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Improving Dietary Diversity among Tribal Populations: A Decade of Intervention in Sonbhadra District of Uttar Pradesh, India

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ABSTRACT

Tribal communities in India often face food insecurity, malnutrition, and limited dietary diversity due to socio-economic constraints and dependence on subsistence agriculture. This study evaluates the impact of integrated agricultural interventions under the Tribal Sub Plan (TSP) on the dietary patterns, nutritional intake, and economic well-being of tribal households in Sonbhadra district, Uttar Pradesh. A longitudinal study was conducted from 2013 to 2023, assessing pre- and post-intervention dietary habits using structured household surveys, Principal Component Analysis (PCA), and statistical validation through Z-scores and paired t-tests. The intervention introduced high-yielding crop varieties, backyard poultry farming, and nutrition-sensitive agricultural practices, leading to a significant increase in dietary diversity, protein intake, and household income. The study confirms that crop-livestock integration enhances nutritional security and economic resilience in marginalized communities. Additionally, qualitative data from focus group discussions (FGDs) highlighted improved food accessibility, household empowerment, and self-reliance. The findings underscore the importance of scaling up such interventions through policy support, value addition in agriculture, and market linkages for long-term sustainability. This study contributes to the global discourse on agriculture-nutrition linkages and aligns with the Sustainable Development Goals (SDGs) on hunger and health.

Keywords: *Tribal Sub Plan (TSP), Dietary Diversity, Integrated Agriculture, Food Security, Livelihood Improvement, Sustainable Nutrition, vegetables, pulses*

Short Name	Full form
TSP	Tribal Sub Plan
PCA	Principal Component Analysis
FGDs	Focused group discussions
SDGs	Sustainable Development Goals
ICAR	Indian Council of Agricultural Research
IIVR	Indian Institute of Vegetable Research
CARI	Central Avian Research Institute
SD	Standard Deviation
SE	Standard Error
CV	Coefficient of Variation
HDDS	Household Dietary Diversity Score
MDD-W	Minimum Dietary Diversity for Women

Introduction

Globally, indigenous and tribal populations face unique socio-economic and nutritional challenges due to geographical isolation, cultural dietary preferences, and limited access to modern agricultural and healthcare systems [1]. Malnutrition, food insecurity, and nutrient deficiencies are disproportionately prevalent among these communities, adversely affecting their health, productivity, and life expectancy [2]. In India, tribal communities constitute approximately 8.6% of the population and are among the most vulnerable groups, often experiencing inadequate dietary diversity and low nutritional intake due to socio-economic constraints [3]. Addressing these disparities through targeted agricultural interventions has become a critical strategy to improve food security and public health outcomes [4].

The Sonbhadra district of Uttar Pradesh, India, is home to several tribal communities, including the Chero, Bhagia, Panika, Kharwar, Agaria, Tharu, Gond, and Rajgond[5]. These communities are predominantly resource-poor, relying on subsistence farming and forest-based livelihoods for sustenance [6]. Economic marginalization often forces them to rely on nutritionally inadequate diets, with staple foods like "roti-namak" (bread and salt) being consumed when other food sources are inaccessible [7]. Limited access to government welfare programs, coupled with the challenging hilly terrain,

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exacerbates their vulnerability to food insecurity and malnutrition [8,9,10].

To address these challenges, the Government of India implemented the Tribal Sub Plan (TSP) in 1979–80, aimed at ensuring proportionate allocation of development resources for scheduled tribes [3]. Under this initiative, the ICAR-Indian Institute of Vegetable Research (ICAR-IIVR) adopted 1,400 tribal households across 14 villages in the Chopan block of Sonbhadra district. This intervention sought to enhance food security, dietary diversity, and overall nutritional well-being by integrating improved agricultural practices, introducing high-yielding crop varieties, and promoting backyard poultry farming [11].

Dietary habits are significantly influenced by the availability, accessibility, and affordability of food. Poor dietary diversity has been linked to various health complications, including micronutrient deficiencies, stunting, and increased susceptibility to infections [1]. Tribal communities in Sonbhadra traditionally relied on subsistence agriculture and forest produce for food, but erratic monsoons, soil degradation, and deforestation have threatened their traditional food systems [12]. The introduction of improved vegetable varieties, drought-resistant cereals, and protein-rich pulses under the TSP initiative aimed to address these concerns, ensuring year-round food availability and enhancing nutritional intake [13].

Vegetables are considered "protective foods" due to their high vitamin, mineral, antioxidant, and fiber content, which helps prevent various micronutrient deficiencies [2]. The TSP intervention introduced high-yielding varieties of staple vegetables, including tomato (var. Kashi Aman, Kashi Adarsh), brinjal (Kashi Uttam, Kashi Sandesh), chili (Kashi Anmol), and various cucurbits, legumes, and leafy greens (ICAR-IIVR, 2022). Additionally, drought-tolerant rice varieties (e.g., HUR-3022, Bina-11, DRR Dhan-44, CRR Dhan-801) and zinc-fortified wheat (WB-02) were introduced to enhance staple crop productivity and improve micronutrient intake [14].

Pulses, a critical source of dietary protein, were integrated into the cropping system to combat protein-energy malnutrition. Varieties such as UPAS-120 (pigeon pea), HUL-57 (lentil), and T-9 (black gram) were introduced to ensure adequate protein availability [15]. Additionally, backyard poultry farming was promoted through the distribution of 20,000 one-day-old chicks of improved breeds such as CARI-Debendra, CARI-Nirbheek, and Kadaknath. This intervention aimed to increase household protein consumption and generate supplementary income for tribal families [16].

Empirical studies have shown that interventions promoting dietary diversity and protein supplementation significantly improve nutritional outcomes, particularly among marginalized populations [17]. Increased vegetable consumption is associated with reduced incidences of malnutrition-related ailments, including anemia, night blindness, and immune deficiencies [1]. Furthermore, integrating animal protein sources, such as eggs and poultry, has been found to significantly enhance child growth indicators and cognitive development [2].

Previous research highlights the importance of localized and culturally relevant interventions in addressing dietary deficiencies among tribal populations. Successful case studies from African and Latin American indigenous communities demonstrate that agricultural diversification, coupled with nutrition education, can significantly improve dietary patterns and overall health outcomes [18]. The TSP intervention in Sonbhadra was designed following similar principles, emphasizing community participation, resource optimization, and sustainable farming practices [13].

The present study aims to evaluate the impact of the TSP intervention on the dietary habits of the tribal population in Sonbhadra. Specifically, it examines changes in food consumption patterns, nutritional intake, and the role of improved agricultural practices in enhancing dietary diversity. Using a mixed-methods approach, this research compares pre- and post-intervention dietary habits through surveys, statistical analyses, and Principal Component Analysis (PCA) [14]. The findings contribute to the growing body of evidence on the effectiveness of targeted agricultural interventions in addressing food insecurity and malnutrition among tribal communities.

This study is particularly relevant in the context of India's commitment to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being) [19]. By assessing the outcomes of an integrated agricultural intervention, this research provides valuable insights for policymakers, development agencies, and researchers working towards improving the nutritional well-being of vulnerable communities.

In the subsequent sections, the study details the methodology, key findings, and implications for future interventions. By analyzing the effectiveness of TSP-driven initiatives, this research seeks to offer a replicable model for improving food security and dietary diversity among tribal populations in India and beyond.

Materials and Methods

Conceptual Framework

This study adopts an integrated agricultural intervention model that builds upon the Sustainable Livelihoods Framework (SLF) and the Food Security and Nutrition Model, both of which highlight the intricate linkages between agricultural development, livelihood enhancement, and dietary diversification in marginalized communities. SLF emphasizes the role of financial, natural, human, and social capital in improving food security, while the Food Security and Nutrition Model underscores the importance of food availability, access, and utilization in ensuring nutritional adequacy.

The study hypothesizes that targeted interventions—such as the introduction of high-yielding crop varieties, promotion of backyard poultry, and enhancing access to diverse food groups—can significantly contribute to improving the nutritional intake and dietary diversity of tribal households. By ensuring a more stable and nutrient-rich food supply, these strategies aim to address both macro- and micronutrient deficiencies prevalent in tribal communities. Furthermore, the study aligns with Ajzen's Theory of Planned Behavior (1991), which posits that behavioral intentions are shaped by attitudes, subjective norms, and perceived behavioural control. In this context, the adoption of improved agricultural practices and diversified diets is influenced by cultural norms, access to agricultural resources, and knowledge dissemination. Understanding these behavioural determinants helps in designing interventions that are socially acceptable, economically viable, and sustainable within the tribal context.

Study Design and Sampling Justification

This research adopts a longitudinal pre-post intervention study design, spanning ten years (2013-2023).

The longitudinal approach enables an in-depth analysis of dietary changes over time, capturing the sustained impact of interventions on tribal food consumption patterns.

The study was conducted in Sonbhadra district, Uttar Pradesh, which has the highest tribal population in the state (20.7% of the total tribal population). Within Sonbhadra, Dudhi tehsil was selected due to its high tribal population density (31.1% overall and 41.5% in rural areas).

Under the Tribal Sub Plan (TSP) initiated by ICAR-IIVR, 1,400 tribal households from 14 villages in the Chopan block of Dudhi tehsil were targeted for intervention. From this population, a stratified random sampling approach was employed to select 102 households, ensuring representation of diverse geographical and socio-economic conditions. The sample included:

A total of 51 households residing near the forest (Bhalukudar: 24.366572, 83.214041, and Satdwari: 24.366564, 83.214014), representing communities with higher dependency on forest-based livelihoods. Another 51 households from farmland-dominant villages (Salaibanwa: 24.43950, 83.01147, and Dahakudandi: 24.44230, 83.11560), representing agriculturally dependent communities. The respondents for the study were mostly tribal farm women.

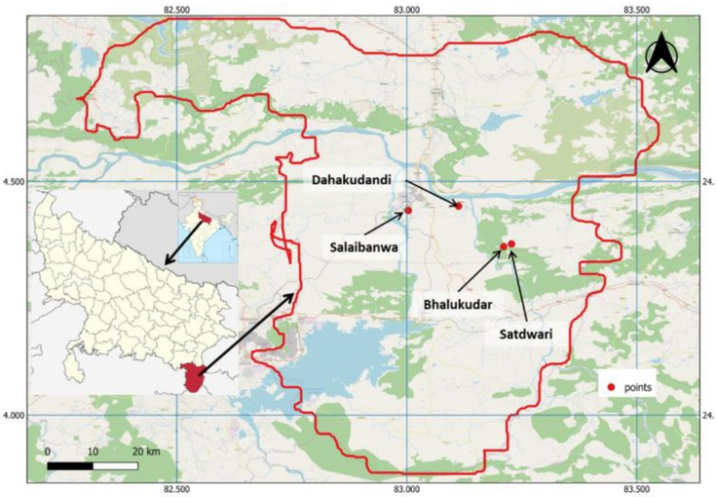

Fig 1: Study area in Sonbhadra District of Uttar Pradesh, India

Analytical Framework and Statistical Approach

The study employs a mixed-methods approach, integrating quantitative statistical analysis with qualitative insights to assess the impact of the intervention.

Statistical Validation of Dietary Changes

To rigorously assess dietary transformations following the intervention, a combination of statistical techniques was employed. Descriptive statistics—including mean, standard deviation (SD), standard error (SE), and coefficient of variation (CV)—were used to quantify dietary intake variations. Z-scores and paired t-tests were applied to determine the statistical significance of changes in food consumption patterns before and after the intervention. The use of Z-scores allowed for standardized comparisons across different food groups, ensuring a reliable measure of dietary shifts. Additionally, Principal Component Analysis (PCA) was utilized to identify key contributors to dietary diversity, reducing data dimensionality and highlighting the most influential food consumption variables.

Impact Assessment through Thematic Analysis

Beyond statistical validation, qualitative insights were gathered through Community Narratives and Focused Group Discussions (FGDs), capturing firsthand experiences of dietary changes and challenges faced by tribal households. The Household Dietary Diversity Score (HDDS) and Minimum Dietary Diversity for Women (MDD-W) indicators were incorporated to evaluate improvements in nutritional intake and dietary quality. The research followed a structured analytical process, starting with pre-intervention data collection (2013-2014) through household surveys, followed by the implementation phase (2014-2023) that introduced high-yielding crops, livestock integration, and nutrition awareness programs. A post-intervention survey (2023) reassessed dietary consumption patterns, with data processing and analysis conducted in 2023-2024, integrating statistical validation (Z-scores and PCA) and thematic analysis from FGDs to comprehensively evaluate the intervention's impact.

Results

Majority (70.59%) of sample tribal farm women were of 36 to 50 years of age and the average age of the sample was 40.86 years. There were only 6.86% women of more than 50 years of age show meagre life expectancy of the tribal farm women and malnutrition might be the probable reason for that. Although 22.55% women were of age of 20 to 35 years, but only 5.88% received the primary education that implies the poor level of functional literacy among them. The women under study were all married and belonged to joint families (43.14%) and nuclear families (56.86%). The sizes of the tribal families were relatively small consisted of average 6 family members. The average annual income recorded was Rs. 27690.00 per household per year and 53.89% worked as agricultural labourer whereas 46.11% had their income from other sources like work in cement factory, forest dwelling etc.

Table 1: Socio-economic profile of the respondents (n=102)

Sl.	Particulars	Values
1	Age (years) of the sample tribal women	Average age= 40.86 years, 20-35 years= 22.55%, 36-50 years= 70.59%, more than 50 years= 6.86%
3	Educational status of the tribal women	Unlettered= 94.12%, Primary education= 5.88%
4	Marital status of the tribal women	Married= 100%
5	Family status of tribal community	Joint families= 43.14%, Nuclear families= 56.86%
6	Family size (No) of tribal community	Avg. family size= 6, Avg. adults in the family (>18 years)= 2, Avg. children in the family (<18 years)= 4
8	Annual income, agricultural labour and other sources of income	Average annual income (Rs./year/household)= 27690.05, Share from agriculture labour= 53.89%, Share from other sources= 46.11%

The result shows that, the tribal community in Sonbhadra district of Uttar Pradesh used to consume both vegetarian and non-vegetarian foods (81.37%), but 19.38% households used to consume pure vegetarian foods. Table 2 highlights the frequency of consumption of the different food items. Wheat and rice were the staple food items consumed daily (62.75%, and 46.08%), four to five days a week (33.33% and 38.24%), two to three days a week (3.92% and 14.71%). Households who did not consume wheat and rice daily were partially dependent upon other course cereals like jawar, bajra, ragi etc.

The distribution of the respondents on consumption of pulses shown range of 13.73% daily, 27.45% four to five days a week, 23.53% two to three days in a week, 34.31% once in a week, 0.98% once in a month indicated inadequate pulse consumption. There were more than 10% of the respondents who used to consume leafy vegetables once in a month or rarely and nearly 20% of the respondents rarely consume seasonal vegetables or did not consume at all. The respondents had a rare chance (51.96%) or never (21.57%) tested off-season vegetables. As the tribal community lives nearby forest area they had access to different kinds of fruit trees and they used to consume the seasonal fruits. However nearly 10% of the respondents did not eat seasonal fruits due to their very poor economic status. They did not have access to forest fruits even. Although some of the tribal people had tested off season fruits, but majority (35.29% rarely; 40.20% never) of them rarely or never tested off-season fruits.The distribution of the respondents for milk intake had a wide range from 12.75% daily, 31.37% four to five days a week, 22.55% two to three days a week, 6.86% once in a week, 11.76% once in a month, 11.76% rarely and 2.94% never. The tribal respondents had average of one to two milch animal for consumption of milk at household level. As per as consumption of paneer is concerned 51.96% respondents rarely consumed paneer in some marriage function and other rituals, 22.55% had never tasted paneer before. The situation was similar regarding mushroom consumption as 22.55% respondents rarely consumed mushroom and 58.82% never tasted it before. A wide range of distribution of the respondents on egg consumption (10.78% four to five days a week, 3.92% two to three days a week, 6.86% once in a week, 36.27% once in a month, 22.55% rarely and 19.61% never) denotes the presence of backyard poultry in the community but the access was meagre due to poor socio-economic status. Though the range of distribution on eating fish was wide nearly 85% of the respondents used to consume fish once a month, rarely or never. The situation was a bit similar for consumption of meat/chicken and the distribution found was 1.96% four to five days a week, 1.96% two to three days a week, 9.8% once in a week, 33.33% once in a month, 27.45% rarely and 25.49% never consumed fishes.

Table 2: Frequency of consumption of the food items (n = 102)

Sl. No.	Food items	Per cent sample respondents						
		Daily	**4-5 days in a week**	**2-3 days in a week**	**Once in a week**	**Once in a month**	**Rarely**	**Never**
1	Wheat	62.75	33.33	3.92	0.00	0.00	0.00	0.00
2	Rice	46.08	38.24	14.71	0.98	0.00	0.00	0.00
3	Pulses	13.73	27.45	23.53	34.31	0.98	0.00	0.00
4	Leafy vegetables	0.00	30.39	27.45	31.37	7.84	2.94	0.00
5	Seasonal vegetables	0.98	33.33	37.25	7.84	0.98	14.71	4.90
6	Off-season vegetables	0.00	5.88	5.88	5.88	8.82	51.96	21.57
7	Seasonal fruits	0.00	9.80	11.76	39.22	17.65	11.76	9.80
8	Off-season fruits	0.00	3.92	9.80	4.90	5.88	35.29	40.20
9	Milk	12.75	31.37	22.55	6.86	11.76	11.76	2.94
10	Paneer	0.00	4.90	0.98	11.76	7.84	51.96	22.55
11	Mushroom	0.00	0.98	1.96	5.88	9.80	22.55	58.82
12	Egg	0.00	10.78	3.92	6.86	36.27	22.55	19.61
13	Fish	0.00	2.94	6.86	5.88	33.33	31.37	19.61
14	Meat/Chicken	0.00	1.96	1.96	9.80	33.33	27.45	25.49

The study investigated the impact of the intervention under the Tribal Sub Plan (TSP) on dietary intake across various food components. The data were analyzed using mean, standard deviation (SD), standard error (SE), and coefficient of variation (CV) to assess changes in consumption patterns before and after the intervention, with significant changes evaluated using z-scores and p-values.

Fig 2: Resource poor tribal women eats roti-namak bread with salt

Fig 3: Bina-11 rice cultivation by Shri Ramraksha at Bhalukudar village

Roti and Rice Consumption: Before the intervention, the mean consumption of roti was 6.588 with a standard deviation of 0.569, indicating a relatively uniform consumption pattern, as shown by a low coefficient of variation (CV) of 0.086. Majority of the tribes used to eat Roti with Salt (Fig 2) Post-intervention, the mean increased to 6.902, and the CV decreased to 0.043, reflecting a more consistent consumption pattern. A significant z-score of -4.703 ($p < .001$) suggests a meaningful improvement in roti consumption due to the intervention.

High yielding wheat varieties like *HUW-234, HD-2967, DBW-252* were introduced and adopted by the respondents. Similarly, rice consumption increased from a mean of 6.294 to 6.510, with a reduction in CV from 0.120 to 0.112, indicating more stable consumption patterns post-intervention ($z = -3.724$, $p < .001$). Improved rice varieties like *HUR-3022, DRR-44, CRR-801, Bina-11, Improved Sambha* were introduced which were suitable for cultivation in Sonbhadra region of Uttar Pradesh. These results suggest that the intervention successfully increased and stabilized the intake of staple foods such as roti and rice.

Fig 4: Seasonal vegetable cultivation by the tribal people

Pulses and Vegetables: Pulse consumption for the respondents were found inadequate. Different improved varieties of pulses were introduced like *UPAS-120, Malviya Chamatkar, NDR-2* in arhar, *HUL-57* in lentil, *T-9* in urd, *HUM-216, Virat* in mung. For pulses, a significant improvement was observed, with mean consumption increasing from 5.186 to 6.039. The CV decreased from 0.210 to 0.136, indicating reduced variability and more consistent consumption among participants ($z = -6.901$, $p < .001$).Tribal populace was introduced to different vegetables like tomato *(Kashi Aman)*, brinjal *(Kashi Sandesh, Kashi Uttam)*, chilli *(Kashi Anmol, Kashi Ratna)* in solanaceous group, bottle gourd *(Kashi Ganga, Kashi Bahar)*, pumpkin *(Kashi Harit)*, sponge gourd *(Kashi Divya, Kashi Saumya)*in cucurbitaceous group, okra *(KashiKranti, KashiPragati)* in malvaceae group, cowpea *(KashiNidhi, KashiKanchan)*, [20] French bean *(KashiRajhans, KashiSampann)* in leguminious group, palak*(All green)*, bathua*(Kashi bathua-1)*,etc leafy and seasonal vegetables also showed substantial increases in mean consumption, with z-scores of -7.574 ($p < .001$) and -6.901 ($p < .001$), respectively. The intervention led to decreased variability in consumption, as reflected by reductions in CV from 0.225 to 0.125 for leafy vegetables and 0.341 to 0.171 for seasonal vegetables. These findings indicate a positive shift toward a more diverse and balanced diet, emphasizing the importance of vegetable intake.

Fig 5: Plantation of mango tree at the house of Shri Rameshwar Bhai, Dahakudandi

Fruits and Dairy Products: Some fruit plants were introduced like mango *(Mangifera indica)*, aonla*(Phyllanthus emblica)*, lemon *(Citrus limon)*, beal*(Aeglemarmelos L.)*, ber*(Ziziphus mauritiana)*, guava *(Psidium guajava)*, custard apple *(Annonas quamosa)*, jackfruit*(Artocarpus heterophyllus)*.The study revealed significant changes in fruit consumption patterns. Seasonal fruit intake increased from a mean of 3.608 to 4.529, while off-season fruit consumption increased from 2.206 to 3.647.

Both categories had shown reduced variability in consumption, as evidenced by lower CVs, and significant z-scores of -6.736 ($p < .001$) and -7.475 ($p < .001$) respectively. Milk consumption also increased, with a mean rising from 4.794 to 5.392 and a z-score of -5.086 ($p < .001$). The decreased CV from 0.354 to 0.204 suggests improved consistency in milk consumption, highlighting the intervention's success in promoting dairy intake as a result of increasing purchasing power.

Fig 6: Backyard poultry rearing by Shri Angad Kumar of Satdwari

Protein Sources: For supplementing the protein sources 20000 Day Old Chicks (DOC) of improved breed *CARI Debendra, CARI Nirbheek and CARI Shyama* were introduced for promotion of backyard poultry farming. Apart they were regularly sensitised about domestic animal health care for better milk and meat production. The consumption of protein sources such as paneer, mushrooms, eggs, fish, and meat/chicken increased significantly after the intervention.

Paneer consumption had increased from 2.314 to 3.402, with a z-score of -7.574 ($p < .001$), while mushrooms showed an increase from 1.725 to 3.255 ($z = -7.599$, $p < .001$). The CV for these items decreased substantially, indicating a more uniform distribution of consumption. Eggs, fish, and meat/chicken also demonstrated significant increases, with corresponding z-scores of -7.167 ($p < .001$), -6.193 ($p < .001$), and -7.220 ($p < .001$), respectively. These findings underscore the intervention's impact on enhancing protein intake, essential for balanced nutrition.

Overall Impact of the Intervention: The results demonstrate that the TSP intervention led to significant improvements in dietary patterns across a range of food items. The increase in mean consumption and reduction in variability for most food components suggest that the intervention effectively addressed dietary deficiencies and promoted a more balanced diet. The significant z-scores and p-values further confirm the intervention's impact, highlighting its role in fostering positive dietary changes among the participants.

The intervention under the TSP has shown to be effective in enhancing dietary intake and reducing variability across different food components, suggesting a move towards more consistent and balanced eating habits among the tribal communities. These findings emphasize the importance of tailored interventions in addressing nutritional needs and promoting health and well-being. Future research should focus on the long-term sustainability of these dietary changes and explore additional strategies to further improve nutritional outcomes in a similar populace.

Table 3: Distribution of the respondents based on mean differences on food habit change due to interventions (n= 102)

	Mean	SD	SE	Coefficient of variation	z	p
Roti$_{(bi)}$	6.588	0.569	0.056	0.086	-4.703	< .001
Roti$_{(ai)}$	6.902	0.299	0.030	0.043		
Rice$_{(bi)}$	6.294	0.752	0.074	0.120	-3.724	< .001
Rice$_{(ai)}$	6.510	0.728	0.072	0.112		
Pulses$_{(bi)}$	5.186	1.088	0.108	0.210	-6.901	< .001
Pulses$_{(ai)}$	6.039	0.820	0.081	0.136		
Leafy Vegetables$_{(bi)}$	4.745	1.069	0.106	0.225	-7.574	< .001
Leafy Vegetables$_{(ai)}$	5.922	0.740	0.073	0.125		
Seasonal vegetables$_{(bi)}$	4.618	1.574	0.156	0.341	-6.901	< .001
Seasonal vegetables$_{(ai)}$	5.814	0.992	0.098	0.171		
Off season vegetables$_{(bi)}$	2.402	1.366	0.135	0.569	-7.115	< .001
Off season vegetables$_{(ai)}$	3.549	1.157	0.115	0.326		
Seasonal fruit$_{(bi)}$	3.608	1.380	0.137	0.382	-6.736	< .001
Seasonal fruit$_{(ai)}$	4.529	1.287	0.127	0.284		
Off season fruit$_{(bi)}$	2.206	1.465	0.145	0.664	-7.475	< .001
Off season fruit$_{(ai)}$	3.647	1.166	0.115	0.320		
Milk$_{(bi)}$	4.794	1.696	0.168	0.354	-5.086	< .001
Milk$_{(ai)}$	5.392	1.100	0.109	0.204		
Paneer$_{(bi)}$	2.314	1.251	0.124	0.541	-7.574	< .001
Paneer$_{(ai)}$	3.402	1.046	0.104	0.307		
Mushroom$_{(bi)}$	1.725	1.091	0.108	0.633	-7.599	< .001
Mushroom$_{(ai)}$	3.255	0.982	0.097	0.302		
Egg$_{(bi)}$	2.853	1.485	0.147	0.521	-7.167	< .001
Egg$_{(ai)}$	4.186	1.280	0.127	0.306		
Fish$_{(bi)}$	2.578	1.238	0.123	0.480	-6.193	< .001
Fish$_{(ai)}$	3.314	1.143	0.113	0.345		
Meat/Chicken$_{(bi)}$	2.412	1.146	0.113	0.475	-7.220	< .001
Meat/Chicken$_{(ai)}$	3.510	1.002	0.099	0.286		

bi= Before intervention; ai= After intervention

To further understand the patterns in dietary intake data, Principal Component Analysis (PCA) was performed. This technique reduces the dimensionality of the dataset while preserving as much variability as possible. The PCA results are summarized in Table 4 and Table 5, detailing the loading of each food item on principal components (PCs) and the characteristics of the components, respectively.

The Table 4, revealed five principal components (PCs) with distinct loading patterns, highlighting the underlying dietary patterns within the data. The model yielded a significant Chi-squared test value of 165.431 (df = 40, p < .001), confirming the appropriateness of the PCA model. Fish and egg loaded strongly on PC1, with values of 0.818 and 0.803, respectively, indicating that this component captures a pattern related to protein-rich foods. The uniqueness values (0.218 for fish and 0.298 for eggs) suggest that a considerable amount of variance in these items is explained by this component. This component is characterized by high loadings for seasonal vegetables (0.826), paneer (0.670), and seasonal fruit (0.631). This suggests a dietary pattern centered around fresh produce and dairy, with uniqueness values indicating that a substantial portion of the variance is captured by PC2. Mushroom (0.813) and off-season fruit (0.731) are prominent in PC3, indicating a component related to less commonly consumed foods or those less seasonally available. The uniqueness values (0.300 and 0.267) suggest that PC3 captures a significant portion of the variance for these items. Rice (0.853) and roti (0.796) loaded heavily on PC4, reflecting a staple food consumption pattern. These high loadings and relatively low uniqueness values (0.233 and 0.288) highlight PC4's effectiveness in capturing variance in staple consumption. Pulses (0.743) and meat/chicken (-0.586) load onto PC5, with meat/chicken having a negative loading. This suggests a component distinguishing between plant-based and animal protein sources. Leafy vegetables also show a positive loading (0.563), indicating an association with plant-based intake.

The application of the varimax rotation method helps in simplifying the interpretation of components by maximizing the variance of the squared loadings, enhancing the clarity of each component's representation.

Table 5 provides an overview of the eigen values and variance explained by each component. Component 1 has an eigen value of 3.477, accounting for 23.2% of the total variance, with a sum of squared loadings indicating it captures 16.3% of the variance. This suggests that PC1 is the most influential component in explaining dietary patterns. Component 2 explains 17.1% of the variance, with an eigen value of 2.559 and the sum of squared loadings showing a 14.1% variance contribution. Together with Component 1, this accounts for 30.4% of the cumulative variance. Components 3, 4 and 5 contribute progressively less to the variance, with cumulative variance proportions of 44.5%, 55.8%, and 64.8% respectively. The gradual decline in variance explained by each component underscores the complexity and diversity of dietary patterns. The PCA highlights distinct dietary patterns among the study population, revealing key areas where the intervention may have had an impact. The strong loadings of protein-rich foods such as fish and eggs on PC1 suggest an emphasis on protein intake in the diet, potentially indicating a positive shift toward better nutritional practices post-intervention. The grouping of fresh produce and dairy under PC2 reflects a balanced diet pattern, emphasizing the importance of fruits, vegetables, and dairy in the respondents' diets. This may suggest improved awareness and accessibility to these food groups following the intervention. The negative loading of meat/chicken on PC5 could imply a shift toward plant-based diets, which might be a result of the intervention's focus on promoting diverse and sustainable dietary practices. The complexity captured by these components highlights the multifaceted nature of dietary changes and the varying influences of cultural, economic, and environmental factors on food consumption patterns. Overall, the PCA provides valuable insights into the effectiveness of the TSP intervention, revealing significant patterns in dietary intake that align with the study's objectives of promoting balanced and improved nutrition among tribal communities. These findings underscore the importance of continued efforts to tailor interventions that address specific dietary needs and challenges faced by the target population, fostering sustainable and healthy eating habits.

Table 4: Principal Component Analysis (n= 102)

	PC1	PC2	PC3	PC4	PC5	Uniqueness
Fish	0.818					0.218
Egg	0.803					0.298
Seasonal vegetables		0.826				0.280
Paneer		0.670	0.442			0.351
Seasonal fruit		0.631				0.498
Milk		0.536		0.409		0.450
Mushroom			0.813			0.300
Off season fruit			0.731			0.267
Off season vegetables			0.638			0.425
Rice				0.853		0.233
Roti				0.796		0.288
Pulses					0.743	0.397
Meat_Chicken					-0.586	0.580
Leafey_Vegetables					0.563	0.462

Table 5: Component characteristics (n= 102)

Component Characteristics						
	Eigen value	**Proportion var.**	**Cumulative**	**Sum Sq. Loadings**	**Proportion var.**	**Cumulative**
Component 1	3.477	0.232	0.232	2.445	0.163	0.163
Component 2	2.559	0.171	0.402	2.118	0.141	0.304
Component 3	1.427	0.095	0.498	2.114	0.141	0.445
Component 4	1.223	0.082	0.579	1.687	0.112	0.558
Component 5	1.033	0.069	0.648	1.354	0.090	0.648

Table 6 illustrates the changes in the nutritional status of tribal families before and after the intervention implemented under the Tribal Sub Plan (TSP). The table presents the mean nutritional scores and categorizes nutritional status into three groups: Very Low Nutrition, Low Nutrition, and Satisfactory Nutrition, highlighting the positive changes achieved through the intervention. The mean nutritional score of the tribal families was 49.80, reflecting a baseline nutritional status that required improvement. The mean nutritional score increased to 53.60, indicating an average positive change of 3.80 points. This improvement suggests that the intervention effectively enhanced the overall nutritional status of the respondents. About 15.10% of families were fallen into the very low nutrition category, indicating significant nutritional deficiencies. This percentage decreased to 12.30%, representing a positive change of 2.80 percentage points. The reduction in very low nutrition status reflects the intervention's success in addressing the most severe cases of nutritional deficiency. A substantial 63.30% of families were classified as having low nutrition, highlighting a critical area for improvement. The proportion of families in the low-nutrition category decreased to 51.50%, marking an improvement of 11.80 percentage points. This significant reduction demonstrates the intervention's impact on elevating the nutritional status of those previously in the low-nutrition bracket. Only 21.60% of families achieved satisfactory nutrition, indicating a need for enhanced dietary practices. The percentage of families with satisfactory nutrition increased to 36.20%, reflecting a positive change of 14.60 percentage points. This considerable improvement suggests that the intervention successfully promoted better dietary habits, resulting in enhanced nutritional status.

Fig 7: Tribal children got access to the seasonal vegetables due to intervention

The changes in nutritional status presented in Table 6 highlight the effectiveness of the intervention in improving the dietary and nutritional health of tribal families. The increase in mean nutritional scores and the shifts in nutritional status categories underscore the intervention's success in addressing dietary deficiencies and promoting healthier eating habits. The significant reduction in both very low and low nutritional status suggests that the intervention effectively targeted the most vulnerable groups, providing them with the necessary resources and education to improve their nutrition. The notable increase in the proportion of families achieving satisfactory nutrition reflects the intervention's ability to foster sustainable dietary changes that lead to better overall health outcomes.

These findings demonstrate the critical role of tailored interventions in improving nutritional status, particularly in under-resourced communities. The positive changes observed in this study highlight the importance of continued support and education to maintain and further enhance the nutritional health of tribal families. Future efforts should focus on sustaining these improvements and exploring additional strategies to address any remaining barriers to achieving optimal nutrition.

Table 6: Changes in Nutritional status of the tribal families (in percent)

	Before	After	Positive Change
Mean	49.80	53.60	3.80
Very Low Nutrition (< Mean- 1SD)	15.10	12.30	2.80
Low Nutrition (Between Mean ± 1SD)	63.30	51.50	11.80
Satisfactory Nutrition (> Mean + 1 SD)	21.60	36.20	14.60

Discussion

The analysis of the results provides a comprehensive understanding of the impact of integrated agricultural interventions on the dietary habits and nutritional status of tribal households in the Sonbhadra district of Uttar Pradesh, India. These findings align with existing research on the effectiveness of nutrition-sensitive agricultural interventions in marginalized communities, particularly in addressing food insecurity and malnutrition [21]. The baseline data revealed that a significant proportion of households had low dietary diversity scores, indicating limited access to a variety of food groups. This is consistent with studies that highlight the challenges faced by tribal and rural communities in achieving dietary diversity due to socio-economic constraints, reliance on staple crops, and limited market access [22]. Low dietary diversity is often associated with micronutrient deficiencies and poor health outcomes, particularly among women and children [23]. The findings underscore the need for targeted interventions to improve access to diverse and nutrient-rich foods in such communities.

Post-intervention data demonstrated a significant improvement in dietary diversity scores among participating households. The introduction of high-yielding crop varieties, backyard poultry farming, and nutrition-sensitive agricultural practices diversified food sources and enhanced nutritional intake. Similar outcomes have been reported in other studies, where nutrition-sensitive agricultural interventions successfully increased dietary diversity in rural and tribal settings [24]. For instance, the promotion of home gardens and small-scale livestock farming has been shown to improve household access to nutrient-rich foods, particularly in resource-constrained environments [25].

A notable increase in the consumption of protein-rich foods, vegetables, and fruits post-intervention. The promotion of backyard poultry farming provided households with a sustainable source of animal protein, which is critical for growth and development, particularly in children [26]. Additionally, the cultivation of diverse crops, including micronutrient-rich vegetables and fruits, addressed previous nutritional gaps. This aligns with findings from Jones, 2017 [25], who reported that on-farm crop diversity is positively associated with improved household diet quality and micronutrient intake. The intervention led to measurable improvements in the nutritional status of women and children, with reductions in under nutrition and anemia rates. Enhanced dietary diversity, particularly the inclusion of animal-source foods and micronutrient-rich plants, contributed to these positive health outcomes.

These findings are supported by [27], who demonstrated that dietary diversity is strongly associated with improved child nutritional status in low-income settings. The inclusion of animal-source foods, such as eggs and poultry, has been particularly effective in addressing micronutrient deficiencies and improving overall health [26].
The economic analysis revealed that the interventions led to increased household incomes through surplus production and sales of poultry and high-value crops. This economic upliftment enabled households to invest in better food, healthcare, and education, creating a virtuous cycle of improved well-being. Similar economic benefits have been observed in other studies, where small-scale poultry farming and crop diversification significantly enhanced household incomes and food security [28]. For example, the introduction of Kuroiler chickens in West Bengal improved livelihoods and provided a sustainable source of income for rural households [28].
Qualitative data reflected positive community perceptions regarding the interventions, with households reporting greater food security, dietary satisfaction, and empowerment, particularly among women involved in poultry farming. Community acceptance and participation are critical for the sustainability of such interventions, as highlighted by the Food and Agriculture Organization [29]. Empowering women through agricultural interventions not only improves household nutrition but also enhances their decision-making roles within the community, contributing to long-term development outcomes.

Conclusions

The integrated agricultural interventions under the Tribal Sub Plan (TSP) have significantly improved dietary diversity, nutritional intake, and economic resilience among the tribal households in Sonbhadra district, Uttar Pradesh. The findings confirm that crop diversification, backyard poultry farming, and nutrition-sensitive agricultural practices are effective strategies for enhancing food security and addressing malnutrition in marginalized communities [30, 32].
Beyond dietary changes, the intervention has fostered self-reliance and empowerment among the tribal population, enabling them to utilize their local resources more efficiently. The project's success highlights the need for scaling up through horizontal expansion, extending the model to other underserved tribal regions. Additionally, value addition in agriculture, such as post-harvest processing of vegetables and egg products, can further improve household incomes and market integration [31].
To sustain these improvements, continued support from government agencies, policymakers, and extension services is essential. Advanced capacity-building programs and financial incentives can further strengthen the adoption of diversified agricultural practices. Moving forward, integrating technology, market linkages, and policy-driven incentives will be crucial for long-term food security and economic upliftment of tribal communities.

Authors' contributions: All authors contributed significantly to the study: Shubhadeep Roy, Neeraj Singh and Anirban Mukherjee were involved in conception and design of the experiments. Fieldwork, and data collection were conducted by Shubhadeep Roy and Neeraj Singh. Anirban Mukherjee, Saikat Maji and Kumari Shubha performed data analysis. Ankita Sarkar helped in writing the research paper and interpretation. KalyanGhadei, Ankita Sarkar, KumariShubhaprovided critical revision. All authors discussed the result, contributed to manuscript's final revision and approved the submitted version.

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Future scope of the study: The outcome of the study will help policy makers to develop better plan for diatery diversity of tribal populace in the study area and multi location trials may be planned in other tribal areas for better understanding the diatery diversity and adhering nutritional security of the tribal people.

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