Journal Pre-proof

Assessing the rural food environment for advancing sustainable healthy diets: Insights from India

Shalander Kumar, Abhishek Das, Kavitha Kasala, Bradley Ridoutt, Elias Khan Patan, Jessica Bogard, Padmaja Ravula, Soumitra Pramanik, Lilly Lim-Camacho, Nedumaran Swamikannu

PII: S2666-1543(23)00095-9

DOI: https://doi.org/10.1016/j.jafr.2023.100588

Reference: JAFR 100588

To appear in: *Journal of Agriculture and Food Research*

Received Date: 1 January 2023

Revised Date: 4 April 2023

Accepted Date: 10 April 2023

Please cite this article as: S. Kumar, A. Das, K. Kasala, B. Ridoutt, E.K. Patan, J. Bogard, P. Ravula, S. Pramanik, L. Lim-Camacho, N. Swamikannu, Assessing the rural food environment for advancing sustainable healthy diets: Insights from India, *Journal of Agriculture and Food Research* (2023), doi: https://doi.org/10.1016/j.jafr.2023.100588.

Assessing the Rural Food Environment for Advancing Sustainable Healthy Diets: Insights from India

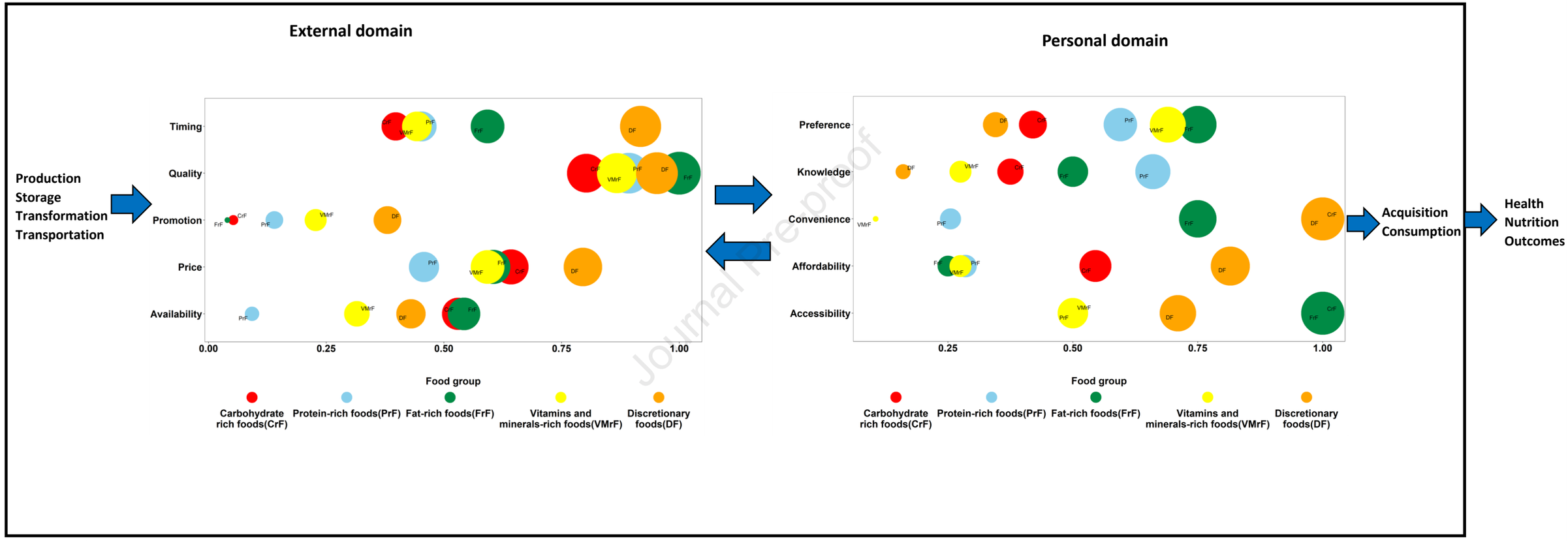
Shalander Kumar[1*], Abhishek Das[1], Kavitha Kasala[1], Bradley Ridoutt[2,3], Elias Khan Patan[1], Jessica Bogard[2], Padmaja Ravula[1], Soumitra Pramanik[1], Lilly Lim-Camacho[2] and Nedumaran Swamikannu[1]

[1]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India.
[2]The Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
[3]University of the Free State, Department of Agricultural Economics, South Africa.

***** Corresponding author: Shalander Kumar; Shalander.Kumar@icrisat.org

Assessing the Rural Food Environment for Advancing Sustainable Healthy Diets: Insights from India

Food Systems



The results obtained through scoring methodology indicate that the food choices are often nonlinear and complex and are influenced by various elements of the rural food environment.

These findings can be applied to rural regions undergoing rapid transition in food environments in LMICs.

Assessing the Rural Food Environment for Advancing Sustainable Healthy Diets: Insights from India

Abstract

World agricultural production has seen significant growth in the past four decades, yet malnutrition remains a persistent problem, particularly in the global south and more so in the rural areas. Need for a holistic approach to food systems is becoming crucial in designing policies that support the transition to sustainable and healthy diets. The present study is aimed to understand the rural food environment in the Telangana state in southern India by analyzing the combination of external and personal factors affecting food choices, attitudes, and consumption behavior. We developed a scoring-based methodology to assess the external and personal domains and dimensions to understand the food environment. The results showed that rural households favored carbohydrate-rich food groups obtained mostly from their own production or subsidized sources. On the other hand, protein and micronutrient-rich food groups were neglected due to affordability and preference for taste, cultural factors, and the limitations of external food environment. The findings of this study provide a deeper understanding of the food environment in low and middle-income countries (LMICs) conext. By highlighting the interplay between agriculture, food environments, and nutrition outcomes, this study contributes to the ongoing effort to address the global malnutrition crisis and support the development of healthier and more sustainable food systems. These findings can be useful to guide policy actions towards achieving food security and nutrition in the rural regions where food environments are under rapid transitions in the LMICs.

Keywords: Food Environment, Food Systems, Sustainable, Food Choices, Healthy Diets

1 Introduction

Malnutrition in all its forms currently affects one in three people globally and is considered one of the most significant public health challenges [1]. Low- and middle-income countries (LMICs)[1] are increasingly facing a triple burden of malnutrition, including undernutrition and increasing overweight, obesity, micronutrient deficiencies, and diet-related non-communicable diseases. A variety of national and international programs designed to address nutritional challenges have achieved their goals to a lesser extent than expected [2-4]. The food environments have been increasingly gaining policy attention for their role in shaping transitioning diets and the triple burden of malnutrition in the LMICs. However, empirical research on food environments in LMICs is still limited [5-7]. Despite significant growth in agricultural production over the past four decades for example in India, high malnutrition persists [8-10]. In rural areas, despite the increase in agricultural production, high rates of malnutrition still persist, highlighting the need for a holistic approach that takes into account all the elements of the food environment. The traditional focus on agricultural development and commodity-specific value chains alone has not been enough to effectively address malnutrition in the LMICs [11-12]. The systems perspective is crucial as it considers the processes and actors involved in food production, distribution, marketing, and regulation. However, there have been a very few studies directly engaged with the subject of the local food environment as the bridge connecting food production and food choices [13-14].

To design effective nutritional interventions, the entire food system and food environment considering availability, affordability, accessibility, convenience, and desirability need to be understood. Studies on tracking rapidly evolving food environments and investigating relationships among components of the food environment and dietary, nutrition, and health outcomes; as well as identifying appropriate policy entry point to facilitate healthier food environments that promote nutritious diets and improve public health outcomes, are very scant particularly in the LMICs context [15-16].

Currently, the evidence base is insufficient to understand how different aspects of the food environment influence individual choices and diets in LMICs. The measures needed to unpack these relations are further lacking. Metrics to quantify features of the food environment will be needed to track changes over time and determine the impact of interventions that aim to improve diet for better nutrition [5,17].

It is important to acknowledge that the food environment inherently covers a broader perspective within the food system and is therefore difficult to define. The term food environment first emerged in ecology [18]. The food environment is a concept defined relative to the way people interact with the food system and reflects cultural norms and preferences, economic conditions, and geography, all of which change over time [19-25]. Recently, the food environment in LMICs was defined with dimensions and domains of the external and personal environment [5], and the most recent definition of the food environment was stated as a "consumer interface within the food system that encompasses the availability, affordability, convenience, quality, and promotion, and sustainability of foods and beverages in wild, cultivated, and built spaces that are influenced by the socio-cultural and political environment and ecosystems within which they are embedded." [26]. The concept of food environment is valuable as an organizing framework that can facilitate research on critical features and determinants of food intake and nutrition. Furthermore, it guides the exploration of the cognitive frameworks (e.g., perception of desirability) that dictate food choice and that can be modified to promote more positive dietary outcomes [17].

The aim of the present study was to understand the rural food environments by looking into a combination of external and personal factors using a scoring methodology to investigate the influence on the food choices, attitudes, and consumption behavior in the rural population in an LMICs context. The study assesses the drivers of food choices people make in relation to internal and external food environments. The study brings

[1] For the current 2023 fiscal year, lower middle-income economies are those with a GNI per capita between $1,086 and $4,255 for more details please follow the world bank website: https://www.worldbank.org/en/country/mic/overview#:~:text=They%20are%20defined%20as%20lower,62%25%20of%20the%20world%27s%20poor.

out a new understanding of the complex interactions between food consumption behavior and the food environment (both personal and external), especially in the rural environment.

This case study on rural food environments in India aims to bring a novel perspective to the understanding of malnutrition and the role that food environments play in shaping diets by developing a scoring-based methodology to assess the external and personal domains and dimensions of the food environment, providing a comprehensive understanding of the elements that can be leveraged to improve nutrition outcomes. The existing literature [5,14-15, 26] considers only the general understanding of the food environments and their components without being context specific. With our approach, we can score and quantify the different components of the food environments. This evidence base makes food environment analysis more robust and enables the researcher to understand the complexities of the domain and dimensions of food environments in LMICs. Therefore, it will be helpful for policymakers to identify the intervention points for the implementation of relevant initiatives. The insights from this study on the rural food environments may be applicable and relevant to other LMICs facing similar challenges in shaping diets to promote a sustainable healthy ecosystem.

1.1 Background

As per the Multidimensional Poverty Index (MPI) baseline report 2021 by the NITI Aayog- a policy think tank, which has three equally weighted dimensions—Health, Education, and Living Standards, one in seven individuals in Telangana state in India is multidimensionally poor which is less than the national average of one in four individuals in India are poor. Therefore,a more fragile semi-arid region of Telangana was selected for the present study. Semi-arid tropical regions are often characterized by scanty and uncertain rainfall, on which agricultural production largely depends, infertile soils, poor infrastructure, higher levels of poverty, rapid population growth, and high risks. To understand the availability and the consumption pattern across different food groups in the study villages, we used household-level data collected as part of the Village Dynamics Studies in South Asia (VDSA)[2] project by the International Crops Research Institute for the Semi-Arid Tropic (ICRISAT), from Aurepalle and Dokur villages located in Mahbubnagar district of Telangana, India[3]. The village Aurepalle has a population of 4764 with 985 households while in Dokur it is 3006 with 545 households (as of 2010)[4]. Households in the village belong to five different caste groups based on social progression, namely, forward caste (FC), backward caste (BC), scheduled caste (SC), scheduled tribe (ST), and minorities. In Aurepalle, adult men constituted 42% while adult women were 41% while in the case of Dokur, the adult men constituted 49% followed by adult women who were 42%. Agriculture continues to be the main occupation of the majority of the households in the selected villages. The majority of the households have marginal to small size of landholdings, which is leass than 2 ha, in both villages.

The detailed longitudinal data on household-level agricultural production and food consumption was derived from VDSA households selected randomly from different categories such as landless, small, medium, and large farmers. The consumption of the major nutrients based on different food groups in rural regions often depends on the kind of foods produced in rural agricultural households, their income, and several other socioeconomic and cultural factors that influence the food habits of individuals at the household level [27]. The selected rural locations were predominantly farming communities engaged in the production of food and other crops grown, staples such as paddy and sorghum produced on their own and utilized for consumption as well. The cash crops such as cotton and maize were a significant component of the farming system. Own production of staples helped the easy availability and accessibility of the carbohydrate-rich food group compared to other food groups. The price and affordability attributes of the carbohydrate-rich food group tend to be more economical than other food groups. It was indicated that the availability of rice at a low price within the village during the harvesting seasons for both the rainy (Kharif) and post-rainy (Rabi) crops and the availability of subsidized rice from the Public Distribution System (PDS) has resulted in its increased

[2] http://vdsa.icrisat.ac.in/

[3] The socioeconomic characteristics of the sample households derived from VDSA data are presented in Annex 1

[4] http://vdsa.icrisat.ac.in/Include/vaag/aurepalle.pdf; http://oar.icrisat.org/7208/1/Dokur-village_2011.pdf

preference in the food basket. Further, the availability and affordability of rice has increased, and the availability of traditional grains like sorghum reduced due to a shift in the cropped area from sorghum to cash crops like cotton and maize.A historical perspective (2009-2014) on own-produced food groups has been provided in Table 1 to understand the status of availability of food by nutrient type in the rural households. Similarly, Table 1 also presents households' consumption levels from different food groups. The consumption of all three types, carbohydrates, proteins, and fats-rich foods was found to be much lower in Dokur village as compared to Aurepalle village.

Table 1 about here

It is evident from Table 1 that there was a sufficient amount of own production of different food types (groups); nevertheless, the consumption levels were not sufficient[5]. Mostly, an increasing trend was observed for the procurement of different food groups from outside (Table 2). For each food group, this dichotomy of availability and consumption patterns warrants further investigation of the nature of the food environment that rural households are experiencing. Further analysis revealed that most of the carbohydrate and protein (especially legumes) rich food groups were sourced from home production while the fat and vitamin and mineral-rich food groups mainly were sourced from outside (market).

The literature suggests that the food systems and sourcing even in the rural settings of lower and middle-income countries are becoming more market-oriented, with about three fourth of the food being sourced from the market by the rural farm households in South Asia and Africa [29]. The association of farm production diversity with dietary diversity is not established in the current context. Instead, households with higher food market participation are likely to have higher dietary diversity [30]. Therefore, understanding the food environment becomes more important for designing effective strategies for improving nutrition and sustainable consumption.

Table 2 about here

Following this brief introduction and background, the subsequent section describes the framework of the study, followed by the next section on the methodology underpinning our analysis, we present the results of empirical estimations, which are discussed in the next section, and finally, the conclusions are presented in the last section.

2 Framework of the study

2.1 Sample and Location

The present study considered the sample was drawn from the ICRISAT VDSA household-level database from two villages, namely Aurepalle and Dokur, in the southern region of Telangana state. Aurepalle village is 60 kilometers, while Dokur village is 130 kilometers away from the state capital Hyderabad. The cropping pattern has shifted from subsistence to commercial cropping with the domination of cotton crops in Aurepalle village while paddy followed by castor continues to dominate in Dokur village.

2.2 Sample and Location

The sample size and data collection methods in food environment research especially in LMICs are still evolving which has a particular significance of context-specific qualitative data [5,14, 31-34]. The community-level data were collected to understand the local rural food environments and to map community perceptions of food and diets in rural areas. The qualitative data includes eight focus group discussions (FGDs) involving

[5] As per the Dietary Guidelines of Indians, NIN, 2011 [28], the requirements of different food groups for one consumption unit (CU) for the specific food groups are as follows; Carbohydrate-rich food groups: 680 grams/day/CU; Protein rich food group: 399 grams/day/CU; Fat rich food: 30 grams/day/CU; Vitamin and mineral-rich foods: 400 grams/day/CU. Note that the data presented in Tables 1 and 2 include the concentrated sources of food items under the carbohydrate, protein fat, vitamins, and mineral food groups, even though they contribute to other nutrients as well.

38 men and 40 women and key informant interviews with 80 vendors. The more intensive qualitative and quantitative data were collected from the individual members of each group of respondents during the FGDs and vendor typology survey. We tried to understand the intricacies of peoples' food choices by examining the external and personal domains and dimensions of the food environment. In addition, the present study utilizes unique quantitative longitudinal panel data (2009-2014) from the study villages to understand long-term food consumption behavior.

The present study has adapted the concept of the whole continuum of the food system from Turner et al., 2018 [5] as depicted in Figure 1.

Figure 1 about here.

The food environment consists of two interlinked domains: external and personal. The external domain encompasses objective factors consistent in a specific geographic location for all individuals. Under this, we looked at the food availability, food prices, and presence/absence of specific food vendors/retailers/weekly markets (both formal and informal). In the personal domain, we investigated more objective factors that will vary across strata of households within a geographic area: men, women, and social groups of the village. These included aspects of food access (including own production and safety net programs), food affordability, convenience, desirability, and food utilization. Within this framework, we considered aspects of sustainability (environmental, economic, and social) and social inclusion more broadly (including gender).

2.3 Data and Methods

This rural food environment study was undertaken to explore the strategies that might help improve rural people's nutrition and health and understand the community's perceptions of food and nutrition. Both personal and external domains of the food environment were investigated to understand the food environments in the selected villages of Telangana. While analyzing the themes of personal food environment following aspects were taken into consideration – availability, accessibility, affordability, convenience, desirability, and basic nutrition knowledge. The food groups for ease of understanding were classified into three main groups such as Macronutrient rich food, Micronutrient rich food, and Discretionary food, and five sub-groups under these, which are given below:

- Macronutrient-rich food

Carbohydrate-rich food: cereals including millets, roots, and tubers
Protein-rich food: Pulses and legumes, milk and milk products, eggs, meat, and fish
Fat-rich food: cooking oil, ghee, whole groundnuts

- Micronutrient-rich food

Vitamins and mineral-rich food: Fruits and vegetables

- Discretionary food groups:

Tea and coffee, sweets, snacks (e.g., biscuits, cakes), savory snacks (e.g., fried snacks), and alcoholic and non-alcoholic beverages.

The scoring method was adopted using the data collected through FGDs and also from the individual members of each group of respondents while being part of the FGD for different attributes of the external and personal domain to understand the rural food environment. These scores were arrived at by following the procedure given in Table 3 below:

Table 3 about here

3 Results

3.1 Characteristics of the households and vendors

Eight focus group discussions (FGDs) conducted for the present study included 4 each in Aurepalle and Dokur village, and 50% of these FGDs were with the women groups. The participants in the FGDs represented all the major social categories in the study villages, which included members from the General caste, Other backward castes, and Scheduled Caste (previously considered as socially and economically backward), as presented in Table 4.

Table 4 about here

The sample of vendors involved in the sale of different food groups in the selected villages (Aurepalle, Dokur) and the nearby towns (Amangal for Aurepalle village and Devarakadra for Dokur village) for the study are given in Table 5.

Table 5 about here

3.2 Food Environment

In the present study, the food environment has been analyzed utilizing the key dimensions that are mapped to external and personal domains. The following sections provide details of the interactions between these domains and dimensions that shape rural people's food acquisition and consumption.

3.2.1 External Domain

The external domain includes an expanded set of exogenous and measurable dimensions such as food availability, prices, vendor and product properties, and marketing and regulation, which may significantly influence the food choices people make.

Availability

The availability dimension indicates the level of the physical presence of food. It refers to whether a vendor or product is present or not within a given context and is included within the external food environment domain. Table 6 depicts the product (food) availability scores. As availability always precedes accessibility (i.e., food cannot be accessible if it is not available), the availability of food items was classified into macronutrient-rich food, micronutrient-rich food, and discretionary food.

In our analysis, higher scores across the locations indicate higher product availability. Table 6 reveals that Aurepalle village and its nearby town Amangal have relatively abundant availability of fat-containing food groups and discretionary food groups along with the carbohydrate-rich food groups, as reflected from the availability scores. Similar trends were observed in the Dokur village and its nearby town, Devarakadra. However, the availability of protein-rich foods was low across the four locations. Another deficient group was the micro-nutrient-rich food. A comparison of the availability of different foods within each location also revealed relatively low scores for protein-rich food groups and higher scores for fat-rich foods and discretionary food types.

Table 6 about here

Prices

Prices and affordability are well-established dimensions within food environment research. Prices refer to the amount of money consumers pay to buy the food products included within the external food environment domain. Based on the scores for the prices, it was found that prices interact with individual purchasing power to determine affordability within the personal food environment domain. Prices and affordability are sensitive to fluctuations in food availability and accessibility. In Table 6, the higher price score indicates a better opportunity for consumers because more vendors trade or products are sold at less than or equal to their average price.

Protein-rich foods were sold at higher prices in Aurepalle compared to Dokur, whereas fat-rich food groups and discretionary food groups were relatively low-priced in Aurepalle. The micronutrient (vitamins and minerals) rich food group was sold higher than macronutrient-rich food groups for vendor-wise products in Dokur, while discretionary food groups were low priced.

Intra-village and intra-town comparisons revealed that protein-rich foods were priced higher than other food groups in Aurepalle and Dokur villages and Amangal and Devarakadra towns, whereas discretionary food groups were low priced.

Vendor properties

Vendor and product properties feature prominently within food environment research. Vendor and product properties here refer to external food environment aspects such as the opening hours and vendor typology as well as the composition of foods such as the quality of the products. Table 6 shows that a higher time score indicates higher accessibility (with respect to the opening hours of the shops) to that particular food group. Across all locations, the accessibility of discretionary food groups was much better and dominated the other food groups.

The vendor density has been depicted using the vendor typology; a static approach typically used to assess the external food environment. The mapping was done using the Global Positioning Systems (GPS) coordinates of the households and the vendors in the selected villages from VDSA data. Vendors were classified as fruit vendors, Kirana (groceries), meat, poultry, fish vendors, milk and dairy products vendors, and vegetable vendors. This helped to understand the external food environment regarding the availability of foods by vendor typology within a given setting. From Figure 2a and Figure 2b, the typology reveals that the vendors were spread across the Aurepalle village indicating better accessibility (in terms of distance) to different food groups than in Dokur village.

Figure 2a about here

Figure 2b about here

The perception of the relative quality of the food was also scored, indicating that the higher the score, the better the food quality, as detailed in Table 6. A number of the food items except fruits and vegetables were available with rural vendors in packaged form and were of reasonably good quality. The fat-rich food group got the highest score on quality as all available items were in packaged form from reliable brands. The quality score of the carbohydrate-rich food group was lower in Dokur compared to other locations.

Marketing

Marketing and regulation fall within the external food environment and include promotional information, branding, advertising, sponsorship, labeling, and policy regulations pertaining to the sale of foods. In the present study, the proportion of the total display area in a vendor shop allocated to a particular food group type was considered to represent the level of promotional efforts by the vendors for the respective food group.

The higher the display area for a particular food group higher the score it gets, as indicated in Table 6. Across all locations, the marketing display of the discretionary food group was observed to be enormously dominating over other food groups.

3.2.2 Personal Domain

The personal domain includes a set of individual-level dimensions, including food accessibility, affordability, convenience, and desirability. We considered continuous and complex interactions among these domains and dimensions that are likely to shape people's food acquisition and consumption.

Accessibility - distance

Accessibility is related to individuals and falls within the personal food environment domain. Accessibility is highly dynamic and can include distance, time, space and place, daily mobility, and modes of transport that collectively shape individual activity spaces. In the present study, we included the distance required to procure the food item within the selected locations.

In Table 7, the higher accessibility (distance) scores across the locations indicate relatively better access to food items by consumers. The score would be higher if more food items in particular food groups are being sold and made available at less than or equal to the average distance. In the case of Aurepalle village, discretionary food items were more easily accessible with respect to distance compared to its counterpart Dokur village. When compared within the sample villages and towns, carbohydrate and fat-rich food groups were more accessible, followed by discretionary food groups.

Affordability - relative price

Prices and affordability are sensitive to fluctuations in food availability and accessibility. Prices interact with individual purchasing power to determine affordability within the personal food environment domain. In our analysis higher affordability score (relative price) indicates higher affordability for the consumers. It was observed that the discretionary foods and protein-rich foods were more affordable in Dokur village than in Aurepalle village. Within the village, discretionary foods were more affordable, followed by carbohydrate-rich foods.

Table 7 about here

Convenience - easy to store

Personal convenience and desirability are an area of the personal food environment domain where public research has yet to catch up with the private sector. The factors such as quality, safety, level of processing, shelf-life, and packaging are included under convenience. Here we have considered the food products' shelf life as the convenience component's attribute. A higher convenience score indicates a better shelf-life, thereby indicating greater convenience in consuming food products. The convenience scores for the discretionary food groups and the carbohydrate-rich food groups were the highest, followed by fat-rich foods, and the lowest for the micronutrient-rich foods (Table 7). A similar trend was observed in both the villages, Dokur and Aurepalle, with the vitamins and minerals-rich food group as the least convenient (shelf-life) among all the food groups.

Desirability – preferences, and knowledge

People's individual preferences, acceptability, tastes, desires, attitudes, culture, knowledge, and skills shape the desirability of food products that are captured under the personal food environment domain. We considered preferences and knowledge attributes of desirability (Table 7). A higher desirability (preference) score indicates a higher preference to consume that particular food group. The results show that the preference for the fat-rich food group was the highest among all the food groups. In general, the scores for knowledge and preference for different food groups were higher in the Dokur village compared to the Aurepalle village.

4 Discussion

The present study focuses on understanding the rural agrarian food environment, and this work in the villages of Telangana, India represents a fragile ecosystem of Semi-Arid Tropics. Traditional food environments in rural settings of LMICs are typically characterized by the limited availability and accessibility to diverse food groups [25, 35- 37].

The food environments in rural communities in India reflect [38-40] a nutrient-poor and high-carbohydrate diet along with increasing addition of discretionary foods that have more added sugar. This trend bends toward

staple and discretionary foods that consist of more refined carbohydrates with low fiber content. It was revealed from the FGDs that the rural communities regularly consumed the traditional deep-fried snacks (discretionary foods) sold by hawkers [41-42].

Our findings indicate that the availability, accessibility, and consumption of different food groups in the selected rural communities were strongly shaped by various elements of the food environment. The rural households' preferred consumption was the carbohydrate-rich food groups, a significant proportion of which came from their own farm production and subsidized PDS supply. However, the protein and micronutrient-rich food groups were being neglected, mostly procured from the market as influenced by affordability and preference of desirability, taste, and cultural factors as well as limitations of the external food environment. This made rural households vulnerable due to insufficient consumption of protective foods (protein, vitamin, and mineral-rich food groups). Interestingly, despite severe deficit of protein consumption and high awareness of its importance, rural people aspired for unaffordable non-vegetarian sources and neglected the relatively low-cost protein sources through pulses. Based on the insights from FGDs conducted in the rural communities, traditionally, some households were getting protein and micro-nutrient-rich foods from foraging and common property resources (CPRs) that includes animals such as wild boar, hare, birds, and plant products such as wild greens, wild fruits, roots, and tubers. However, due to the dwindling of the CPRs and restricted forest area, the consumption of these wild foods has declined over a period of time. In addition, due to globalization and aggressive marketing strategy, the consumption of small packaged high carbohydrate and sugary foods and beverages (discretionary food groups) at low prices has infiltrated the rural economies and has become a part of daily diets [42-43]. Moreover, similar to the trends shown in the literature on vendor product properties, the shop opening hours for discretionary food groups were more prolonged than other food groups [6, 33]. These patterns led to the deterioration of diets, thereby contributing to the triple burden of malnutrition and overall food insecurity and poor nutrition outcomes. Various elements of the food environment and their interaction were found to influence the demand and consumption of micro-nutrient-rich fruits and vegetables. An increased commercial orientation of agriculture has resulted in the lesser production of small scale vegetables and fruits in local backyards and farms [44-45]. As a consequence, the major source was external vendors who entered the local food environment infrequently. Vendor frequency was less because of inconsistent demand and the high risk of waste in the absence of refrigeration [46]. This appeared to result in a perpetuating negatively reinforcing cycle of higher prices and lesser demand and consumption.

The rural food environment must consider the co-existence of formal and informal food markets and non-market-based food sources such as own production and food transfers. During the last two decades, there has been a dramatic change in food environments across LMICs with the increasing penetration of formalized supermarkets and branded processed foods [47]. Even though supermarkets have not yet been established in the present rural locations, the availability of branded processed foods has risen. Meanwhile, informal food vendors remain a key source of diverse foods, especially among the poor reports Battersby and Crush, 2014 [48] similar to our study findings.

Collectively, these complex and unprecedented developments in LMIC food environments are influencing to shape the nutrition transition [49] towards increasingly discretionary dietary preferences via the introduction of energy-dense street and snack foods, where readily available and accessible, these types of foods provide an affordable source of desirable and convenient calories [50].

The study's results portray the complexity of drivers likely to influence people's food choices. In our case study, although there was a higher knowledge and preference for protein-rich and micro-nutrient-rich foods, the favorable cost, promotion by the vendors, and accessibility drove consumers towards the carbohydrate-rich and discretionary food group. Accessibility and other cultural factors led to higher consumption of fat-rich foods. It shows that multiple factors and their interactions influence the outcomes of food choices people make. Therefore, the food environment research approach can be very useful in designing impactful strategies to improve nutrition through sustainable local food systems.

5 Conclusions

To date, food environment research has primarily been undertaken within high income countries (HICs) in response to the high prevalence of obesity and associated nutrition-related non-communicable diseases. However, there is less knowledge about how people interact with food environments in rural settings in the LMICs to make food choices that may increase the risk for malnutrition-induced non-communicable diseases [15].

The present study contributes to the assessment of the domains and dimensions of the food environment in rural context by using a simple scoring method to evaluate the personal and external domains of the rural food environment and bring out the nuances of complexity involved in the study of the food environment. Our study shows that the decisions on food choices are often nonlinear and complex. It is not only the availability and affordability but various elements of the rural food environment components of availability, affordability, accessibility, convenience, and desirability as well as the external food environment that influence the food choices.

As the diets are undergoing rapid transitions across the globe, the development of appropriate methods and data becomes important in the study of the food environment. This is, even more, significant in the dynamic and diverse settings to bring about a substantial evidence base for policymaking to tackle the triple burden of malnutrition. Further, the complex, dynamic, and rapidly changing nature of such settings poses significant challenges that also require the adaptation of food environment definitions, conceptual frameworks and methods, and metrics appropriate for LMIC contexts.

We recognize that the results are context-specific, and the policy implications are restricted to our study location. However, the inference of our findings in relation to the globally applicable food environment conceptual framework [5] and the wider literature provides a degree of generalizability and transferability to wider food environment research in LMICs.

Based on our findings we recommend the following policy perspectives for improving the food environment in LMICs:

- Implementation of appropriate nutrition education and awareness interventions may help in promoting healthier diets even with the current level of availability and affordability.
- Implementation of context-specific suitable business models using a digital platform and increased local production may improve the consumption of fruits and vegetables.
- Further research is needed to better understand the complex and, rapidly changing nature of food environments in LMICs.

Author Contributions

SK: conceptualization, review and editing, supervision, project administration, and funding acquisition; AD and KK: conceptualization, methodology, validation, formal analysis, investigation, data curation, and original draft; BR: review and editing; EKP: data collection and data curation; JB, RP, SP, LLC & NS: review and editing. All authors have read and agreed to the published version of the manuscript

Funding

This research was funded by Bill and Melinda Gates Foundation (BMGF) through VDSA (Grant ID- 51937) and CRP Grain Legumes and Dryland Cereals (GLDC) through CGIAR Fund Donors and bilateral funding agreements.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

The authors thank Dr. Anthony Whitbread for facilitating collaboration between the ICRISAT and CSIRO teams. We also thank Mr. Mohammed Ismail for his support in preparing the maps.

Supplementary Material

Annex 1

Data Availability Statement

The data will be made available on request

References

[1] Micha, Renata, Venkatesh Mannar, Ashkan Afshin, Lorena Allemandi, Phillip Baker, Jane Battersby, Zulfiqar Bhutta et al. Submitted/Donor 2020 global nutrition report: action on equity to end malnutrition.Submitted/Donor (2020). https://globalnutritionreport.org/reports/2020-global-nutrition-report/. Accessed on 16 December 2022.

[2] World Health Organisation. Work Programme of the UN Decade of Action on Nutrition, 2016-2025. Geneva (2017). https://www.fao.org/fsnforum/activities/consultations/decade-nutrition-priority-actions Accessed on 16 December 2022.

[3] Narayan, Jitendra, Denny John, and Nirupama Ramadas. Submitted/Donor Malnutrition in India: status and government initiatives.Submitted/Donor *Journal of public health policy* 40, no. 1 (2019): 126-141. https://doi.org/10.1057/s41271-018-0149-5

[4] Aayog, Niti. Submitted/Donor Accelerating Progress on Nutrition in India (Third Progress Report) about Technology, Behavior change Communication, Capacity Building etc.Submitted/Donor (2020). http://14.139.60.153/bitstream/123456789/13575/1/AbhiyaanMonitoringReport.pdf Accessed on 16 December 2022.

[5] Turner, Christopher, Anju Aggarwal, Helen Walls, Anna Herforth, Adam Drewnowski, Jennifer Coates, Sofia Kalamatianou, and Suneetha Kadiyala. Submitted/Donor Concepts and critical perspectives for food environment research: a global framework with implications for action in low-and middle-income countries.Submitted/Donor *Global food security* 18 (2018): 93-101. https://doi.org/10.1016/j.gfs.2018.08.003

[6] Drewnowski, Adam, Eva C. Monterrosa, Saskia de Pee, Edward A. Frongillo, and Stefanie Vandevijvere. Submitted/Donor Shaping physical, economic, and policy components of the food environment to create sustainable healthy diets.Submitted/Donor *Food and Nutrition Bulletin* 41, no. 2_suppl (2020): 74S-86S. https://doi.org/10.1177/0379572120945904

[7] Chaudhry, Monica, Lindsay M. Jaacks, Monu Bansal, Palak Mahajan, Ayushi Singh, and Shweta Khandelwal. Submitted/Donor A Direct Assessment of the External Domain of Food Environments in the National Capital Region of India.Submitted/Donor *Frontiers in Sustainable Food Systems* (2021). https://doi.org/10.3389/fsufs.2021.726819

[8] Pingali, Prabhu. Submitted/Donor Agricultural policy and nutrition outcomes–getting beyond the preoccupation with staple grains.Submitted/Donor *Food security* 7, no. 3 (2015): 583-591. https://doi.org/10.1007/s12571-015-0461-x

[9] Shankar, Bhavani, Sutapa Agrawal, Amy R. Beaudreault, Laxmaiah Avula, Reynaldo Martorell, Saskia Osendarp, Dorairaj Prabhakaran, and Mireille Seneclauze Mclean. Submitted/Donor Dietary and nutritional change in India: implications for strategies, policies, and interventions.Submitted/Donor *Annals of the New York Academy of Sciences* 1395, no. 1 (2017): 49-59. https://doi.org/10.1111/nyas.13324

[10] Pingali, Prabhu, Anaka Aiyar, Mathew Abraham, and Andaleeb Rahman. *Transforming food systems for a rising India*. Springer Nature, 2019. https://library.oapen.org/handle/20.500.12657/22829 Accessed on 16 December 2022.

[11] Maestre, Mar, Nigel Poole, and Spencer Henson. Submitted/Donor Assessing food value chain pathways, linkages and impacts for better nutrition of vulnerable groups. Submitted/Donor *Food Policy* 68 (2017): 31-39. https://doi.org/10.1016/j.foodpol.2016.12.007

[12] Morgan, Emily H., Corinna Hawkes, Alan D. Dangour, and Karen Lock. Submitted/Donor Analyzing food value chains for nutrition goals.Submitted/Donor *Journal of hunger & environmental nutrition* 14, no. 4 (2019): 447-465. https://doi.org/10.1080/19320248.2018.1434106

[13] Ridoutt, Bradley, Jessica R. Bogard, Kanar Dizyee, Lilly Lim-Camacho, and Shalander Kumar. Submitted/Donor Value chains and diet quality: a review of impact pathways and intervention strategies.Submitted/Donor *Agriculture* 9, no. 9 (2019): 185. https://doi.org/10.3390/agriculture9090185

[14] Turner, Christopher, S. Bhogadi, H. Walls, S. Surendran, B. Kulkarni, S. Kinra, and S. Kadiyala. Submitted/Donor Drivers of food acquisition practices in the food environment of peri-urban Hyderabad, India: A qualitative investigation.Submitted/Donor *Health & Place* 74 (2022): 102763. https://doi.org/10.1016/j.healthplace.2022.102763

[15] Herforth, Anna, and Selena Ahmed. Submitted/Donor The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions.Submitted/Donor *Food Security* 7, no. 3 (2015): 505-520. https://doi.org/10.1007/s12571-015-0455-8

[16] Farrell, Penny, Cut Novianti Rachmi, Georgina Mulcahy, Matthias Helble, and Anne Marie Thow. Submitted/Donor Food environment research is needed to improve nutrition and well-being in Asia and the Pacific.Submitted/Donor *Public Health Nutrition* 24, no. 14 (2021): 4706-4710. https://doi.org/10.1017/S136898002100241X

[17] Toure, Djeinam, Anna Herforth, Gretel H. Pelto, Lynnette M. Neufeld, and Mduduzi NN Mbuya. Submitted/Donor An Emergent Framework of the Market Food Environment in Low-and Middle-Income Countries.Submitted/Donor *Current developments in nutrition* 5, no. 4 (2021): nzab023. https://doi.org/10.1093/cdn/nzab023

[18] Palo, R. Thomas, and Charles T. Robbins. *Plant defenses against mammalian herbivory*. CRC Press, 1991.

[19] Swinburn, Boyd, Gary Sacks, Stefanie Vandevijvere, Shiriki Kumanyika, Tim Lobstein, Bruce Neal, Simon Barquera et al. Submitted/Donor INFORMAS (International Network for Food and Obesity/non-communicable diseases Research, Monitoring and Action Support): overview and key principles.Submitted/Donor *Obesity reviews* 14 (2013): 1-12. https://doi.org/10.1111/obr.12087

[20] Morland, Kimberly, Steve Wing, and Ana Diez Roux. Submitted/Donor The contextual effect of the local food environment on residents' diets: the atherosclerosis risk in communities study.Submitted/Donor *American journal of public health* 92, no. 11 (2002): 1761-1768. https://doi.org/10.2105/AJPH.92.11.1761

[21] Cummins, Steven CJ. Submitted/Donor The local food environment and health: some reflections from the United Kingdom.Submitted/Donor *American journal of public health* 93, no. 4 (2003): 521-521. https://doi.org/10.2105/AJPH.93.4.521

[22] French, Simone A., Mary Story, and Jayne A. Fulkerson. Submitted/Donor School food policies and practices: a state-wide survey of secondary school principals.Submitted/Donor *Journal of the American Dietetic Association* 102, no. 12 (2002): 1785-1789. https://doi.org/10.1016/S0002-8223(02)90382-2

[23] French, Simone A. Submitted/Donor Public health strategies for dietary change: schools and workplaces.Submitted/Donor *The Journal of nutrition* 135, no. 4 (2005): 910-912. https://doi.org/10.1093/jn/135.4.910

[24] Food and Agriculture Organization of the United Nations. Influencing food environments for healthy diets. *Influencing Food Environments for Healthy Diets*. (2016). https://cgspace.cgiar.org/bitstream/handle/10568/80578/InfluencingFoodEnvironmentsForHealthyDiets.pdf?sequence=2 Accessed on 16 December 2022

[25] Nutrition, H. L. P. E. Submitted/Donor food systems: a report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.Submitted/Donor *Rome: Commitee on World Food Security* (2017): 152. https://www.fao.org/3/a-i7846e.pdf Accessed on 16 December 2022.

[26] Downs, Shauna M., Selena Ahmed, Jessica Fanzo, and Anna Herforth. Submitted/Donor Food environment typology: advancing an expanded definition, framework, and methodological approach for improved characterization of wild, cultivated, and built food environments toward sustainable diets.Submitted/Donor *Foods* 9, no. 4 (2020): 532. https://doi.org/10.3390/foods9040532

[27] Reddy, A. Submitted/Donor Regional disparities in food habits and nutritional intake in Andhra Pradesh, India.Submitted/Donor *Regional Disparities in Food Habits and Nutritional Intake in Andhra Pradesh, India (May 19, 2010). Regional and Sectoral Economic Stuidies* 10, no. 2 (2010): 125-134. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1611726 Accessed on 16 December 2022.

[28] National Institute of Nutrition. Dietary guidelines for Indians: a manual. (2011). https://maternalnutritionsouthasia.com/wp-content/uploads/Dietary-guidelines-for-Indians-a-manual.pdf Accessed on 16 December 2022.

[29] Reardon, Thomas, Ashok Mishra, Chandra SR Nuthalapati, Marc F. Bellemare, and David Zilberman. Submitted/Donor COVID-19's disruption of India's transformed food supply chains.Submitted/Donor *Economic and Political Weekly* 55, no. 18 (2020): 18-22. http://libraryopac.iimk.ac.in/EPW/6_EPW_Vol_LV_No_18.pdf#page=18 Accessed on 16 December 2022.

[30] Matita, Mirriam, Ephraim W. Chirwa, Deborah Johnston, Jacob Mazalale, Richard Smith, and Helen Walls. Submitted/Donor Does household participation in food markets increase dietary diversity? Evidence from rural Malawi.Submitted/Donor *Global Food Security* 28 (2021): 100486. https://doi.org/10.1016/j.gfs.2020.100486

[31] Miewald, Christiana, Francisco Ibanez-Carrasco, and Shane Turner. Submitted/Donor Negotiating the local food environment: The lived experience of food access for low-income people living with HIV/AIDS.Submitted/Donor *Journal of Hunger & Environmental Nutrition* 5, no. 4 (2010): 510-525. https://doi.org/10.1080/19320248.2010.530550

[32] Li, Yingjun, Poppy Alice Carson Mallinson, Nandita Bhan, Christopher Turner, Santhi Bhogadi, Chitra Sharma, Aastha Aggarwal, Bharati Kulkarni, and Sanjay Kinra. Submitted/Donor Neighborhood physical food environment and cardiovascular risk factors in India: Cross-sectional evidence from APCAPS.Submitted/Donor *Environment international* 132 (2019): 105108. https://doi.org/10.1016/j.envint.2019.105108

[33] Turner, Christopher, Sofia Kalamatianou, Adam Drewnowski, Bharati Kulkarni, Sanjay Kinra, and Suneetha Kadiyala. Submitted/Donor Food environment research in low-and middle-income countries: a systematic scoping review.Submitted/Donor *Advances in Nutrition* 11, no. 2 (2020): 387-397. https://doi.org/10.1093/advances/nmz031

[34] Laar, Amos K., Phyllis Addo, Richmond Aryeetey, Charles Agyemang, Francis Zotor, Gershim Asiki, Krystal K. Rampalli et al. Submitted/Donor Perspective: Food Environment Research Priorities for Africa—Lessons from the Africa Food Environment Research Network. Submitted/Donor *Advances in Nutrition* 13, no. 3 (2022): 739-747. https://doi.org/10.1093/advances/nmac019

[35] Food and Agriculture Organization of the United Nations. Sustainable Food Systems – Concepts and Framework. Rome: Food and Agriculture Organisation of the United Nations. (2018). http://www.fao.org/3/ca2079en/CA2079EN.pdf. Accessed on 16 December 2022

[36] Lee, Amanda, Cliona Ni Mhurchu, Gary Sacks, Boyd Swinburn, Wendy Snowdon, Stefanie Vandevijvere, Corinna Hawkes et al. Submitted/Donor Monitoring the price and affordability of foods and diets globally. Submitted/Donor *obesity reviews* 14 (2013): 82-95. https://doi.org/10.1111/obr.12078

[37] Nutrition, H. L. P. E. Submitted/Donor food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome; 2017.Submitted/Donor (2021). https://www.fao.org/3/i7846e/i7846e.pdf Accessed on 16 December 2022.

[38] Tripathy JP, Thakur JS, Jeet G, Chawla S, Jain S, Prasad R, Urban rural differences in diet, physical activity and obesity in India: are we witnessing the great Indian equalisation? Results from a cross-sectional STEPS survey, BMC Public Health, (2016); 16:816. doi: 10.1186/s12889-016-3489-8.

[39] Aila B, Nallapu SS. A study of nutrition related practices in a rural community. International Journal of Contemporary Medical Research. (2020); 7(10): J5-9. http://dx.doi.org/10.21276/ijcmr.2020.7.10.27

[40] Sowmya N, Lakshmipriya N, Arumugam K, Venkatachalam S, Vijayalakshmi P, Ruchi V, Geetha G, Anjana RM, Mohan V, Krishnaswamy K, Sudha V. Comparison of dietary profile of a rural south Indian population with the current dietary recommendations for prevention of non-communicable diseases (CURES 147). The Indian journal of medical research. (2016) Jul;144(1):112. https://doi.org/10.4103%2F0971-5916.193297

[41] Gupta V, Downs SM, Ghosh-Jerath S, Lock K, Singh A. Unhealthy fat in street and snack foods in low-socioeconomic settings in India: a case study of the food environments of rural villages and an urban slum. Journal of nutrition education and behavior. (2016); 48(4):269-79. 10.1016/j.jneb.2015.11.006

[42] Puttarathnamma D, Prakash J, Prabhavathi SN. Consumption trends of processed foods among rural population selected from South India. Int J Food Nutr Sci. (2015); 2(6):1-6. http://www.dx.doi.org/10.15436/2377-0619.15.039

[43] Government of India. Report of Working Group on Addressing Consumption of Foods High in Fat, Salt and Sugar (HFSS) and Promotion of Healthy Snacks in Schools of India Prepared by Working Group Constituted by Ministry of Women and Child Development Government of India **(**2015). https://wcd.nic.in/sites/default/files/Final%20Report%20of%20Working%20Group%20on%20HFSS-merged.pdf

[44] Gulati A, Juneja R. Transforming Indian Agriculture. In Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems (2022). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-19-0763-0

[45] Majhi B, Kumar A. Changing cropping pattern in Indian agriculture. Journal of Economic & Social Development. (2018);14(1). http://dx.doi.org/10.14807/ijmp.v11i9.1420

[46] Raut RD, Gardas BB, Narwane VS, Narkhede BE. Improvement in the food losses in fruits and vegetable supply chain-a perspective of cold third-party logistics approach. Operations research perspectives. (2019) Jan 1;6:100117.https://doi.org/10.1016/j.orp.2019.100117

[47] Downs, Shauna M., Anne Marie Thow, Suparna Ghosh-Jerath, and Stephen R. Leeder. Submitted/Donor Developing interventions to reduce consumption of unhealthy fat in the food retail environment: A case study of India. Submitted/Donor *Journal of Hunger & Environmental Nutrition* 9, no. 2 (2014): 210-229. https://doi.org/10.1080/19320248.2014.908452

[48] Battersby, Jane, and Jonathan Crush. Submitted/Donor Africa's urban food deserts. Submitted/Donor In *Urban Forum*, vol. 25, no. 2, pp. 143-151. Springer Netherlands, 2014. https://doi.org/10.1007/s12132-014-9225-5

[49] Popkin, Barry M. Submitted/Donor Urbanization, lifestyle changes and the nutrition transition. Submitted/Donor *World development* 27, no. 11 (1999): 1905-1916. https://doi.org/10.1016/S0305-750X(99)00094-7

[50] Gupta, Vidhu, Shauna M. Downs, Suparna Ghosh-Jerath, Karen Lock, and Archna Singh. Submitted/Donor Unhealthy fat in street and snack foods in low-socioeconomic settings in India: a case study

614 of the food environments of rural villages and an urban slum. Submitted/Donor *Journal of nutrition education*
615 *and behavior* 48, no. 4 (2016): 269-279. https://doi.org/10.1016/j.jneb.2015.11.006

616

Table 1: Availability and consumption of different food groups in the study villages from VDSA Data

		Daily availability# of foods groups from home production in the VDSA sample rural households						Daily consumption of food groups by the individuals in the selected villages					
Village	**Food Groups$^{\Upsilon}$ (grams/CU)**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Aurepalle	Carbohydrate-rich food	1060	1190	660	300	1070	570	440	470	470	450	430	410
	Protein-rich food	1180	1410	1370	1460	1070	1150	130	130	130	150	150	150
	Fat-rich food	80	70	30	00*	00*	20	20	30	30	30	30	30
	Vitamins and minerals-rich food	10	20	00*	00*	20	00*	100	130	130	110	180	180
Dokur	Carbohydrate-rich food	2490	2480	3100	24200	3970	3670	430	430	350	320	310	300
	Protein-rich food	2000	2730	2680	2810	3050	2760	290	520	130	120	110	100
	Fat-rich food	230	150	500	750	330	20	20	20	20	20	20	20
	Vitamins and minerals-rich food	00*	00*	30	110	30	90	90	150	80	60	110	100

Notes:
#: Here, an edible portion of the particular food groups was considered.
*The values are <0.001
Υ Carbohydrate-rich food: Cereals including millets, roots, and tubers
Protein-rich food: Pulses and legumes, milk and milk products, eggs, meat, and fish
Fat-rich food: Cooking oil, ghee, whole groundnuts
Vitamins and mineral-rich food: Fruits and vegetables
CU-Consumption Unit: One unit represents Recommended Dietary Allowance (RDA) of energy for a sedentary man as per the Dietary Guidelines of Indians NIN (2011)

Table 2: Share of major nutrients consumed from food produced at home (H) and purchased from outside (O) in percent

Village	Food group	2009		2010		2011		2012		2013		2014	
		H	**O**	**H**	**O**	**H**	**O**	**H**	**O**	**H**	**O**	**H**	**O**
Aurepalle	Carbohydrate-rich food	24.60	75.40	34.40	65.60	30.93	69.07	16.59	83.41	4.90	95.10	7.39	92.61
	Protein-rich food	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00
	Fat-rich food	38.39	61.61	38.44	61.56	38.38	61.62	27.63	72.37	27.06	72.94	34.05	65.95
	Vitamins and minerals-rich food	6.19	93.81	7.12	92.88	2.54	97.46	11.11	88.89	15.08	84.92	4.28	95.72
Dokur	Carbohydrate-rich food	25.06	74.94	36.74	63.26	35.77	64.23	40.13	59.87	38.64	61.36	27.30	72.70
	Protein-rich food	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	5.00	95.00	0.00	100.00
	Fat-rich food	2.00	98.00	4.74	95.26	4.41	95.59	22.47	77.53	29.67	70.33	29.59	70.41
	Vitamins and minerals-rich food	1.46	98.54	3.87	96.13	3.20	96.80	6.82	93.18	6.09	93.91	3.92	96.08

Notes: H- Home-produced foods; O-Foods purchased from outside
Source: Authors' calculations based on VDSA panel data

Table 3: Calculation of score for eliciting external and personal domain characteristics of the selected rural food environment

Domain	Attributes	Formulae for scoring
External	Availability	Variety availability score = Number of products selling in the particular food group by a vendor/ Total number of products in that particular food group
	Price	Product price score = Number of products selling at less than or equal to average price/ Total number of products being sold by the vendor
	Vendor and product properties	Timing score = closing time-opening time-interim time/24-hour period
		Food category quality score = Average (proportion of best quality + proportion of medium quality) *We considered the share of the best quality and medium quality products in the total products being sold based on the perceptions of the vendors
	Marketing	Promotion score = Average (proportion of total display area of the shop covered by a particular product)
Personal	Accessibility- physical distance	Average distance per food item per person = Average (Number of persons * distance of seller) Average distance food group wise per person = Average distance per food item (those food items in that group) per person If average distance per food item per person <= average distance food group wise per person, then 1; otherwise, 0 Score of food group = Total score of food items in that group/ Total Number of food items in that group
	Affordability - relative price	Cheap, somewhat cheap, and Neutral (based on perceptions of the consumer) =1 Somewhat expensive and Very expensive =0 Score of food group = Total score of food items in that group/ Total Number of food items in that group
	Convenience - easy to store	If the food item is easy to store in the consumer's perception, then 1 If the food item is not easy to store, then 0 Average group score for particular food item = Total score of particular food item / Number of groups that responded Average food category score = Total score of particular food category / Number of food items in the food category responded *We are not considering those who have not responded during the Focus Group Discussion
	Desirability-preferences, and knowledge	If the respondents liked to consume more of a food item, then 1, otherwise 0 Average group score for particular food item = Total score of particular food item / Number of groups Average food category score = Total score of particular food category / Number of food items in a food category
		If the consumers perceived the food as a healthy diet, then 1, otherwise 0 Average group score for particular food item = Total score of particular food item / Number of groups Average food category score = Total score of particular food category / Number of food items in the food category

Table 4: Composition of the households in terms of social categories in percentage

Caste[1] Category	Aurepalle–Group-1		Aurepalle–Group-2		Dokur-Group-1		Dokur-Group-2	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
General[2]	36	-	-	-	62	50	60	9
Other backward caste[3]	64	-	67	100	38	50	40	73
Scheduled Caste[4]	-	100	33	-	-	-	-	18
Overall	100 (n=11)	100 (n=09)	100 (n=09)	100 (n=10)	100 (n=10)	100 (n=08)	100 (n=11)	100 (n=10)

Notes:

1. **Caste** is a form of social stratification characterized by endogamy, hereditary transmission of a style of life which often includes an occupation, ritual status in a hierarchy, and day-to-day social interaction and exclusion based on cultural notions of purity and pollution in India.
2. General caste/General Category/Open Category is a term used in India to denote castes whose members are, on average, ahead of other Indians economically and socially.
3. Other Backward Caste is a collective term used by the Government of India to classify educationally or socially disadvantaged castes.
4. Scheduled castes are sub-communities within the Hindu caste system that have historically faced deprivation, oppression, and social isolation in India because of their perceived 'low status'.

Table 5: Sample details of vendors in the study locations

Town/Village	Fruits	Groceries /Kirana	Meat, poultry, and fish	Milk	Petty shop*	Vegetables
Amangal	5	10	2	-	-	10
Aurepalle	-	5	3	3	4	2
Devarakadra	5	10	2	-	-	10
Dokur	-	2	2	2	1	2
Total Number	10	27	9	5	5	24

- Vendors are not available/ Not surveyed

*Petty shops are small vending units that provide food items such as packaged ready-to-eat foods and beverages and tea and snack items/eatables in India.

Table 6: External Food environment-comparison of scores across the selected food groups						
Attributes	**Town/Village**	**Food Group**				
		Carbohydrate-rich foods	**Protein-rich foods**	**Fat-rich foods**	**Vitamins and minerals-rich foods**	**Discretionary foods**
Availability	Aurepalle	0.38	0.1	0.56	0.29	0.35
	Amangal	0.78	0.1	0.56	0.26	0.44
	Dokur	0.33	0.1	0.5	0.38	0.58
	Devarakadra	0.63	0.07	0.55	0.33	0.35
Price	Aurepalle	0.72	0.36	0.39	0.62	0.81
	Amangal	0.65	0.5	0.83	0.66	0.77
	Dokur	0.67	0.43	0.5	0.59	0.77
	Devarakadra	0.53	0.54	0.7	0.5	0.83
Timing	Aurepalle	0.52	0.59	0.67	0.59	0.92
	Amangal	0.3	0.34	0.44	0.3	0.89
	Dokur	0.31	0.42	0.79	0.42	0.87
	Devarakadra	0.46	0.46	0.47	0.46	0.99
Quality	Aurepalle	0.91	0.96	1	0.81	0.94
	Amangal	0.8	0.81	1	0.85	0.99
	Dokur	0.63	0.99	1	0.96	0.88
	Devarakadra	0.87	0.81	1	0.85	1
Promotion	Aurepalle	0.03	0.18	0.04	0.17	0.41
	Amangal	0.04	0.11	0.02	0.27	0.37
	Dokur	0.1	0.17	0.06	0.19	0.32
	Devarakadra	0.04	0.1	0.04	0.28	0.42
Source: Authors' calculations using VDSA household data						

Table 7: Personal food environment scores for different food groups										
Food groups	**Accessibility**		**Affordability**		**Convenience**		**Preference**		**Knowledge**	
	Aurepalle	**Dokur**	**Aurepalle**	**Dokur**	**Aurepalle**	**Dokur**	**Aurepalle**	**Dokur**	**Aurepalle**	**Dokur**
Carbohydrate-rich foods	1	1	0.42	0.67	1	1	0.42	0.42	0.33	0.42
Protein-rich foods	0.5	0.5	0.13	0.44	0.38	0.13	0.5	0.69	0.63	0.69
Fat rich foods	1	1	0.25	0.25	0.75	0.75	0.75	0.75	0.5	0.5
Vitamins and minerals-rich foods	0.67	0.33	0.25	0.3	0.08	0.13	0.63	0.75	0.25	0.3
Discretionary foods	0.75	0.67	0.69	0.94	1	1	0.38	0.31	0.13	0.19
Source: Authors' calculations using VDSA household data										

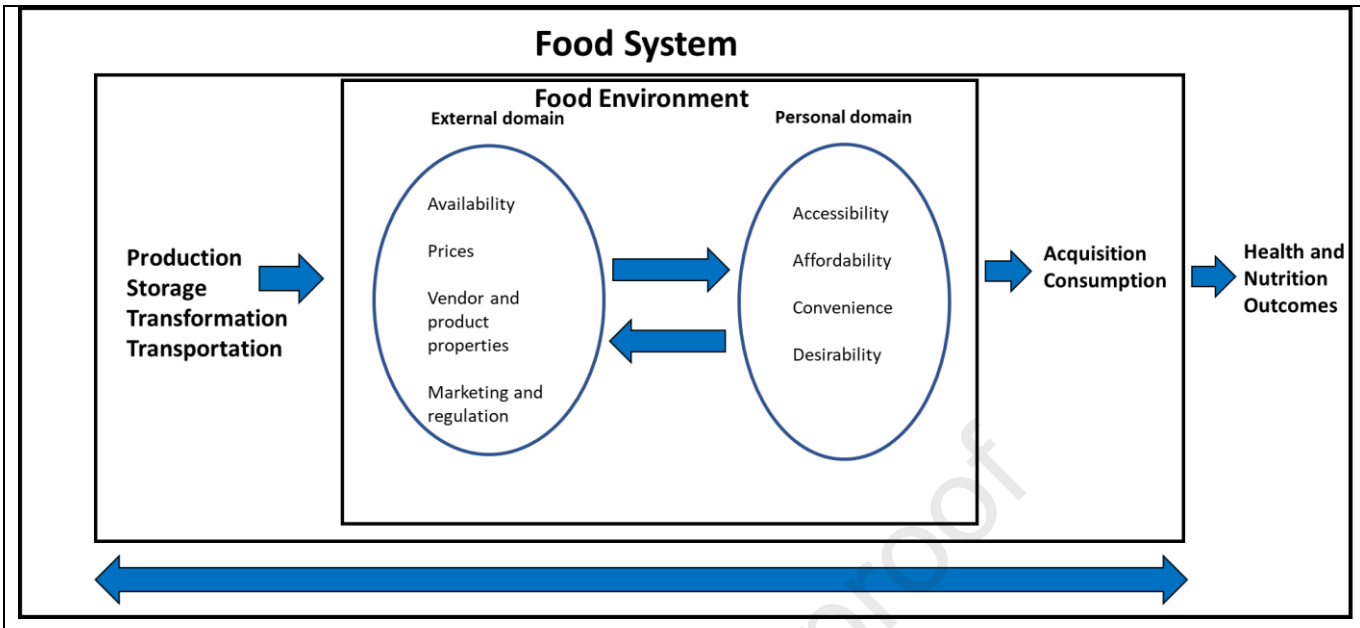


Figure 1: Framework of the Food Environment

Source: Authors drawn adapted from Turner et al., 2018

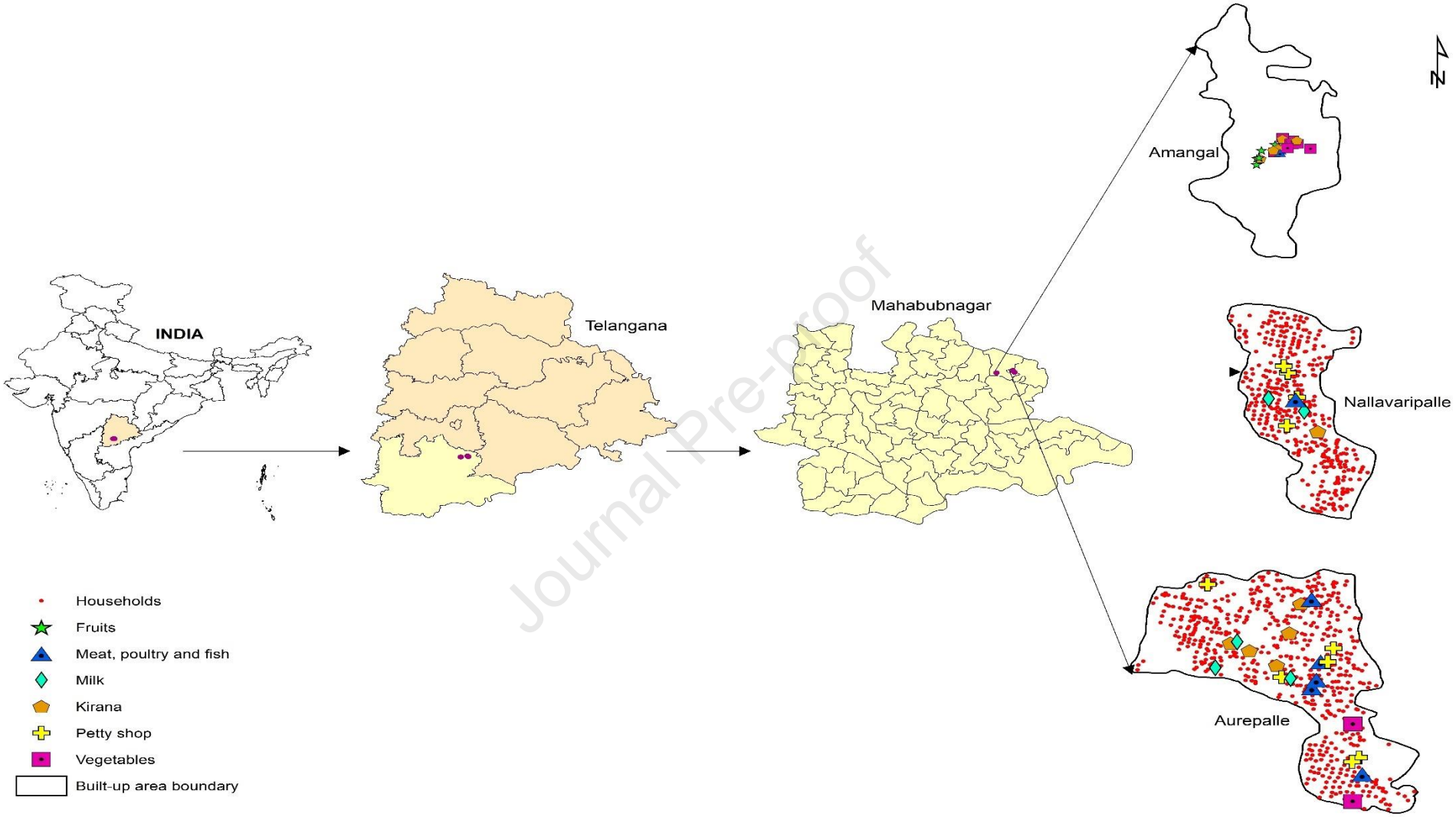


Figure 2a: Spatial distribution of vendor types in Aurepalle and Amangal study locations; Source: Map created using GPS coordinates of households and vendors in the selected location. The maps drawn are not as per the scale.

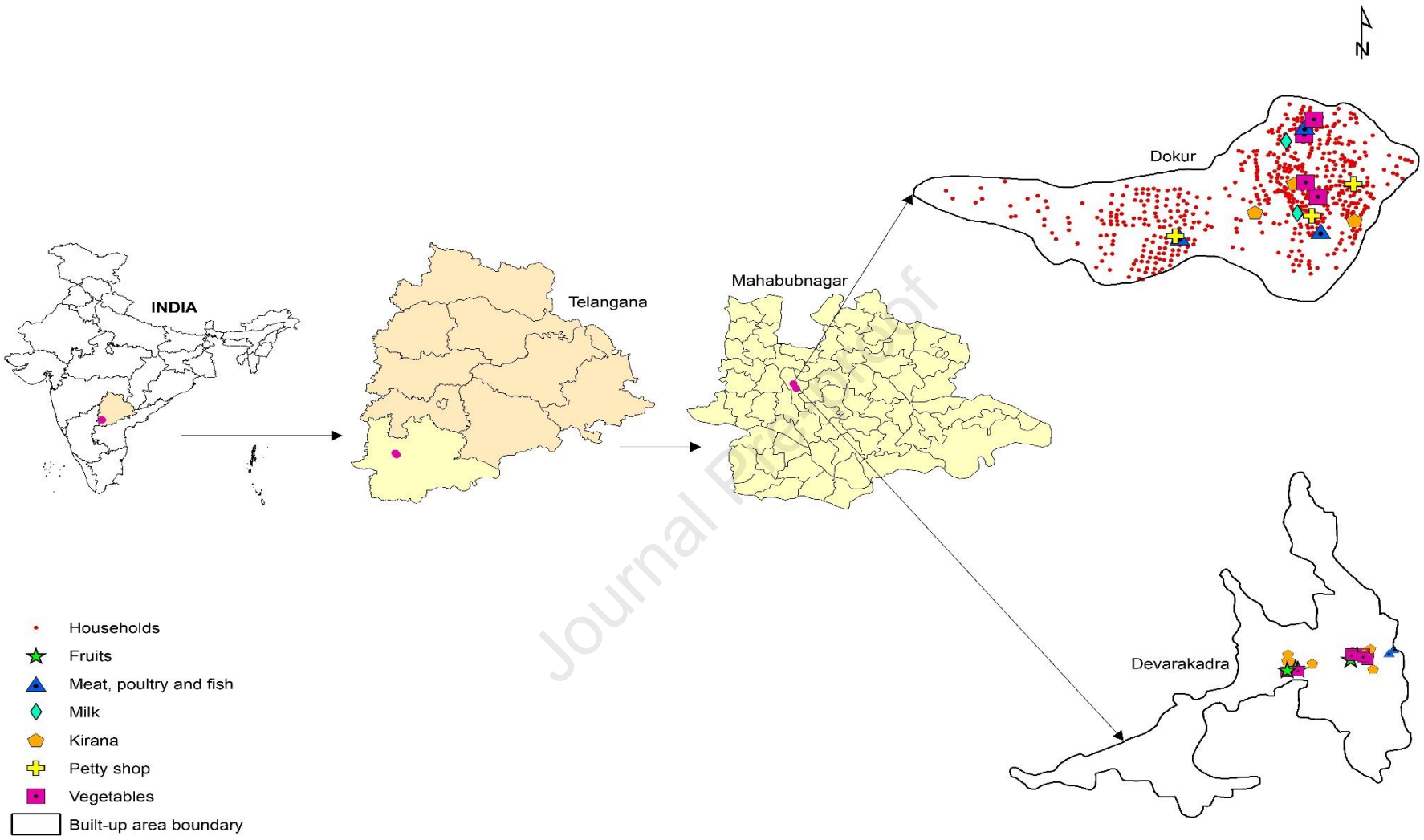


Figure 2b: Spatial distribution of vendor types in Dokur and Devarakadra study locations; Source: Map created using GPS coordinates of households and vendors in the selected location. The maps drawn are not as per the scale.

Supplementary Material

Annex 1: Socioeconomic characteristics of participants								
Villages/Socioeconomic variables	AUREPALLE				DOKUR			
	M1	M2	F1	F2	M1	M2	F1	F2
Average land size (Hectares)	2.4490	0.3822	1.9501	2.1242	1.5889	1.9809	1.3759	1.6574
Average Ownership of farm assets (2014-2015) (INR)	152387	12658	91349	154888	103449	170145	122310	204301
Average Ownership of Non-farm assets (2014-2015) (INR)	696876	340098	600823	748558	860099	935908	469826	673290
Average Crop income per annum (2014-2015) (INR)	34722	9611	72315	50276	53385	69417	41833	45112
Average Livestock income per annum (2014-2015) (INR)	86138	6093	44628	64336	48218	79242	48239	69392
Average Total farm labor income per annum (2014-2015) (INR)	11803	34462	14639	18692	21135	25863	21677	25453
Average Non-farm income per annum (2014-2015) (INR)	103612	85747	103702	136153	96448	109695	62420	78233
Average large ruminants (Number)	1.56	0.20	1.04	0.95	0.96	2.23	2.05	0.28
Average small ruminants (Number)	6.52	0.56	7.19	9.28	13.60	22.85	0.00	46.48
Average poultry (Number)	3.91	3.66	5.29	0.30	1.56	5.09	3.71	2.32
M: Male Group F: Female Group Source: Authors' calculations using VDSA household data								

Assessing the Rural Food Environment for Advancing Sustainable Healthy Diets: Insights from India

Research Highlights

- Inadequate knowledge of food environments limits effectiveness of nutritional interventions
- Study presets a scoring method to analyze the food environment more precisely
- Households preferred readily available and accessible energy-dense foods
- Nutrition literacy interventions may help in promoting healthier diets
- Food environment research is vital to design policies to support transition towards healthy diets

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.