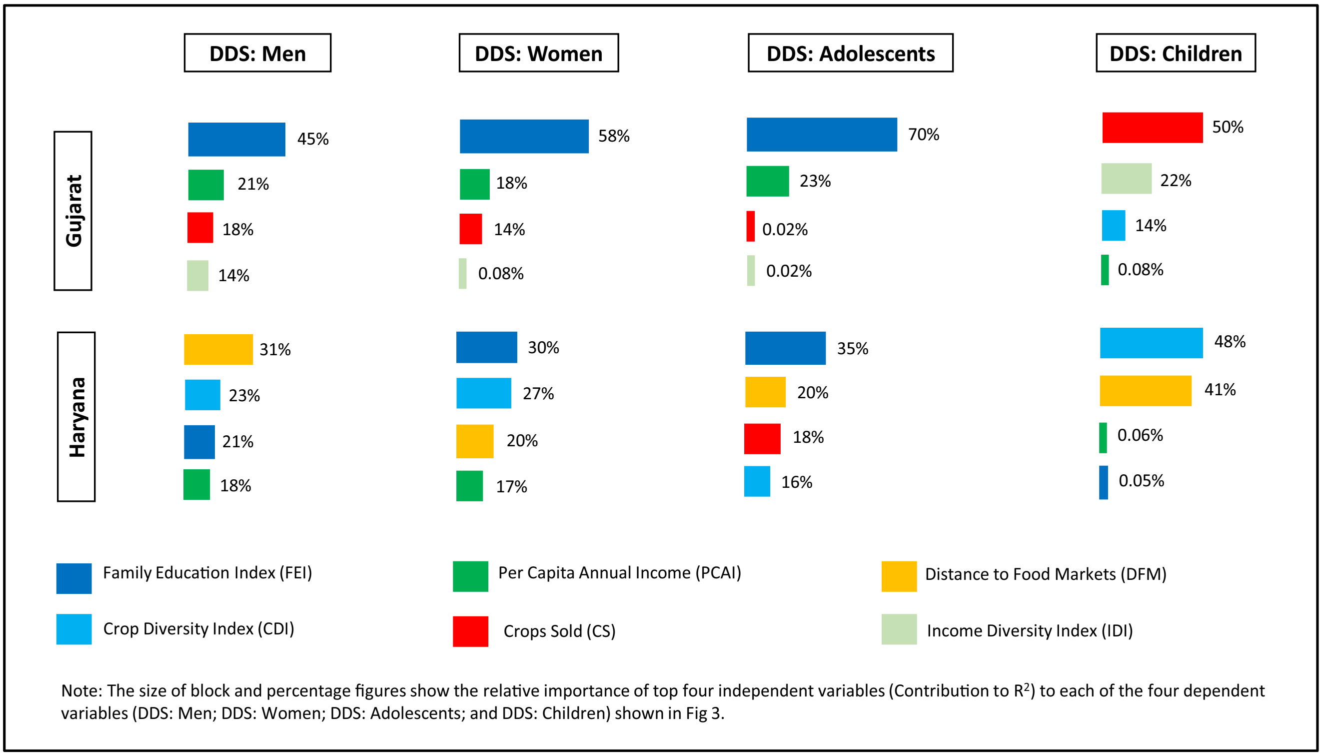

Fig. 5 A summarized chart showing the relative importance of the top four factors associated with DDS among men, women, adolescents and children in Gujarat and Haryana

Considering the relative importance of the main variables of interest considered in our study, crop diversity was the second, fourth, and most important factor explaining adult, adolescent, and child DDS in Haryana, respectively (Fig. 5). In Gujarat, it was the third most important factor associated with child DDS. Regarding income diversity, it was the fourth most important factor for men, women, and adolescents and the second most important factor for children in Gujarat. These results suggest that our two main variables of interest, crop diversity and income diversity, play an important role in explaining variation in DDS, though their relative importance varied between Gujarat and Haryana. In Haryana, CDI was a much more important factor associated with dietary diversity, particularly for children, and in Gujarat income diversification was a more important factor (Fig. 5).

Considering the importance of other variables in our study, family education was a strongly important factor in both Gujarat and Haryana. It was the most important factor for male, female, and adolescent DDS in Gujarat and for female and adolescent DDS in Haryana. Previous studies have suggested that higher levels of education, particularly maternal education (Ruel et al. 1992; Kabubo-Mariara et al. 2009; Snapp and Fisher 2015; Alderman and Headey 2017), have a positive effect on farmer household dietary diversity. In addition, in Gujarat, annual per capita income (PCAI) was the second largest contributor to adult and adolescent dietary diversity whereas income earned from selling crops was the largest contributor to DDS among children. These results suggest that the income pathway to nutrition can play a crucial role in improving dietary diversity among farmer households in Gujarat.

In Haryana, distance traveled to food markets (DFM) was one of the most important factors in explaining all family members' DDS, with farther distances traveled associated with higher dietary diversity. While this result may seem counter-intuitive, it is similar to results from previous studies in India (e.g., Kumar et al. 2016) and may capture the fact that families with diverse diets may have to travel farther distances on average to obtain diverse foods. For example, a limited variety of food items within each food group are typically found in local village markets in Haryana, based on our experience, and individuals who wish to purchase rarer food items, such as dark green leafy vegetables and vitamin A-rich vegetables and fruits, likely travel farther to purchase these items. These results suggest that improving family education, enhancing farm incomes, and expanding local village markets may improve dietary diversity of farmer households in our study.

The available literature suggests that gender inequity exists at many levels and in multiple forms, especially when considering food allotment in India (Aurino 2017;

Tarozzi 2012; Sen 2005; Arokiasamy 2004). Overall, we found that female DDS was on average lower than male DDS within the same household (Table 1) and this is similar to results reported in previous studies (e.g., Nithya and Bhavani 2018). There are several reasons why this may occur. First, the male head of the household is typically the primary earner of income in rural India, resulting in larger control of financial resources (Paul and Meena 2016) that may allow him to buy and consume a wider variety of foods. Second, women in rural India are more likely to follow a vegetarian life-style compared to men (IIPS 2017), and this would likely result in reduced dietary diversity. This can be seen in Table 1 where women on average eat less meat and eggs than their male counterparts. To further understand possible causes of gender disparity, we examined which factors were associated with differences in DDS between men in women within the same household. We found that family education (FEI) was associated with higher female relative to male DDS in Haryana, suggesting that increasing farmer households' education status could be an important pathway to reducing dietary diversity gender disparity in India. In Gujarat, we also found that a reduced distance traveled to food markets (DFM) was associated with higher female DDS relative to male DDS. When we compared dietary diversity between male and female adolescents and children, we found no significant differences in DDS based on gender. It is important to note, however, that this analysis was done comparing male and female children and adolescents across different households, reducing statistical power compared to the analysis of adult DDS that compared males and females within the same household.

There are several limitations to our study and avenues for future research. First, we used the MDD-W (Minimum Dietary Diversity for Women) food groups (FAO 2016) for assessing dietary diversity among men and adolescents. This is because, the current food group standards do not exist for men and/or adolescents, and we suggest that future work should examine whether MDD-Women food groups are equally applicable to male and adolescent dietary diversity. Second, our results are observational using cross-sectional data, and we do not examine agricultural transitions in the same farmer households through time using panel data. Therefore, our results are only correlational and not casual. We attempted to better control for possible confounding effects that occur at the regional scale by including district fixed effects, and block fixed effects as a robustness check. Future work should follow the same farming families through time to better understand the causal relationship between crop and income diversity and intra-household dietary diversity. Third, we did not collect information on the amount of food consumed that was produced on farm versus purchased in markets. However, doing this would better identify the pathways in which crop diversity improve dietary diversity among farmer households, either through the consumption or the income generation pathway. Fourth, we surveyed villages randomly relative to the day on which local markets may be present in a given village. Yet, in villages where a local market is not available every day of the week, this may introduce some noise in our analyses, as it is likely that dietary diversity is higher in the days following the presence of a local market. As we did not collect data on the days when local markets were available (i.e. if there was any particular monthly/weekly market on the day of survey), we could not include a dummy variable for market presence. We do not believe that this systematically biased our results as our surveys were random relative to the availability of a village market, however, future work would benefit from accounting for this added source of variance. Fifth, the sample sizes of adolescents and children were smaller than that of adults (Male and Female) as the research design only included one adolescent or child from each farmer household due to financial, child availability, and time related constraints. While the sample size for child regressions ($n = 243$: Fig. 2) was substantially smaller than that of other family members, our regressions were still able to capture the relationships between CDI and distance traveled to markets that showed the strongest associations with DDS for other family members. We do acknowledge, however, that it is possible that these regressions were underpowered and the effect of other variables that do not have as strong of an effect size were not captured in our results. Sixth, due to time and financial constraints, we were unable to collect crop and dietary data multiple times in a year (e.g. in the monsoon and winter seasons). However, a recent study conducted in India (Rao and Raju 2019) suggests that diets do not reflect significant variations across seasons. Seventh, it was challenging to develop causal interpretations for some relationships, for example why CDI was associated with child and adolescent DDS in Haryana but not Gujarat, and future work would benefit from spending more time in the field speaking with farmers to uncover potential mechanisms for these findings. Finally, this study is a case study that compares only the states of Gujarat and Haryana, which we selected because these two states represent different agricultural transition pathways in India. Our study aims to offer insight into potential implications of these two different agricultural transition pathways on dietary diversity, and is not attempting to extrapolate results to all states of India. Future work should examine multiple states in India that represent a range of variation along a gradient to better attribute causal relationships between diversification pathways and dietary diversity.

In summary, our results suggest increased crop diversity was associated with higher dietary diversity for adults in both states, and for adolescents and children in Haryana. This suggests that higher crop diversity may be associated with improved dietary diversity among farmer households. This is concerning given that crop diversity is falling across much of India, possibly due to pricing policies of the Government of India that promote cereals, such as rice and wheat, and discourage the production of alternative crops, such as coarse cereals and pulses, that could provide essential nutrients to farmer households (Pingali et al. 2019). Interestingly, we did not find a significant association between income diversity and dietary diversity, though it is one of the most important factors explaining variation in dietary diversity in Gujarat. Overall, this suggests that diversifying farmer livelihood portfolios may have a modest effect on intra-household dietary diversity. Instead, we find that higher income generation, through selling crops, growing more cash crops, and taking part in salaried professions, is associated with higher dietary diversity among farmer households in both states. We find that socio-economic factors such as education, market integration and annual income are some of the largest explanatory factors of intra-household dietary diversity among farmer household in India. Yet, which factors are most important vary across sites and individuals within a given household, suggesting that the associations between crop and income diversity, socio-economic indicators, and farmer dietary diversity are complex, and future policies that aim to improve farmer household dietary diversity cannot adopt a one-size-fits all approach.

5 Conclusions

Using primary data collected from 1106 farmer households in India, this paper investigated how crop and income diversity is associated with dietary diversity among members of farmer households in Gujarat and Haryana. We were interested in understanding this association to better understand the implications of increased crop specialization and income diversification on farmer household dietary diversity. Our results suggest a positive and significant association between crop diversity and DDS among men, women in both states, and among adolescents and children in Haryana. These results suggest that increased crop specialization may be associated with reduced dietary diversity of farming households in India. Considering the relative importance of factors associated with dietary diversity, family education and per capita annual income were among the most important factors explaining male, female and adolescent DDS in Gujarat. Crop sold (%) to market was the most important factor explaining dietary diversity among children in Gujarat. In Haryana, distance traveled to food markets, family education, and crop diversity were the most important factors explaining individual DDS. Our results suggest that dietary diversity in Gujarat can likely be improved through the income generation pathway, where incomes can be increased through selling crops, growing cash crops, and taking part in salaried professions. In Haryana, crop diversification and developing more diverse local food markets could be suggested as more appropriate interventions to improve farmer household dietary diversity. We broadly find that the association between crop and income diversity, socio-economic and market drivers, and dietary diversity among members of a farmer household is complex, and future policies that aim to improve dietary diversity among farmer households in rural India would benefit by being targeted to a given location and context.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

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