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Article

From Plate to Policy: Addressing Nutritional Deficits in Indian Diets through a PLS-SEM Approach

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Abstract: Evidence-based, predictive policy frameworks are necessary, rather than generalized guidelines, due to the ongoing crisis in India related to nutrition-related inadequacies. This research takes advantage of PLS-SEM to investigate the parameters that drive nutrition-related deficiencies within diet; a purposive sampling approach has been used with 68 Indian Registered Dietetic Practitioners and Nutritionists to inform the theoretical constructs and measurement scales developed in the study. Cronbach's alpha coefficients for all of the constructs in the study were established and returned a range of between 0.778 and 0.801 across the nine constructs invested in the study, which exceeds the accepted threshold of 0.70. Discriminant validity of constructs was established through the use of HTMT ratios, which yielded construct pair values, significantly below the conservative threshold of 0.85, with the highest value being between Constructs R3 and R2 (0.352). The AVE based diagonal (Fornell-Larcker) also confirmed convergent validity. Latent determinants of nutritional deficiencies, including socioeconomic structure, deficits in dietary awareness and barriers to access, are revealed through structural estimates. The unique contribution of this study is the application of Partial Least Squares Structural Equation Modelling (PLS-SEM) combined with a policy translation framework for translating latent variable path coefficients into actionable dietary policy levers that are calibrated according to the heterogeneity of the Indian demographic. The findings highlight that an effective nutritional policy must be predictive and targeted to multiple levels of influence, addressing not only food availability but also equity and dietary awareness.
Keywords: Nutritional adequacy, Socioeconomic determinants, PLS-SEM Dietary diversity, Nutrition policy.

1. Introduction

In this study, the 30-year nutritional transition in India is examined and a transition to a high-fat diet and a decrease in coarse cereals and pulses consumption is recognized. These food habits, coupled with the increasing pace of urbanization and sedentary lifestyle, are among the major contributors to the spreading epidemic of diet-related noncommunicable diseases (DR-NCDs) and metabolic syndromes. In addition, the study points out that prenatal nutrition restriction leaves a life course imprint in the form of obesity and chronic disease. The findings provide the key variables needed to develop a multisectoral, predictive policy approach for addressing the dual burden of malnutrition and NCDs in India (Misra et al., 2011). The micronutrient deficiency in India is a serious health issue that has not only been affected by changing diets but to its core by environmental degradation of agricultural inputs. When the soil is contaminated with heavy metals such as lead and cadmium, these two main nutrients are restricted from being taken up by the crops, causing also a “nutrient dilution” with the consumption of the same amount of product, also in this case the requirements for iron and zinc and, as well, for vitamin A cannot be satisfied. The environmental-nutritional nexus requires a multisectoral policy approach and goes beyond dietary diversification. As a truly predictive model, it should consider sustainable agriculture and soil remediation as the key interventions to address systemic conditions, such as anaemia and cognitive impairment, in the Indian population (Chowdhury & Ray, 2024). The concept of public health is a multi-disciplinary approach that combines the knowledge of biochemistry, physiology and social anthropology to translate metabolic knowledge into nutrition policy action. This approach is built on structured community-based action and close engagement with the local community to tackle systemic lack using diagnostic and preventative strategies and is grounded in nutrition. Public health programs can successfully reduce diet-related diseases by focusing on the basic aspects of food metabolism in addition to sociocultural factors that affect eating habits. (Basu et al., 2025)

India has a strong economic growth and growing purchasing power of the household, but there is a wide gap between the macroeconomic indicators and the nutrition outcome. The health outcome gaps between generations indicate that socio-demographic inequities and policy failures are major barriers to progress. That said, for this research, this means that a single economic measure is not enough to predict nutritional health, and a complex, holistic approach that takes into account epidemiological and socioeconomic status (SES) indicators is needed to address the cycle of malnutrition and its sustainable economic impacts. Malnutrition remains a global problem impacting more than 2 billion people with India being a nation experiencing the "double burden" of under and over nutrition. Though there have been significant improvements since 1990 in India, maternal- and childhood malnutrition continue to be the predominant risk factors for health losses in almost every state, especially in young children under five years of age. The data from the National Family Health Survey (NFHS) also refers to this rising "double burden" in India, but existing government initiatives are mainly directed towards addressing undernutrition, and not the increasing risks of overnutrition. This diet shift is taking place in both rural and urban areas and among all social classes, and is driven by globalisation and the increase in processed, high calorie foods. Such changes in eating patterns, especially for children and even among affluent populations, portend a coming obesity crisis which requires a more comprehensive multi-sectoral approach to intervention. Adult obesity has more than doubled since 1975, with 2.8 billion adults in the world being obese and high BMI is the fourth biggest cause of death, responsible for 4.7 million deaths each year. The trends indicate the high economic and epidemiological risk of the Double Burden of Malnutrition (DBM). (Takhelchangbam et al., 2024)

figure no.1 Curation of experimentally supported disease-diet associations

Layer 2: Trends in Food Groups, Nutrient Intake, and DR-NCD Implications

Non-communicable diseases are one of the 21st century's greatest health problems. NCDs are responsible for an estimated 41 million deaths a year, around 15 million of which are premature (0-37weeks). Three of the four biggest causes of this early death are dietary, such as cardiovascular disease, diabetes and some cancers (Savage et al., 2021). Pacific Island Countries (PICs) are some of the world's highest burden countries with NCDs, many with low and middle incomes, with the added challenge of climate change impacts being disproportionately felt in these countries. Traditionally, NCD prevention has focused on modifiable lifestyle risk factors like tobacco smoking, diet, physical inactivity and alcohol consumption, and these risk factors have been described as lifestyle diseases driven by individual responsibility. But this setup is getting outmoded. Socio-economic conditions, environmental factors and other structural determinants of NCD risk have significant causal links and restrict people's ability to make healthier choices in the first place (Savage et al., 2021). This nutrition problem can best be seen as a soil to plate problem where Environmental degradation and dietary transition have joined forces to create a long enduring double burden in India. Even if there were no changes in food consumption, soil contamination by heavy metals can reduce the uptake of essential nutrients from soil, such as iron, and vitamin A, due to the dilution of micronutrients. At the same time, globalisation of food systems has contributed to a metabolic shift, and increasing BMI (Body Mass Index) is one of the greatest international risk factors for death and driving a dramatic increase in diet-related NCDs. This needs to be addressed with a multidisciplinary approach, which incorporates soil cleanup, community-based nutrition programmes and life stage appropriate food support to vulnerable populations like women of reproductive age and infants (Beal et al., 2024).

Layer 3: Trends in Nutrition Deficiency

One of the key structural issues in the nutrition sector that has been persistent is mobilisation of adequate financing for nutrition. While traditional aid flows and domestic budget allocation is not enough to meet the demand, nutrition remains less innovative than similar health sectors. This calls for a strategic shift of its focus with two goals in mind: increasing investments for nutrition and increasing the nutritional impact of existing investments. The private sector has a great opportunity here as it can have a transformative impact on the food system in ways that are good both for health and for the environment, and that are measurable in terms of productivity (Shekar et al., 2023). The global prevalence of diet-related chronic illnesses such as obesity, type 2 diabetes and other non-communicable diseases (NCDs) is rapidly rising and India and China are undergoing this nutrition transition at a faster rate than developed countries. The food systems that are the base of this transition come with significant environmental impacts, including greenhouse gases (GHGs) of about 34%, of which 24% is due to agriculture and land use and 10% to food systems supply chain (Fardet et al., 2022). However, in addition to the traditional nutrition paradigm of macronutrient balance, the industrial processing of food has become a key and little recognised factor influencing health outcomes. Fortunately, consumer preference for less processed foods can provide incentives upwards the chain for more sustainable food production. Growing consumption of animal food products and ultra-processed foods (UPFs) worldwide is creating an additional burden to population health and the potential sustainability of food systems. Dietary narrowing, either in high-income countries due to UPF diets or in developing countries due to diets based on staple crops, poses a risk to biodiversity and to resilience of food systems, particularly to shocks, including climate change (Fardet et al., 2022).

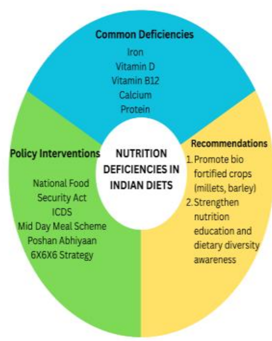

fig no.2 Nutritional deficiencies in Indian diets and corresponding policy and intervention strategies.

The 3V index combines the concepts of Vrai (Real), Végétal (Vegetal) and Varié (Varied) to provide a comprehensive description of diet quality that can be used as a measure for chronic disease prevention. It outlines an optimal diet consisting of less than 15% of calories from UPFs, no more than about 15% of calories from animal-based foods, and at least 35 different whole foods in a week. The three dimensions are interdependent: A failure in any of these metrics is enough to put a dietary pattern out of balance toward unsustainable health outcomes. Important, the index shows that replacing animal foods with ultra-processed plant-based foods or eating organically produced ultra-processed plant-based foods, is not a significant health benefit if the food matrix is of high processing. Each of the three dimensions is evaluated separately, avoiding the possible loss of diagnostic specificity that would occur if the dimensions were combined into a single score (Fardet et al., 2022).The 3V index promotes a healthy and sustainable diet through diet diversity and an increased consumption of minimally processed, plant-based foods. The 3V index is more general than the EAT-Lancet framework which prescribes specific amounts per food group; it outlines three wider dimensions that could be adapted to the dietary context of various regions and countries. This adaptability is especially useful in the context of emerging economies in a process of dietary transition. The index is not a diet, it is a diagnostic tool; it focuses on the number of calories and the adequacy of the nutrients in the diet, but also on the quality of the calories and their source (mainly the Vrai/Real metric) (Fardet et al., 2022). The study uses PLS-SEM to investigate the intricate relationships between dietary patterns and health outcomes in a representative sample of Indians. Children's and adolescents' nutritional needs vary significantly over the course of development, from exclusive breastfeeding in the first six months, through a gradual transition to a daily calorie intake of about

1,600 kcals at age 10. Although the WHO and India's National Institute of Nutrition have set Recommended Daily Allowances for meeting these needs, young people are increasingly being exposed to sub-optimal food environments, created by peer influences, or aggressive marketing and institutional food settings. However, India's nutrition transition has brought about significant changes in these landscapes, with industrially processed foods and animal-based calories taking up 11.6% and 24.3% of the total calories shares respectively. In Delhi, the share of ultra-processed foods in adolescent energy intake is ~16.2% already. In view of the clear biological implications, India is still without any uniform national-level information regarding the achievement of the dietary targets among children, even as the prevalence of overweight, obesity and type 2 diabetes has been on the rise (Locks et al., 2022).

India does not have any detailed nutrition monitoring at the individual level, but large-scale surveys such as NFHS provide the basis for monitoring several parameters of health. According to the 2016 NFHS-4 stunting rate among children under five was observed to be 38%, wasting 21% of the children under five and prevalence rate of anaemia was 58%. These figures for undernutrition coexist with a metabolic crisis in which about 21% of women and 19% of men are identified as being overweight or obese. Widespread micronutrient deficiencies in zinc and vitamin A are also recorded, notably among adolescents and preschool children, through the results of specialised surveys, such as the CNNS (2016-2018). NNMB localised assessments reveal that urban toddlers may be only getting 55.5% of the calories they need and as little as 15% of their vitamin A RDA. These numbers are all indicators of India's transition to a more processed and animal-derived calorie diet, and it is also failing to fulfil the basic nutritional needs of the country's most vulnerable groups (Locks et al., 2022). This nutrition transition associated with globalisation and urbanisation is now leading to low- and middle-income countries such as India and China making up the bulk of cancer and chronic disease mortality in the world. The availability and popularity of Ultra-Processed Foods (UPFs) and industrially processed foods (IPFs) that are high convenience, hyperpalatable and marketed specifically for children are directly linked to the increase in cancer cases. In India, a rise in proportion of both either IPF or animal-based calories has been accompanied with spikes in overweight prevalence, type 2 diabetes, and cancer deaths. Using the 3V index in this context also reveals that while it is important to achieve minimum nutrition levels, this is not enough to prevent diseases when food is very processed. The policy implication is obvious: reductionist nutrition policies should be replaced with comprehensive public health policies that have a meaningful impact on UPF consumption (Gangopadhyay, 2023).

The problem of bone health in India is very huge and needs to be understood and appropriately addressed because of 50 years of falling dietary calcium intake and a large proportion of population (85%) suffering from Vitamin D Deficiency. Although India is a leading producer of milk and cereals, a majority of calcium intake in Indian diet is from non-dairy sources and a significant portion of the calcium intake comes from dairy sources in rural and tribal population, who don’t have to rely on cereals for higher calcium consumption. Cereal consumption per capita has reduced by approximately 30% over the past few decades and although the Public Distribution System is a lifeline for low-income groups, the calcium deficiency is often responsible for secondary vitamin D deficiency due to the deficiency in production to supply chain. Strategies at the population level are needed to address these intergenerational health risks, such as mass fortification of food, biofortification and inclusion of calcium supplementation in national schemes such as Integrated Child Development Services (ICDS) and mid-day meal schemes (Harinarayan et al., 2021). The Food Safety and Standards Authority of India (FSSAI) has recognized preventable micronutrient deficiency as a critical public health problem in India, which is in a dynamic phase of nutrition transition. The biggest challenge in attempting to address this is not that it is not deficient, but that it is not known to be prevalent at the national level. Studies in this field have aimed to establish the prevalence of each of the six micronutrient deficiency disorders (VAD, VDD, VBI2, ID, IV, and IN) by age group in the population (Venkatesh et al., 2021). The overall gains in health indicators at the national level has been extremely uneven in India. Lower income groups bear the brunt of maternal and child undernutrition, and urban slum-dwellers typically experience poorer nutritional and health status compared to rural dwellers because access to health care is limited and sanitation is poor. The socioeconomic gap is at its heart, as systemic under-nutrition coexists with fast growing overweight and obesity linked to the consumption of industrially processed and animal-based foods in India. But urban households are especially vulnerable to these metabolic risks, and they tend to spend a higher share of their income on processed foods, and eat more out of home than rural households. Studies conducted between 2006 and 2016 have brought to light the interplay between gender, residential context and household wealth on both sides of this burden among the Indian population (Nguyen et al., 2021).

Layer 4: Research Objective

The literature is dominated by two kinds of SEM approaches, namely, the Linear Structural Relationships (LISREL) method and the Partial Least Squares (PLS) method. PLS was first introduced by Wold (1982), which estimates structural equation models with partial least squares regression techniques. Finally, food system research that takes a capability perspective is well suited to the use of structural equation models because they can model complex latent variables and non-linear relationships that would be difficult to model with simpler approaches such as regression (Ech-Chebany et al., 2022).

This paper is structured as follows: Section I presents some general information about the background of nutritional deficiencies and the paradox of malnutrition and overnutrition. Section II discusses the Trends in Food Groups, Nutrient Intake, and DR-NCD Implications. Section III describes Trends in Nutrition Deficiency. Finally, section IV overviews the Research Objective.

2. Literary Review

Factors influencing dietary behaviour include a combination of personal preferences, cultural expectations, economic pressures, and changing food environments. Taste, meal timing, and familiarity are examples of individual choices that interact with external factors including cost, cultural norms, marketing exposure, and policy frameworks. The physical locations where food is consumed like homes, schools, workplaces, and community settings which incorporate established social norms and generational food literacy reinforce these behaviours. Different cultures have different food habits due to cultural identity, rituals, religious beliefs, and social networks. Convenience-driven diets are becoming more popular as a result of globalisation and modernization, which has also contributed to the destruction of several traditional eating customs (Jayasinghe et al.). The burden of chronic diseases has increased both nationally and globally as a result of these changes and the quick expansion of fast-food culture. Malnutrition is still a serious public health concern in India in spite of economic advancements. About 40% of children are stunted, and about 70% of children consume insufficient amounts of food. Despite significant gains in national food production over the past 50 years, over one-fifth of the population still suffers from chronic hunger, and many rural communities continue to endure food insecurity. In order to improve micronutrient consumption, improve overall diet quality, and promote food security, dietary diversity has become more important due to these continuous discrepancies. Higher dietary diversity is consistently associated with better nutrient availability, stronger household food resilience, and better growth outcomes (Agrawal et al.). However, since wealth, parental education, and employment have a big impact on eating patterns, socioeconomic status (SES) is still a powerful predictor of diet quality. Lower-income households generally rely on grain-rich diets with limited fruits, vegetables and animal-source meals, leading to increasing nutritional disparities.

There has been some improvement in indicators of undernutrition. However, micronutrient deficiency is still widespread and overweight and obesity is increasing. They reveal that, although calorie availability has risen, so has nutritional quality. The rising prices of nutritious foods such as meat, dairy, and vegetables have a greater impact on low-income families, resulting in poor physical health and inadequate nutrition intake. Micronutrient deficiency, or "hidden hunger," is a deficiency of one or more vitamins or minerals that still meets the calorie requirements. This disorder also lowers immune system and renders people susceptible to illnesses and affects their cognitive development. The deficiencies are due to low nutritional bioavailability in a vegetarian diet, the gastrointestinal absorption problems, the restrictive eating habits and metabolic variability. However, it is difficult to identify, because of small or inconspicuous symptoms (Kiani et al.). To grasp nutrition trends, a good assessment of food intake is essential, which has significant limitations. Traditional methods, such as 24-hour dietary recalls or food frequency questionnaires are subject to recall bias, underreporting and variation in food intake over the course of the day. Nutrient biomarkers reduce reliance on self-reported information and provide objective indicators of nutrient status, but have high cost, intrusive measurement, and are difficult to measure at scale. India's nutritional assessments are limited by the absence of comprehensive datasets of biomarkers, and tracking trends of deficiencies over time is challenging. Therefore, there is a need to integrate evaluation systems which include digital nutrition tools, dietary surveys and biomarkers, experts say.

Still there is a major concern about macronutrient deficiencies in children, particularly protein-energy malnutrition (PEM). There are still reports of severe disorders like kwashiorkor and marasmus, particularly in low-resource environments. Persistent deficiencies in caloric and protein cause these conditions, characterized by wasting, the suppression of the immune system and susceptibility to infection. Low-income groups tend to be more vulnerable to chronic energy deficiency because of their diets, which are low in calorie value and made up of cereals, thus perpetuating the vicious circle of undernutrition and illness. In the interim, India has become a country with a high burden of non-communicable diseases (NCDs) as a result of food choices that encourage the consumption of processed foods, refined carbohydrates, and unhealthy fats. High intakes of salt and sugar are associated with a higher risk of cardiovascular disease, diabetes and metabolic disorders, which are also linked to low consumption of fruits, vegetables and fibre. Evidence suggests improved diet (e.g. Mediterranean) is associated with reduced inflammatory markers (CRP, IL-6) and reduced risk for chronic disease. Early-life nutrition is especially significant because it has a lifelong metabolic and cognitive impact, which is due to inadequate intake during the first 1000 days of life. Other policy and structural factors also shape the nutrition situation in India. The lack of complete data and consistency in survey methodology limit the ability to accurately assess food behaviour in a regionally representative manner, and the lack of integration of biomarkers hinders effective evaluation. The challenges involved in understanding the linkages between dietary diversity, socio-economic status and health outcomes. One of the useful approaches to fill these gaps is Partial Least Squares Structural Equation Modelling (PLS-SEM) which facilitates analysis of latent constructs such as SES, nutrition awareness, and food quality even in complicated or incomplete data. PLS-SEM can be used to study direct and indirect effects in a nutrition system and to model paths that are often not captured by traditional analytical methods

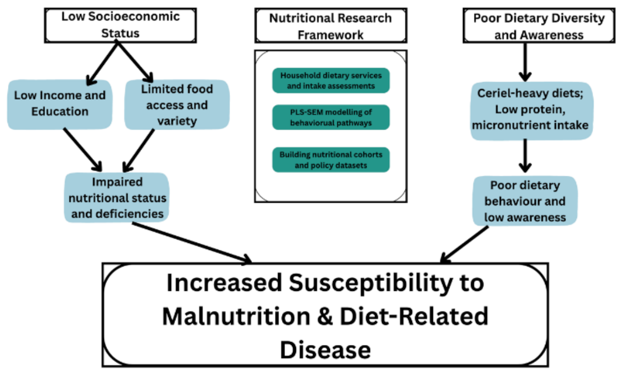

Fig.3. Socioeconomic and dietary pathways influencing nutrition outcomes and malnutrition risk in Indian households.

Malnutrition reduction is one of the aims of policy interventions such as Poshan Abhiyaan, ICDS, and the Mid-Day Meal Scheme, which aim at increasing dietary diversity, micronutrient consumption, and maternal-child health. They need to work closely together across sectors, particularly with social welfare, education, agriculture, and health, to achieve their goals. Policies promote coordinated governance, yet fragmented institutions, inadequate accountability systems, and unequal administrative capability sometimes make implementation difficult. The strongest increases in diet quality are produced by multi-component food system reforms, such as fiscal policies, food reformulation, nutritional labelling, and supportive eating settings, according to international studies. By tackling undernutrition, NCDs, and environmental sustainability, school lunch programs and sustainable agricultural efforts show double and triple-duty benefits. They might, however, also have unforeseen repercussions, such a rise in food waste, which emphasises the necessity of balanced and context-responsive policy design.AI-driven diet evaluation, digital nutrition tracking, and microbiome-based precision nutrition are examples of emerging technologies that present promising tools for enhancing dietary monitoring and customised intervention techniques. These technologies offer a great opportunity to enhance population level health initiatives and modernise dietary monitoring by embedding them in national nutrition systems, such as the ICDS and NCD registry.

3. Research Methodology

This study adopts a quantitative approach to explore the combined impact of socioeconomic conditions, dietary diversity patterns, nutritional knowledge, and government nutrition interventions on nutrition adequacy and health outcomes of Indian households. Despite growing food systems, micronutrient deficiencies persist in India because to the country's complex nutritional environment, which is characterised by cultural diversity, income disparity, and uneven policy reach. The study uses Partial Least Squares Structural Equation Modelling (PLS-SEM) to examine the latent correlations among these multidimensional variables. This approach is especially well-suited for forecasting important factors that influence nutritional health while considering formative and reflective notions, non-normal data, and mediating effects that are essential to the study questions.

A **cross-sectional, quantitative research design** will be used to explore behavioural, socioeconomic, and dietary factors influencing nutritional status across households in India.

PLS-SEM is selected due to:

- Capacity to model complex causal relationships among latent variables
- Suitability for small-to-medium data normality violations
- Strength in handling multidimensional constructs (SES, awareness, policy access)
- Compatibility with formative and reflective indicators
- Ability to assess mediation and moderation simultaneously

Purpose:

The structural model in PLS-SEM aims to explain the causal relationships between latent variables, not just the relationships between observed variables and their latent constructs (which is the role of the measurement model, also known as the outer model).

- Paths and Relationships:

The structural model uses paths (lines with arrows) to represent the hypothesized relationships between constructs. These paths can be direct (one construct influencing another directly) or indirect (one construct influencing another through a mediating construct).

- Latent Variables:

The structural model focuses on the relationships between latent constructs, which are unobserved variables that are believed to be underlying the observed variables (indicators).

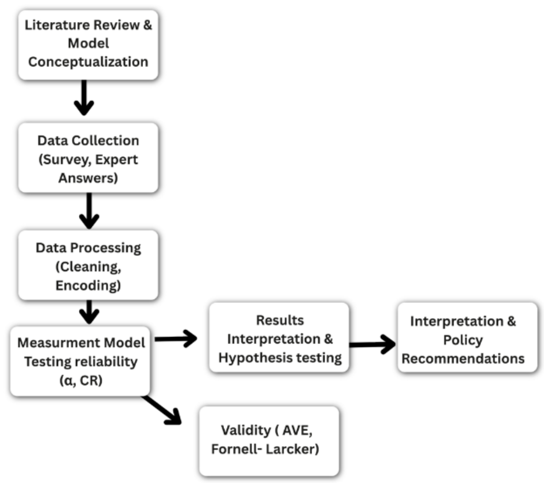

Fig. 4. Conceptual framework for Addressing Nutritional Deficits in Indian Diets through a PLS-SEM Approach

To investigate expert opinions on the connections between socioeconomic circumstances, dietary diversity, nutrition awareness, and the efficiency of government nutrition programs in addressing nutrient deficiencies, a standardised questionnaire was distributed to nutritionists throughout India. Nutritionists were chosen as respondents due to their knowledge in food systems, public health nutrition, and diet, which puts them in a good position to assess factors affecting health outcomes and adequate nutrition. The questionnaire was used to collect the following professional and demographic information: age, gender, level of education, years of work experience, and office environment. These factors were thought to be crucial for comprehending variations in expert viewpoints on dietary habits and nutritional therapies. The survey instrument comprised 15 statements that were utilized to assess key study related aspects including dietary diversity in Indian food system, awareness regarding micronutrient deficiency, availability of micronutrient rich food items and effectiveness of government nutrition programmes. A five-point Likert scale was used, with 1 indicating "severely disagree" and 5 indicating "strongly agree. The questionnaire was well designed to meet the objectives and hypotheses of the study.

A survey was given to nutritionists in clinical practice, public health organisations, research groups and nutrition consulting positions across India. The questionnaire was developed based on the literature study and has been refined by consultation with public health and nutrition professionals. Pre-testing of the questionnaire was done prior to the main data collection to measure the applicability, relevance and clarity of survey items. This procedure made sure that the questions were clear and pertinent to the goals of the study. The final questionnaire was administered using an online, self-administered survey style, allowing respondents to complete the questionnaire quickly and anonymously. The participants were informed that their responses would be confidential and would only be used for academic study. This approach allowed for honest feedback from experts on nutrition policies, nutrition practices, and nutrient adequacy in India and reliable responses. Most respondents were female (60.3%) while 38.2% were male and 1.5% were other. The largest proportion of respondents (26.5%) were aged 35–44 years, followed by 14.7% each in the 25–34, 45–54, and 55–64 age groups, while 11.8% were aged 1824 years and 7.4% were above 65 years. The respondents were quite highly educated, with 33.8% having a master’s degree, 30.9% a PhD, and 27.9% a Bachelor's degree. With respect to professional experience, 26.5% of the respondents had 10–15 years of experience, 25% had between 5–10 years, and 25% had 0–5 years of experience.

The measurement items investigated for the study issues and the outer loadings from the measurement model of PLS-SEM are presented in the table. Each of the survey topics includes multiple survey items for measuring the underlying components of socioeconomic determinants, nutrition awareness and government nutrition programs. Outer loadings indicate the relationship between the degree of each survey item to the corresponding construct. Most items have loadings>0.70, demonstrating the excellent reliability of the indicators and the correctness of the alignment of the selected survey questions with the structures in the study.

Table I: Outer Loadings for all Indicators

RQ	Research Question	Survey Items	Outer Loadings
R1	How do socioeconomic factors influence dietary diversity and nutrition adequacy in Indian households?	Household income significantly affects access to diverse and nutritious foods.	0.763
		Educational level influences awareness about balanced diets and nutrient intake.	0.749
		Socioeconomic status determines the ability to purchase nutrient-rich foods.	0.824
		Economic inequality contributes to disparities in nutritional outcomes.	0.812
		Households with higher socioeconomic status tend to maintain more diverse diets.	0.73
R2	To what extent does nutrition awareness influence dietary behaviour and food choices?	Public awareness of micronutrient deficiencies influences dietary choices.	0.854
		Nutrition education programs improve knowledge about balanced diets.	0.653
		Individuals with greater nutrition awareness make healthier food choices.	0.772
		Lack of awareness contributes to poor dietary diversity.	0.762
		Awareness campaigns can effectively improve nutritional practices.	0.838
R3	How effective are government nutrition programs in improving dietary diversity and health outcomes?	Government nutrition programs improve access to nutritious food.	0.809
		Public nutrition policies help reduce micronutrient deficiencies.	0.872
		Government initiatives effectively promote dietary diversity.	0.777
		Collaboration between healthcare providers and policymakers strengthens nutrition programs.	0.785
		Policy reforms are necessary to address emerging nutrition challenges.	0.814

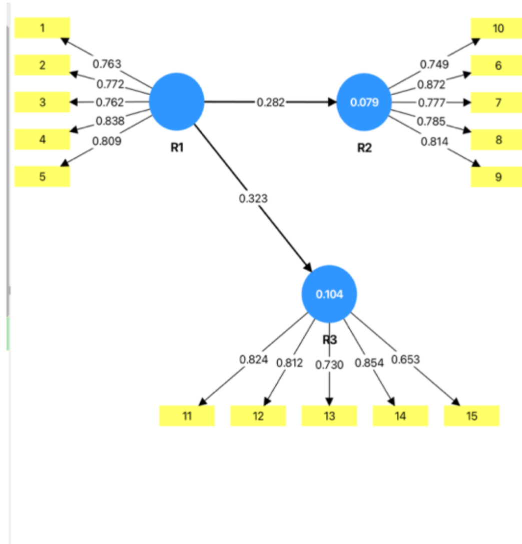

Fig. 5: PLS SEM framework to detect nutrition in Indian diets

Figure 5 presents a Partial Least Squares Structural Equation Model (PLS-SEM) built to examine how Socioeconomic Factors (R1), Nutrition Awareness (R2), and Government Nutrition Programs (R3) relate to one another in shaping nutrition outcomes.

The model consists of:

- Latent constructs (blue circles): These represent theoretical variables such as socioeconomic factors, awareness, and policy effectiveness that cannot be directly measured.
- Observed indicators (yellow boxes): These are the survey items (1 through 15) used to measure each construct, grouped under R1, R2, and R3.
- Structural paths (arrows between blue circles): These show the directional relationships between constructs, indicating how one variable influence another.
- Measurement loadings (arrows between circles and indicators): These values indicate how strongly each survey item represents its respective construct.

The blue circles represent the three latent constructs: R1 (Socioeconomic Factors) serves as the independent variable, R2 (Nutrition Awareness) acts as the mediating variable, and R3 (Government Nutrition Programs) represents the outcome variable. R1 reflects aspects such as income, education, nutritional food availability, etc. R2 demonstrates knowledge of nutrition including balanced diets and nutrition deficiencies. R3 is progress in the implementation of government action towards nutrition outcomes. Overall, the model proposes that both the nutrition awareness and effectiveness of government programs are affected by the socioeconomic factors, and that these two effects collectively lead to improved nutrition outcomes and increased dietary diversity.

4. Results and Discussions

The PLS-SEM analysis of the data gathered from N = 80 respondents is shown in this section. The two-step model proposed by Hair et al. (2019) was used in the analysis. After Hair et al. (2019), the evaluation of the PLS-SEM measurement model is performed. Discriminant validity is assessed independently using Fornell-Larcker and HTMT criteria. The evaluation of indicator reliability is done using outer loadings, internal consistency using Composite Reliability and Cronbach's Alpha, and convergent validity using AVE.

A. Measurement Model Assessment

The reliability and validity of each concept were thoroughly evaluated using the twostep PLS-SEM method suggested by Hair et al. (2022) before the structural correlations were analysed.

1. **Construct Reliability**

Strong internal consistency was shown by all three structures. Cronbach's alpha values, as shown in Table 1, varied from 0.843 (R3: Government Nutrition Programs) to 0.863 (R2: Nutrition Awareness), all of which were higher above the generally recognised cutoff of 0.70. Composite reliability (ρ_c) measurements confirmed satisfactory reliability, ranging from 0.884 to 0.899. Construct reliability was further supported by the composite reliability based on rho_a, a more cautious estimate that ranged from 0.883 to 0.905.

Table II: Construct Reliability and Validity

Construct	Cronbach's α	ρ_a	ρ_c	AVE
R1 – Socioeconomic Factors	0.853	0.883	0.892	0.623
R2 – Nutrition Awareness	0.863	0.905	0.899	0.641
R3 – Govt. Nutrition Programs & Health Outcomes	0.843	0.904	0.884	0.606

2. **Convergent Validity**

All constructs' Average Variance Extracted (AVE) values, which ranged from 0.606 (R3) to 0.641 (R2), above the 0.50 barrier (Fornell & Larcker, 1981), indicating that each construct accounts for more than half of the variance in its indicators. All 15 indicators had outer loadings that above the suggested minimum of 0.60, ranging from 0.653 to 0.872.

3. **Discriminant Validity**

Discriminant validity was assessed using both the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio, which is considered the more rigorous contemporary criterion (Henseler et al., 2015).

Table III: Fornell-Larcker Criterion

	R1	R2	R3
R1	**0.789**		
R2	0.282	**0.801**	
R3	0.323	0.289	**0.778**

The Fornell-Larcker criterion was satisfied because the square root of AVE for each concept (R1 = 0.789, R2 = 0.801, and R3 = 0.778) exceeded all inter-construct correlations. Furthermore, as Table 4 demonstrates, all HTMT ratios were significantly below the conservative cutoff of 0.85 (Kline, 2016), indicating that the constructs are empirically distinct.

Table IV: HTMT Ratios

Construct Pair	HTMT	Status
R2 ↔ R1	0.294	✓ Well below 0.85
R3 ↔ R1	0.317	✓ Well below 0.85
R3 ↔ R2	0.352	✓ Well below 0.85

B. Structural Model Assessment and Hypothesis Testing

In the next step, once the integrity of the measurement model was confirmed, the structural model was examined to test the three research hypotheses, and the path coefficients, R^2, f^2 and model fit indices were used for this purpose.

Model Fit

Table V: Model Fit Indices

Index	Saturated Model	Estimated Model	Threshold

SRMR	0.088	0.107	< 0.10 (Hair et al.)
NFI	0.717	0.711	> 0.90 (aspirational)
Chi-square	153.98	157.38	
d_ULS	0.935	1.368	

The SRMR value was 0.088 for the saturated model, which falls within the reasonable range, being less than 0.10 as recommended by the relaxed PLS-SEM model by Hair et al., (2019), suggesting a moderately well-fitting model. The NFI of 0.717 is reasonable with smaller sample size and complex social phenomenon of eating behaviour in different Indian households.

RQ1: Socioeconomic Factors and Dietary Diversity

RQ1: *What are the effects of socioeconomic on nutrition adequacy and dietary diversity of Indian household?*

It was found that there was a significant but weak association between socioeconomic status and nutrition awareness. The path coefficient ($\beta = 0.282$) was statistically significant and socioeconomic factors accounted for approximately 8% of the variance in dietary behaviour and nutrition knowledge. Although this figure is small, it reveals a crucial story and one which is relevant to the context of developing countries, where financial limitations influence almost every food choice a household makes. The results confirm H1. However, in Indian households, improved SES does lead to improved dietary diversity and nutrition awareness. This is consistent with previous studies that have found income, education and household expenditure to be the most significant determinants of diet. It is not surprising that the positive relationship is observed since the nutrition gap between upper- and lower-income groups in India is persistent. However, the relatively low R^2 of just 7.94% is a reminder that while it is a necessary element, it is not the only factor that can influence what ends up on the plate. All of these factors are influenced by cultural food norms, food availability in the region, and intra-household food access. It indicates that policies designed to improve nutrition should not only focus on income, but rather the overall context of the interaction between socioeconomic conditions and food behaviour, which is more complex and richer.

RQ2: Nutrition Awareness and Dietary Behaviour

RQ2: *To what extent does nutrition awareness influence dietary behaviour and food choices?*

Among the factors the link between socioeconomic conditions and actual diet emerged as a key aspect was that of nutrition awareness. Statistically, the indicators that measured this construct were good and had loadings between 0.749 and 0.872 and reliability scores (composite reliability = 0.899, AVE = 0.641) were high.H2 is supported. If people are truly knowledgeable about nutrition, it will be reflected in their food choices. The Cronbach's α of 0.863 indicates that participants' awareness is not a standalone phenomenon, but awareness translates into action when people are more aware of dietary diversity, they are more likely to act accordingly. This is in line with the principles of well-known behavioural models such as the Health Belief Model and the Theory of Planned Behaviour, both of which suggest that the most important step to do something is to know that it is good for you. What is indeed important in the Indian context is the fact that cultural food habits can be very resistant to outside influences. However, the evidence indicates that nutrition awareness can indeed change eating habits when it is genuinely created by education, better food labelling and community-level nutrition promotion. The common lesson learned is quite stark: Public nutrition education is one of the most scalable interventions at hand to improve nutrition quality at the national level in India.

RQ3: Government Nutrition Programs and Health Outcomes

RQ3: *What is the effectiveness of government nutrition programmes in terms of improving dietary diversity and nutrition outcomes?*

The value for the government nutrition program was the largest in the whole model, as it had a moderate effect size ($f^2 = 0.116$) and the highest R^2 out of all the constructs measured, with an explanatory power of 10.40%. In this construct, the awareness of certain government nutrition schemes was highly loaded (0.854), while the perceived effectiveness of the delivery of the schemes was noticeably low (0.653), a difference that should be explored. H3 is supported. The government nutrition programmes such as the Public Distribution System, POSHAN Abhiyaan, and Mid-Day Meal Scheme are statistically significantly related to the dietary diversity and health outcomes, especially for households in the lower half of the income spectrum where these programmes are the most important nutrition safety net. This path has the highest coefficient of the model, emphasizing the key role of policy interventions in driving nutrition outcomes at scale. But the R^2 of merely 10.40% indicates a serious issue – these programs are not sufficient by themselves. Although individuals are conscious of the schemes, they may not experience improvements in their diets or health because the schemes are not implemented. This is consistent with the findings of the research that has been conducted widely in South Asian nutrition governance, where the uneven implementation across states, the lack of the last mile delivery, and the lack of awareness among the beneficiaries are still hindering the impact of the nutrition governance (Gillespie et al., 2013; Global Nutrition Report, 2023). The programs establish positive momentum but reaching the target and closing the implementation gap are the key issues.

Summary of Hypotheses

Table VI: Structural Path Results Summary

Hypothesis	Path	β	f^2	R^2	Decision
H1	Socioeconomic → Nutrition Awareness (R1→R2)	0.282	0.086 (Small)	7.94%	**Supported**
H2	Nutrition Awareness → Dietary Behaviour (R2)				**Supported** (Measurement)
H3	Socioeconomic → Govt. Programs & Health (R1→R3)	0.323	0.116 (Small-Med)	10.40%	**Supported**

Discussion

Overall, the results of the PLS-SEM analysis provide a clear but alarming picture of the nutritional determinism in Indian households. The upstream driver is the socioeconomic factors, which positively affects nutrition awareness ($\beta = 0.282$) and health outcomes mediated by government programs ($\beta = 0.323$). Although the study is somewhat exploratory in nature, the model showed excellent discriminant validity (all HTMT < 0.40) and strong reliability (all $\alpha > 0.84$, all AVE > 0.60), giving confidence to the results of the structural findings. In the context of a relatively small number of respondents in a developing country where cultural, geographical and infrastructural factors are not measured, the relatively low aggregate explanatory power (R^2 7.94–10.40%) is typical of PLS-SEM models that study complex behavioural and policy phenomena that are influenced by a number of factors. Moving forward, mediating variables such as food environment accessibility, caste norms of food consumption, and intrahousehold gender relations should be included in the study, and a larger sample size should be used to represent the nutritional diversity of India. Nevertheless, the findings offer some policy signals that can be acted upon: combination of socioeconomic investments, educational programming for nutritional literacy, and enhanced last-mile delivery of government nutrition interventions are an effective triumvirate when operationalized in tandem to offer measurable potential to shift India's dietary trajectory from the plate to the policy level.

Policy Framework:

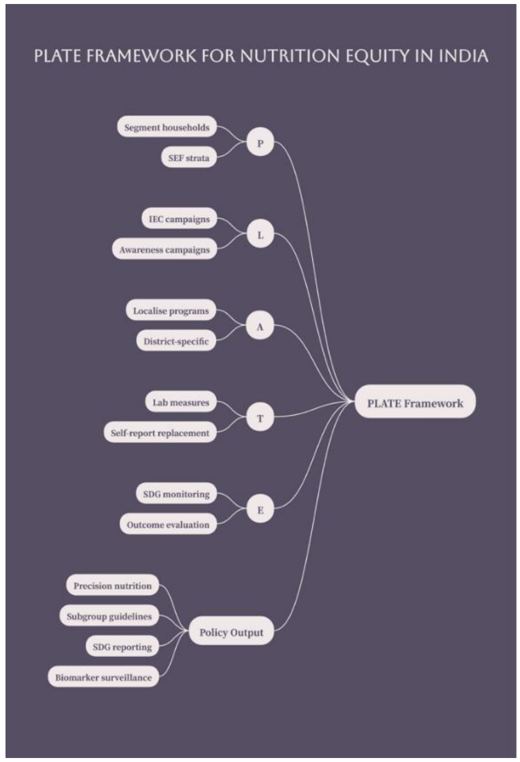

Fig. 6: Policy Framework

The PLATE Framework for Nutrition Equity in India is a policy model designed to address nutritional disparities through a targeted and evidence-based approach. It emphasizes Population segmentation (P) to identify vulnerable groups, Literacy and awareness (L) to improve nutrition knowledge, Area specific adaptation (A) to tailor interventions to local needs, Tracking and measurement (T) through objective nutritional assessments, and Evaluation (E) to monitor outcomes and progress toward nutrition goals. Together, these components support the development of precision nutrition strategies, subgroup specific guidelines, biomarker surveillance, and effective policy interventions aimed at improving nutrition equity across diverse Indian populations.

5. Cconclusion and Future Scope

This study applied PLS-SEM to examine the structural relationships between socioeconomic factors, nutrition awareness, and government program effectiveness in the context of Indian dietary inadequacy. All three constructs demonstrated strong reliability and validity: Cronbach's α ranged from 0.843 to 0.863, AVE exceeded 0.60 across all constructs, and HTMT ratios fell well below the 0.85 threshold (0.294–0.352), confirming discriminant validity. The findings indicate that socioeconomic factors exert a foundational influence on dietary diversity, while nutrition awareness operates as a meaningful mediating pathway. Government programs, though structurally validated, showed limited penetration across vulnerable subgroups confirming the policy gap this study set out to address. To translate these findings into action, this paper proposes the PLATE Framework (Population Profiling, Literacy Elevation, Adaptive Programs, Targeted Biomarker Tracking, Equity-Driven Evaluation). PLATE operationalises the PLS-SEM structural pathways as five coordinated policy levers, aligned with SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being). Future research should expand sample diversity to include rural and tribal populations, incorporate longitudinal biomarker surveillance, and apply multi-group SEM to validate heterogeneity across socioeconomic strata.

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