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The Adoption and Impact of Food Safety Measures on Smallholder Dairy Farmers' Economic Welfare

Evidence from the Indo-Gangetic Plains of India

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ABSTRACT

This study examines the adoption of compliance with food safety measures (FSM) using cross-sectional data collected at the farm level in three key states of the Indo-Gangetic Plains, Bihar, Punjab, and Uttar Pradesh in 2023. A Food Safety Index (FSI) was developed to assess the intensity of adoption of food safety practices. Determinants of compliance with practices were assessed using multiple linear regression and an ordered logistic model. Generalized propensity score matching was used to evaluate the heterogenous impact of the adoption of FSM on farm-level performance indicators. The findings indicate that farmers are embracing a moderate level (0.48–0.58) of the food safety index at the farm level. The various socio-economic and demographic factors influence compliance with FSM which include education, income, marketing channel, training exposure, awareness level, and infrastructure. The impact assessment reveals the direct relationship between FSM compliance and performance indicators. However, a lower level of compliance may not yield significant improvements. The study suggests incentivization through pricing reforms, improving infrastructure, and strengthening formal marketing channels.

Keywords: adoption intensity, dairy farmers, food safety measures, impact assessment, clean milk.

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ACRONYMS

AI	:	Artificial Insemination
AMUL	:	Anand Milk Union Limited
COMFED	:	Bihar State Milk Cooperative Federation Ltd
CSU	:	Central Surveillance Unit
CV	:	Coefficient of Variation
DAHD	:	Department of Animal Husbandry and Dairying
DRF	:	Dose Response Function
FBD	:	Food Borne Diseases
FSI	:	Food Safety Index
FSM	:	Food Safety Measures
FSS	:	Food Safety and Standards
FSSAI	:	Food Safety and Standards Authority of India
GoI	:	Government of India
GPS	:	Generalized Propensity Score
GVA	:	Gross Value Added
ha	:	Hectare
HH	:	Household Head
IDSP	:	Integrated Disease Surveillance Program
MILKFED	:	Punjab State Cooperative Milk Producer's Federation Ltd
MOSPI	:	Ministry of Statistics and Program Implementation
NDDB	:	National Dairy Development Board
NPDD	:	National Program for Dairy Development
OBC	:	Other Backward Class
OLS	:	Ordinary Least Square
PARAG	:	Pradeshik Cooperative Dairy Federation, Uttar Pradesh
PCDF	:	Pradeshik Cooperative Dairy Federation
SC/ ST	:	Scheduled Caste/ Scheduled Tribe
SD	:	Standard Deviation
SUDHA	:	Bihar State Milk Co-Operative Federation Ltd.
TEF	:	Treatment Effect Function
VERKA	:	Punjab Milk Producers Federation & Cooperative Society
VIF	:	Variance Inflation Factors

1. Introduction

Compliance with food safety measures (FSM) holds paramount importance in ensuring the well-being of individuals and maintaining the integrity of the food supply chain. The concept revolves around safeguarding the quality of food products and ensuring they remain uncontaminated (Chattu, 2015; Cole, 2018; Garcia *et al*., 2020; Nordhagen *et al*., 2022; Ponnusamy & Lal, 2015; Pal *et al.,* 2018) particularly by foodborne diseases (FBDs) (Lemma *et al*., 2018; Simelane & Worth, 2020; Unnevehr, 2015). The impact of FBDs has been observed to be more severe in low- and middle-income countries including India (Feyisa *et al*., 2023b; Vemula *et al*., 2012). According to a study conducted by the World Bank Group and the Netherlands government, the economic burden of FBDs on India amounts to US$28 billion (Rs. 1,78,100 crore) annually (Kristkova *et al.*, 2017). However, Jaffe *et al*. (2019) reported a reduction in this cost to around 15 billion dollars the following year. Jaffe *et al*. (2019) also unveiled that India, along with China, accounts for 49 percent of the total economic burden of FBDs in low- and middle-income countries and 71 percent in Asia. This is supported by the data from the Integrated Disease Surveillance Program (IDSP) under the Ministry of Health and Family Welfare, Government of India, which indicates that a considerable proportion of the 40–50 weekly outbreaks documented by the Central Surveillance Unit (CSU) are incidents of foodborne diseases.

Approximately 21 percent of India's burden of FBDs is attributed to animal-source foods (Jaffe *et al*., 2019). This concern is more pronounced in the dairy sector (Hernández-Castellano, 2019; Rathod & Dixit, 2020). Bisht *et al*. (2021) classified food commodities that serve as a vehicle for foodborne outbreaks in India, noting that dairy products lead to the number of outbreaks within livestock and fisheries categories. The study recorded that from June 2009 to December 2018, 65 outbreaks in India were connected to milk and its derivatives, 58 outbreaks were linked to meat, poultry, and eggs, and 25 outbreaks were associated with fish and shellfish. However, this figure underestimates the true extent of the disease burden, as a substantial number of cases may have gone unreported. The practice of adulterating dairy products is widespread, driven either by financial motives or resulting from inadequate hygiene conditions within the supply chain (Handford *et al.*, 2016).

Reports from developing countries frequently highlight unhygienic milking practices, the milking of unhealthy animals, improper storage conditions, and the feeding of chemically treated crop residues (Amenu *et al*., 2019; Girma *et al*., 2014; Gwandu *et al*., 2018; Montgomery *et al*., 2020; Nyokabi *et al.*, 2024). Furthermore, deliberate contaminations such as the 2008 melamine crisis in eastern India (Bhatt *et al*. 2008; CBC News, 2008), adulteration (Dhanalakshmi, 2020), or cases of aflatoxin contamination in milk samples because of contaminated feed (Sushma, 2019; The Hindu Bureau, 2023) raise doubts in the safety and quality of milk in India. Also, the presence of recognized potential pathogens like *Salmonella*, *Escherichia coli*, or *Listeria* questions hygiene practices and safety protocols (Ferens & Hovde, 2011; Kousta *et al*., 2010). Such practices not only degrade the quality but also introduce harmful substances, posing serious health risks to consumers (Chaudhary & Sharma, 2024). The presence of melamine, for example, can irritate the urinary tract lining and lead to obstructions, abdominal pain, and uraemia. In 2008, over 10,000 children were hospitalized after consuming milk adulterated with melamine (Gossner *et al*., 2009). Synthetic milk, which contains urea, caustic soda, refined oil, and detergents (Kandpal *et al*., 2012), presents significant health risks. Urea can stress the kidneys, potentially causing renal failure, while detergents may be carcinogenic, leading to gastrointestinal issues and other severe health complications (Mudgil & Barak, 2013).

Upholding adherence to food safety standards from production to consumption is essential for the protection of public health (Chauhan, 2021; Nyokabi *et al.*, 2021; Sundram, 2023). India is the leader in global milk production, contributing 23 percent to the world's total milk production. However, consistent concerns persist regarding the milk quality due to inadequate adoption of food safety measures (Dhanashekar *et al.*, 2012; Nicolini *et al*., 2022; Pal *et al*., 2018). Acknowledging the significance of compliance with food safety measures, the government of India has undertaken several initiatives. Foremost among these is the amalgamation of the Food Safety and Standards (FSS) Act of 2006 and the establishment of the Food Safety and Standards Authority of India (FSSAI). The FSSAI is actively engaged in implementing and enforcing stringent regulations and standards across the entire supply chain to ensure the integrity of the food industry. Further, the Department of Animal Husbandry and Dairying (DAHD) launched the Quality Milk Program in 2019 with an initial outlay of Rs. 271.64 crore ($33 million). The objective of this initiative is to achieve global (Codex) standards for domestic consumption and ensure traceability of milk and milk products. Under this initiative, all cooperative dairy plants and dairy cooperative societies are required to carry out chemical and microbiological tests. Instant testing of the chemical and microbiological quality of milk is supposed to be ensured before reaching the consumers. These initiatives are primarily focused on encouraging dairy farmers to adopt good production practices that require day-to-day actions to prevent, eliminate, or reduce food safety hazards at the farm level. To control many potential and emerging milk safety hazards and cater to the requirements of the dairy processing industry and growing consumers' concerns for food safety, farmers have to adopt a number of such control measures that enhance milk safety at the farm level. To help farmers succeed in their endeavor toward attaining production of safe and clean milk at their farms, and to generate awareness among the farmers about compliance with food safety measures, several training programs have been initiated by processing industries and government departments. However, several studies suggest that compliance with FSM in milk production in India is not very encouraging (Kumar *et al*., 2011; Kumar *et al*., 2017a; Kumar *et al*., 2020).

Many studies in the dairy sector are focused on other aspects like the production efficiency of milk (Chavas *et al.*, 2022; Yilmaz *et al*., 2020; Yu *et al*., 2023), economic situation (Poczta *et al*., 2020), marketing of milk (Ariningsih *et al*., 2019; Kena *et al*., 2022), international trade and value chain (Bai *et al*., 2023; Kemitare *et al*., 2021; Birthal *et al*. 2017), and sustainability (Andre Feil *et al*., 2020; Peterson & Mitloehner, 2021; Segerkvist, 2020). The studies related to compliance with FSM in milk production received less attention and remained inadequately explored. Against this backdrop, we aim to analyze the adoption intensity of FSM in milk production, identify the factors driving compliance, and estimate the impact of adoption of FSM on dairy farmers' farm performance.

The structure of this paper is as follows: the subsequent section gives a status of the dairy sector in the study area and reviews related studies in similar contexts. The methodology section details the sampling technique, sample size, data collection, and analytical framework, followed by a discussion of the socio-economic characteristics of the sample. In the next section briefly discusses the results, and the final section concludes and formulates potential policy recommendations.

2. Status of dairy sector in the selected states of Indo-Gangetic Plains

The key indicators of dairy development from the study area have been presented in Table 1. The table provides a brief profile of the share of livestock in agricultural gross value added (GVA), milk production, productivity, livestock unit, available infrastructure, vaccination practices, breeding practices, status of cooperatives, and training programs from various sources. India's status as the world leader in total milk production is a testament to the vast and diverse dairy activities across the country. The continued surge in milk production from merely 17 million tons in 1950/51 to an impressive 230.6 million tons in 2022/23 reflects a significant and noteworthy trend in the country's dairy sector. The livestock sector plays a crucial role in driving the growth of agricultural GVA with the dairy sector playing a central role within it. The three states of the Indo-Gangetic plains: Bihar, Punjab, and Uttar Pradesh, together account for 27.3 percent of national milk production. These three states exhibit distinct economic profiles and geographical features. While Punjab stands out with its relatively prosperous economy and fertile plains, Uttar Pradesh boasts a diverse economy and geographical landscape. Bihar faces economic challenges but is focused on agricultural activities and is making strides toward development. Despite significant disparities among these states, a common thread unites them all: their reliance on the dairy sector for livelihood. These states contribute to India's dairy sector through their unique strengths, be it high productivity, large-scale operations, or emerging growth. Punjab is the most highly productive state at 10.7 liters per animal per day, followed by Uttar Pradesh (5.2 liters), and Bihar (4.4 liters). The state significantly focuses on in-milk crossbred cows, showcasing its commitment to breeds engineered for superior milk yields. This emphasis on productivity positively impacts the economic landscape of Punjab, providing substantial support to the livelihoods of those engaged in the dairy sector. Uttar Pradesh, on the other hand, brings sheer scale to the country's dairy activities, ranking first in total milk production. The state yields a remarkable 36.2 million tons from a total bovine population of 17.1 percent of India. Bihar’s dairy sector has emerged as a noteworthy player, producing 12.5 million tons of milk from a total bovine population of 7.6 percent of

India. Despite persistent economic constraints, Bihar actively participates in the dairy sector and contributes substantially to national milk production.

Cooperatives play a vital role in the dairy sector by empowering small and marginal farmers through collective bargaining power. The significant presence of dairy cooperatives in India has played a transformative role in the country's dairy sector. The most notable among them is the National Dairy Development Board (NDDB) and its flagship cooperative ‘AMUL’. Apart from AMUL, there are several state-level dairy cooperatives and federations such as Bihar State Milk Cooperative Federation Ltd (COMFED) under the brand name ‘SUDHA’, Punjab State Cooperative Milk Producer’s Federation Ltd (MILKFED) under the brand name ‘VERKA’, and Pradeshik Cooperative Dairy Federation, Uttar Pradesh (PCDF) under the brand name ‘PARAG’. These cooperatives follow a similar model of improving dairy farming, and their success highlights the importance of community-driven initiatives in economic development and food security. In India, 23.6 percent of cooperatives originate out of these three states, with the largest number in Uttar Pradesh, followed by Bihar and Punjab.

In July 2021, the Department of Animal Husbandry and Dairying (DAHD) restructured the National Program for Dairy Development (NPDD) scheme for implementation from 2021/22 to 2025/26, introducing two key components. Component ‘A’ focuses on creating and strengthening infrastructure for quality milk testing. Component ‘B’, *Dairying through Cooperatives*, aims to boost the sale of milk and dairy products by enhancing farmers' access to markets. Between 2014/15 and 2022/23, the total approved outlay for Component ‘A’ was Rs. 30153.5 million, with the central government's share amounting to Rs. 22972.5 million. State-wise allocations under this component included Rs. 2632.3 million for Bihar (with a central share of Rs. 2101.9 million), Rs. 2512.1 million for Punjab (central share of Rs. 1671.9 million), and Rs. 798.5 million for Uttar Pradesh (central share of Rs. 664.9 million). For Component ‘B’, the total approved outlay for the period 2022/23 to 2023/24 was Rs. 11306.4 million. Within this, Bihar received Rs. 580.5 million, Punjab Rs. 3711.8 million, and Uttar Pradesh Rs. 1218.6 million. The NPDD scheme also includes training programs for farmers on good hygienic practices, clean milk production, milch animal rearing, adoption of cattle feed, and green fodder management. The total number of farmers trained under the scheme is detailed in the following table.

Table 1: Key indicators of dairy development in the study area in 2022/23

Particulars	Bihar	Punjab	Uttar Pradesh	India
Livestock share in agriculture GVA (percent)				
At current prices	30.8	38.6	25.7	30.2
Milk Production (million tons)	12.5	14.3	36.2	230.6
Exotic/crossbred cows	3.8 (30.4)	5.2 (36.4)	5.1 (14.1)	73.1 (31.7)
Non-descript/ indigenous cows	4.1 (32.8)	0.5 (3.5)	6.9 (19.1)	46.7 (20.3)
Buffaloes	4.3 (34.4)	8.5 (59.4)	22.9 (63.3)	103.2 (44.8)
Goat	0.3 (2.4)	0.1 (0.7)	1.3 (3.6)	7.6 (3.3)
Number of animals in milk (in millions)				
Exotic/crossbred cows	1.6	1.1	1.6	23.4
Non-descript/ indigenous cows	3.5	0.1	5.0	37.2
Buffaloes	2.5	2.4	12.0	46.7
Goat	4.5	0.1	4.4	41.9
Total Livestock units, 2019 (in millions)				
Total bovines	23.1	6.5	52.0	303.8
Total livestock	36.5	6.9	67.8	535.8
Average yield per in-milk animal (liters/animal/day)				
Exotic/crossbred cows	6.5	13.5	8.4	8.5
Non-descript/ indigenous cows	3.3	8.7	3.8	3.4
Buffalo	4.6	9.5	5.3	6.1
Goat	0.2	1.8	0.8	0.5
Average milk yield of total bovines (liters/ animal/ day)	4.4	10.7	5.2	5.7
Infrastructure (as on 31-03-2023)				
Veterinary Institutions[#]	2732	2898	5050	69202
Institute availability (No. of bovines/ institute)	8462	2259	10305	4390
Artificial Insemination (AI) centers[*]	7291	3449	10651	109212
Cattle breeding farms[*]	1	2	7	229
Buffalo breeding farms[*]	0	1	4	33
No. of AI performed during 2015/16 to 2022/23 (in million)	4.4	2.6	16.6	80.6
Animals vaccinated against Foot-and-mouth disease (FMD) (%)	89	93	81	82
Number of dairy cooperatives in 2022/23	29750	9104	36414	231991
Total approved outlay under component A of the NPDD scheme (in millions) [α]	2632.3	2521.1	798.5	30153.5
Total approved outlay under component B of the NPDD scheme (in millions) [β]	580.5	3711.8	1218.6	11306.4

Farmers approved for training under component A of the NPDD scheme §	-	14224	26400	573103
Farmers approved for training under component B of the NPDD scheme §	30648	95994	256386	787358
Milk processing capacity of dairy plant with cooperative sector (thousand liters/ day) in 2020	2955	2485	4413	85846

***Source*:** Author's calculations based on field survey; Livestock Census, 2019; Basic Animal Husbandry Statistics, 2023; Ministry of Cooperation, Annual Report 2022/23, MOSPI, 2022/23 database.

Note: Figures in parenthesis are percentages, #Veterinary institutions include hospitals/ polyclinics, dispensaries, and stockmen centers/ mobile dispensaries, *Under animal husbandry department and others, αApproved outlay is cumulative of projects approved under NPDD scheme from 2014/15 to 2022/23, βApproved outlay is cumulative of projects approved from 2022/23 to 2023/24 (Till 25.07.2023)

3. Findings from previous studies

While studies on the dairy sector in developing countries are plenty, only a few studies explained the issues of compliance with FSM in dairying. These studies focused on the extent of the adoption of FSM and their implications for dairy farmers economic performance. They also highlighted which factors induce the adoption of FSM in milk production at the farm level. The salient findings from these studies are organized into the following three sub-sections, along with research gaps.

3.1. Adoption intensity of food safety measures in milk production

Though the Department of Animal Husbandry and Dairying (DAHD) has documented and widely circulated the importance of good dairy practices and launched some programs to ensure clean milk production in India, the adoption of FSM in milk production has remained elusive. The previous studies carried out indicate that compliance with FSM is not very encouraging (Kumar *et al.*, 2011; Kumar *et al*., 2017a; Kumar *et al*., 2020; Lindahl *et al*. 2018; Gayathri *et al*., 2023). Kumar *et al*. (2011) conducted a study across Bihar, Punjab, and Uttar Pradesh, revealing discouraging levels of compliance with milk safety measures at the dairy farm level. They emphasized the need for concerted efforts to address this gap. Kumar *et al*. (2020) conducted a study among smallholder dairy farmers in Bihar and reiterated that farm-level food safety compliance was unsatisfactory even in 2015. Studies conducted in neighboring South Asian countries (Nepal and Sri Lanka) also found low adoption intensity of food safety measures (Kumar *et al*., 2017b and Korale-Gedara *et al.*, 2023). Further, on average, farmers spent an additional 0.5 Rupees per liter in India (Kumar *et al*. 2011) and 1.99 Rupees per liter in Nepal cost of compliance (Kumar *et al*., 2017b), roughly an 8 percent increase in India and 10 percent in Nepal. These studies also find an inverse relationship between herd size and the per unit additional cost of compliance.

3.2. Drivers of adoption intensity of food safety measures in milk production

Several studies have assessed the drivers of adoption intensity at the farm level (Amenu *et al*., 2019; Azanaw *et al*. 2019; Feyisa *et al*. 2023a; Nyokabi *et al.* 2024; Kumar *et al*., 2011; Lindahl *et al*., 2018; Kumar *et al*. 2020). Kumar *et al*., (2011); Kumar *et al*., (2017a) and Kumar *et al*. (2020) indicated a positive correlation between herd size and the level of adoption of FSM in milk production. However, beyond herd size, various factors such as socio-economic characteristics, resource endowments, farm attributes, and marketing channel choices, among others, also influence the adoption intensity (Kumar *et al*., 2017a; Nyokabi *et al*., 2024). Additionally, training and awareness play a significant role in adopting safe milk production (Lindahl *et al*., 2018; Amenu *et al*., 2019). These studies have employed various statistical approaches to assess the factors influencing adoption intensity. Azanaw *et al*. (2019) utilized multivariable logistic regression on education, experience, income, training, and health checkups. The study emphasized that the probability of having good FSM is higher among farmers supervised by health professionals. Kumar *et al*. (2011) used ordinary least square (OLS) regression and an ordered logistic model on education, herd size, formal marketing channel, and experience, concluding that education and milk sold to formal buyers significantly affect the adoption intensity. Korale-Gedara *et al.* (2023) employed a linear regression, ordered logit model and seemingly unrelated regression model on age, education, subsidy, consumption, and training. They indicated that targeted subsidies increase adoption intensity. Nyokabi *et al*. (2024) used OLS methods on livestock size, milk sold, disease outbreak, knowledge, information, trust, farming system, etc. and emphasized the need to increase farmers' knowledge of FSM through training and access to information. All these studies were based on cross-section data.

3.3. Impact of adoption intensity on farm performance indicators

A few studies have also examined the impact of FSM on various farm-level performance indicators (Feyisa *et al*., 2023b; Kumar *et al*. 2017a; Yadav *et al*., 2021). Kumar *et al*. (2017a) utilized the Dose-Response Function (DRF) to estimate the impact of the adoption of FSM on milk yield and profitability. The study revealed a positive relationship between adoption intensity and milk yield and profitability. Kumar *et al*. (2020) used a two-stage residual inclusion model on the productivity and profit of smallholder dairy farmers in Bihar. The study revealed that the adoption of one additional FSM increased milk yield by about 1 percent and profit by 2.3 percent. Feyisa *et al*. (2023b) conducted a study in Ethiopia, employing Generalized Propensity Score Matching and ordered probit endogenous switching regression to evaluate the impact of adopted milk safety practices on food and nutrition security and revealed that adoption intensity had a moderate impact on smallholder dairy farmers in Ethiopia.

3.4. Research gaps

Though the literature on the adoption and impact of FSM on milk production is growing, there are many research gaps that require further exploration. Firstly, there is scant information on FSM compliance at the farm level, and the existing information is outdated, particularly in India, despite extensive research on various other aspects of the dairy sector. Our study focused on 71 practices commonly followed by dairy farmers in their day-to-day operations. The examination of FSM compliance at the farm level will aid policymakers in improving FSM. Secondly, there is a dearth of studies that have comprehensibly determined the factors of the adoption of FSM in milk production in different geographical domains. In this study, we have identified various socio-economic and demographic characteristics of smallholder dairy farmers of three key states of the Indo-Gangetic Plains. Finally, there is a need for a more extensive evaluation of the impact of FSM on farming outcomes, which has been relatively overlooked. Against this backdrop, this study aims to update the variables influencing FSM and decipher their relationships with farm-level performance indicators. The insights gained from this research will support smallholder dairy farmers in making informed decisions to enhance food safety practices at the production level and strengthen their farm operations. The findings will also help policymakers develop strategies for accelerating the adoption of FSM in milk production.

4 Methodology

4.1 Data and Methods

The study is based on cross-sectional data collected at the farm level during 2023, using a multi-stage sampling technique. In the first stage, three key states, Bihar, Punjab, and Uttar Pradesh of the Indo-Gangetic plains, were purposively selected due to their representation of diverse geographic and institutional aspects in Indian milk production and marketing (Kumar *et al*., 2011). These states rank among the largest milk producers in India, contributing 5.4 percent, 6.2 percent, and 15.7 percent to the nation's total milk production, respectively. While Uttar Pradesh leads in milk production, Punjab boasts the highest daily milk availability. Basic Animal Husbandry Statistics (2023) reported that Punjab has 1,283 grams (g) of milk available per day, Uttar Pradesh has 426 g, and Bihar has 274 g.

At the second stage, one district was selected randomly from each state—Patna, Roopnagar, and Aligarh and in the third, three administrative blocks were selected randomly from each district. Bikram, Mokama, and Phulwari Sharif blocks in Patna (Bihar); Anandpur Sahib, Chamkaur Sahib, and Kharar blocks in Roopnagar (Punjab); and Gonda, Jawan, and Lodha in Aligarh (Uttar Pradesh). Finally, in the last stage, households were selected in proportion to the village population through the random walk method. In Bihar, a total of 115 households were selected- 43 from Bikram, 49 from Mokama, and 23 from Phulwari Sharif. In Punjab, 103 households were selected - 29 from Anandpur Sahib, 34 from Chamkaur Sahib, and 40 from Kharar. In Uttar Pradesh, 123 households were selected - 35 from Gonda, 39 from Jawan, and 49 from Lodha. In total, 341 households were selected for the study. Figure 1 gives a visual representation of the study area, showcasing geo-locations of the sampling villages within the selected districts of the key states in Indo-Gangetic Plains (Bihar, Punjab, and Uttar Pradesh).

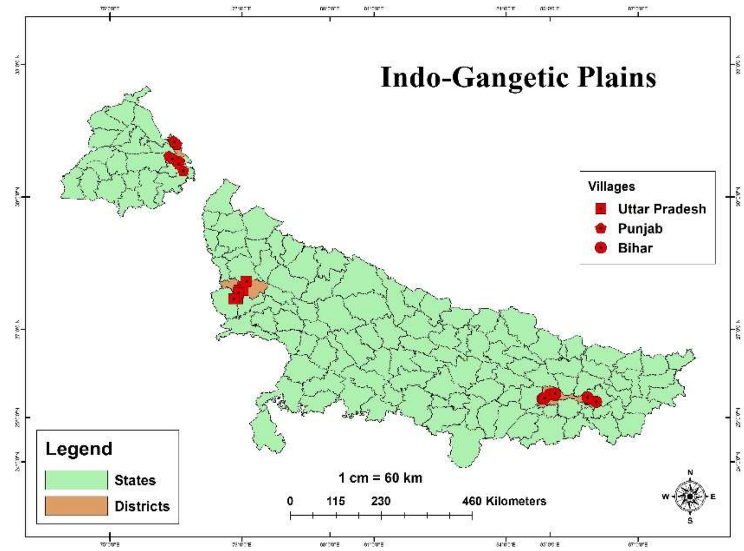

Figure 1: Geo-locations of the sampling villages in the study area
Source: Map is made using ArcGIS tool by the authors

4.2 Extent of adoption of food safety practices

This part of the study investigates the extent of adoption of food safety practices at the farm level. The way animals are raised on farms has changed significantly over the past 50 years (Cardoso *et al*., 2016) as well as growth in farm size and increased technology (Fraser, 2008). Advancements in science and technology have supported the introduction of on-farm innovations and have had a structural impact on the sector (Henchion *et al*., 2022). Keeping in mind these on-farm innovations and the DAHD document, we selected 71 practices that ensure microbiological, physical, and chemical safety. These dimensions were further categorized into 7 broad groups, as illustrated in Table 2.

Utilizing the Analytical Hierarchy Process (AHP) by Korale-Gedara *et al*. (2023), the research revealed that, within microbiological safety, practices pertaining to worker hygiene hold greater significance. Moreover, shed management and proper usage of medicines exhibit higher importance in the context of physical and chemical safety measures. The study methodically identifies 39 microbiological safety, 21 physical safety, and 11 chemical safety measures, detailed in the Appendix (Table A1), along with their respective adoption percentages. Within microbiological safety, 13 practices focus on utensils hygiene, 11 on farmer's hygiene, and 15 on animal/milk hygiene. In the context of physical safety, 16 practices address shed hygiene, while 5 relate to waste management practices implemented on dairy farms. For chemical safety, 6 practices are concerned with the proper use of medicine and 5 with chemical use among dairy farmers. Once farmer's compliance with food safety practices was obtained, we developed a food safety index (FSI) to measure the intensity of adopting these practices.

The FSI is a weighted composite index designed to gauge the adoption level of food safety practices. It provides a comprehensive assessment of the extent to which these practices have been implemented. Given the distinct food safety risks associated with various dimensions, it is necessary to assign weights that are different from one another. These weights, which sum up to 1, were determined based on their significance in ensuring milk safety. The number of practices followed in each category was multiplied by the respective weight. These product values were then summed across all categories, resulting in the food safety index for a farm household. The FSI of $\mathrm{i^{th}}$ farm is presented as,

$$\mathrm{FSI_i} = \sum_{\mathrm{j=1}}^{3} \mathrm{W_{jn} S_{jin}}$$

Where, $\mathrm{w_{jn}}$ is the weight assigned for $\mathrm{j^{th}}$ component of the index in the $\mathrm{n^{th}}$ farming system. $\mathrm{S_{ji}}$ is $\mathrm{i^{th}}$ farmer's compliance with practices that ensure $\mathrm{j^{th}}$ safety dimension. $\mathrm{S_{jin}}$ is the weighted summation in the $\mathrm{n^{th}}$ farming system out of the total available practices that are needed to ensure the $\mathrm{j^{th}}$ safety dimension of milk.

$$\mathrm{S_{jin}} = \sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{W_{kjn} X_{kj}}$$

Where, $\mathrm{W_{kjn}}$ is the weight assigned for the $\mathrm{k^{th}}$ sub-component in the $\mathrm{j^{th}}$ category in the $\mathrm{n^{th}}$ farming system. The summation of $\mathrm{W_{kjn}}$ is equal to 1. $\mathrm{X_{kj}}$ is the proportion of food safety practices adopted in the $\mathrm{k^{th}}$ sub-component in the $\mathrm{j^{th}}$ category by the $\mathrm{i^{th}}$ farmer.

Building on the work of Korale-Gedara *et al*. (2023), the study assigns weights of 0.60, 0.23, and 0.17 to microbiological, physical, and chemical safety practices, respectively. These weights are further delineated for each subcategory based on the relative importance of ensuring milk safety, as outlined in Table 2. The food safety index ranges from 0 to 1. When a farmer adheres to all the food safety practices, the FSI equals 1, and it is 0 if none of the practices are adopted. Cronbach's alpha coefficient[1] was employed to evaluate the internal consistency of these three categories (Cronbach, 1951). The scores were 0.74 for microbiological, 0.54 for physical, and 0.37 for chemical safety measures, suggesting that microbiological and physical measures have relatively high internal consistency.

Table 2: Weights assigned for each category of adoption practices

S. No.	Adoption practices	No.	Weight assigned
I	Microbiological safety		
	Utensils hygiene	13	0.14
	Farmer's hygiene	11	0.29
	Animal and milk hygiene	15	0.17
II	Physical safety		
	Shed hygiene	16	0.20
	Waste management	5	0.03
III	Chemical safety		
	Proper usage of medicines	6	0.15
	Proper usage of chemicals	5	0.02

4.3 Determinants of the intensity of adoption of food safety practices

Multiple linear regression and ordered logistic regression models were used to test the role of farm characteristics and awareness in determining the intensity of the adoption of food safety practices. Multiple linear regression model measures the intensity of food safety practices usage. It assumes FSI as a continuous variable, expressing its use as a function of observable explanatory variables and an error term. The model is presented as:

$$Y_i^* = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i$$

Where, Y_i^* is the FSI of the i^{th} farmer. β_0 is the intercept, β_i's are coefficients to be estimated, X_i's are vectors of farm characteristics and awareness, and ε_i is the error term.

[1] Cronbach's alpha is a measure of internal consistency, indicating how closely related a set of items are within a group. It is commonly used to assess the reliability of a scale.

In estimating the ordered logit model, the entire sample is classified into three groups based on the value of the dependent variable, FSI. Farmers who have recorded a score below 0.4 were considered low adopters, between 0.4 and 0.7 were medium adopters, and above 0.7 were high adopters.

$$Y^* = \beta_0 + X'\beta + \varepsilon$$

where, Y^* is unobserved. What we do observe is $Y^* = 1$ if $0.4 \leq \text{FSI}$ (low adopters), $Y^* = 2$ if $0.4 < \text{FSI} \leq 0.7$ (Medium adopters), and $Y^* = 3$ if $\text{FSI} > 0.7$ (High adopters).

The farm characteristics used are described in Table 3. Factors such as state, caste, marketing channel, source of water, and breeding practices were used as dummy variables.

Table 3: Description of dependent and explanatory variables

Dependent variable			**Independent variables**		**Expected Sign**
Variable	**Model**	**Description**	**Variables**	**Description**	
			Age of HH	In years	+/-
			Education of HH	Schooling years	+
	Ordered logistic model	1 = Low adopters 2 = Med adopters 3 = High adopters	Family size	Number	+/-
			Caste	Dummy variable	+/-
			State	Dummy variable	+/-
FSI (Compliance with food safety measures)			Herd size	Number	+/-
			Cross bred animals	Number	+/-
			Share of dairy income	Share in total income	+
			Marketing channels	Dummy variable	+
	Multiple linear regression	0.0-1.0	Training	Yes/No	+
			Awareness of infection risk, modern dry cow therapy, and gap in milking after medicine	Yes/No	+
			Source of water	Dummy variable	+/-
			Source of breeding	Dummy variable	+/-

4.4 Impact evaluation estimation

We seek to estimate the causal effect of *adoption intensity* on outcome indicators. But practical application of impact evaluation is challenging especially in non-experimental studies (White and Raitzer, 2017). In non-experimental studies, matching has been widely used to establish the non-treated group that is as similar as possible to the treated group. The Propensity Score Matching (PSM) method, developed by Rosenbaum and Rubin (1983), is the most used in empirical studies. However, the use of the PSM is limited to a binary treatment, where one of the groups has access to the treatment while the other has no access to the treatment. So, like PSM, Hirano and Imbens (2004) developed a method called the Generalized

Propensity Score (GPS) for treatments with a continuous value. As our treatment value ranges between 0 and 1, we employed the GPS method to study the heterogeneous impact of the adoption intensity on productivity, price, and profitability outcomes.

Consider a random sample of households represented by i where $\mathrm{i} = 1, \ldots, \mathrm{N}$. Let $\mathrm{Y_i}\,(\mathrm{t})$ be the potential outcome for household i under treatment level t, $\mathrm{t} \in \Gamma$ where Γ is the treatment interval $(\mathrm{t_0}, \mathrm{t_1})$, and t denotes the dosage (compliance with food safety measures). For each i, there is a set of potential outcomes $\{\mathrm{Y_i}\,(\mathrm{t})\}$, $\mathrm{t} \in \Gamma$ referred to as the individual-level dose-response function.

The main interest in continuous treatment impact evaluation is an average dose-response function, $\mu\,(\mathrm{t}) = \mathrm{E}[\mathrm{Y_I}\,(\mathrm{t})]$, which represents the function of the average potential outcomes over all possible treatment levels. The observed variables for each household i are vectors of covariates, I, the treatment received, $\mathrm{I_i}$, and the potential outcome corresponding to the level of the treatment received, $\mathrm{Y_i} = \mathrm{Y_i}(\mathrm{T_i})$.

Hirano and Imbens (2004) generalized the unconfoundedness assumption to a continuous treatment, where the treatment assignment mechanism is independent of each potential outcome conditional on the covariates: $\mathrm{Y_i}(\mathrm{t}) \perp \mathrm{T_i}|I$ for all $\mathrm{t} \in \Gamma$. Let $\mathrm{r}\,(\mathrm{t}, \mathrm{x})$ be the conditional density of the treatment given the covariates: $\mathrm{r}\,(\mathrm{t}, \mathrm{x}) = \mathrm{f\,T} \mid \mathrm{X}\,(\mathrm{t} \mid \mathrm{x})$. Then, the generalized propensity score is defined as $\mathrm{R} = \mathrm{r}\,(\mathrm{T}, \mathrm{X})$. The GPS was specified and estimated following the three steps.

Step I: The level of milk safety practices adopted was modelled as:

$$\mathrm{T_i}|\mathrm{X_i} \sim \mathrm{N}\,(\beta_0 + \beta_1'\mathrm{X_i}, \sigma^2)$$

Thereafter, β_0, β_1' and σ^2 were estimated using a maximum likelihood estimation. The estimated GPS was obtained using β_0, β_1' and σ^2.

$$\widehat{\mathrm{R}_\mathrm{I}} = \frac{1}{\sqrt{2\pi\hat{\sigma}^2}} \exp\,(1 - \frac{1}{2\hat{\sigma}^2}(\mathrm{T_i} - \beta_0 - \beta_1'\mathrm{X_I})^2$$

Step II: This step involves estimating the conditional expectation of the outcome as a function of observed treatment (T_i) and the estimated GPS ($\widehat{R}_i$). Accordingly, the conditional expectation of the outcome was estimated as a function of treatment level, estimated GPS, and interactions between the two.

$$E[Y_i|T_iR_i] = \alpha_0 + \alpha_1 T_i + \alpha_2 T_I^2 + \alpha_3 R_i + \alpha_4 R_i^2 + \alpha_5 T_i R_i$$

Step III: Given the parameters estimated in the second step, the average potential outcome at each treatment level t was estimated as:

$$E\left[\widehat{Y(t)}\right] = \frac{1}{N}\sum_{I=1}^{N}[\widehat{\alpha}_0 + \widehat{\alpha}_1 t + \widehat{\alpha}_2 t^2 + \widehat{\alpha}_3 \hat{r}(t, X_i) + \widehat{\alpha}_4 \hat{r}(t, X_i)^2 + \widehat{\alpha}_5 \widehat{tr}(t, X_i)]$$

5 Results and Discussion

5.1 Socio-Economic characteristics of sampled dairy farmers

The socio-economic characteristics of sample households are presented in Table 4. The highest FSI average is observed in Punjab (0.58), followed by Uttar Pradesh (0.54) and Bihar (0.48). Overall, FSI was observed at 0.53. Household head (HH) age averages 58 years in Punjab, 57 in Bihar, and 54 in Uttar Pradesh. Average years of schooling were 8.8 in Uttar Pradesh, 7.5 in Bihar, and 7.2 in Punjab. Bihar and Uttar Pradesh have an average household size of eight members, predominantly male-headed (96 and 95 percent, respectively). In Punjab, the average family size is six, with 85 percent headed by males. The number of senior citizens were similar across all states. Uttar Pradesh had more adults than Bihar and Punjab, and Bihar and Uttar Pradesh had more children than Punjab. Punjab, however, has the highest female-to-male ratio (900), followed by Bihar (886) and Uttar Pradesh (884). Scheduled Caste/Scheduled Tribes (SC/STs) constitute 28 percent of respondents in Bihar, 14 percent in Punjab, and 21 percent in Uttar Pradesh. Other Backward Castes (OBCs) account for 30 percent of respondents in Bihar, 15 percent in Punjab, and 43 percent in Uttar Pradesh. General/Others make up 42 percent of Bihar, 71 percent of Punjab, and 36 percent of Uttar Pradesh respondents. Punjab has the maximum operational land holding, gross cropped area, and net irrigated area. Uttar Pradesh exhibits the highest cropping intensity (177.8), followed by Punjab (171.4) and Bihar (153.7). The net irrigated area is 1.3 ha in Bihar, 1.6 ha in Punjab, and 1.2 ha in Uttar Pradesh. The distribution of farmers in each land class reveals that most farmers have marginal land. Table 4 also outlines dairy farm attributes, showing that Punjab has higher herd size, higher milk sales, and productivity. Also, dairy cooperatives and formal channels are predominantly used for milk disposal in all states. The exclusive reliance on a single channel was observed in all the states for the disposal of milk, indicating that most farmers are consistently choosing and utilizing a specific method for the distribution of their milk produce, highlighting a prevalent and uniform practice within the setting. The dissemination of information regarding food safety measures in the dairy sector primarily occurs through informal networks, with friends and household members being the most common sources. In terms of formal training, there is a significant disparity between states. In Punjab, 41.5 percent of dairy farmers have received formal training in FSMs. Conversely, Bihar and Uttar Pradesh show lower training participation.

Table 4: Socio-economic characteristics of sample households

Particulars	Bihar	Punjab	Uttar Pradesh	Overall
FSI (0-1)	0.48	0.58	0.54	0.53
Average age of HH (years)	57.4	57.6	53.7	53.7
Education of HH (years)	7.5	7.2	8.8	7.8
Average size of the family (number)	8.3	5.8	8.1	7.5
Male headed household (percent)	96.5	85.4	95.1	92.3
Average senior citizens (greater than 60)				
Male	0.6	0.6	0.6	0.6
Female	0.6	0.6	0.6	0.6
Average adults (15-59)				
Male	2.4	1.8	2.6	2.3
Female	2.2	1.6	2.2	2.0
Average children (less than 15)				
Male	1.4	0.6	1.1	1.0
Female	1.1	0.5	1.0	0.9
Female to male ratio (per thousand)	886	900	884	890
Dependency ratio w.r.t family size				
Male	0.24	0.20	0.20	0.2
Female	0.19	0.20	0.19	0.2
Caste (percent)				
Scheduled caste/ Scheduled tribe	27.8	13.6	21.1	20.8
OBC	30.4	15.5	43.1	29.7
General/ Other	41.7	70.9	35.8	49.5
Land holding				
Size of operational land (ha)	1.4	1.7	1.3	1.5
Gross cropped area (ha)	2.3	3.5	2.6	2.8
Cropping Intensity (percent)	153.7	171.4	177.8	167.6
Net irrigated land (ha)	1.3	1.6	1.2	1.4
Percent of farmers in each land class				
Landless	13.9	10.7	8.1	10.9
Marginal	33.9	35.9	44.7	38.2
Small	30.4	15.5	21.1	22.3
Medium	16.5	28.2	19.5	21.4
Large	5.2	9.7	6.5	7.1
Dairy farm attributes				
Herd size	1.1	2.5	1.6	1.7
Herd size in each land class (average)				
Landless	0.8	1.4	0.4	0.9
Marginal	0.8	1.9	1.4	1.4
Small	1.6	2.2	1.7	1.8
Medium	0.8	2.9	2.3	2.0
Large	1.7	6.1	2.0	3.3
Milk sale (liters/day)	7.8	17.6	5.1	10.2
Milk Productivity (liters/ day)	6.3	7.3	4.1	5.9
Milk channels followed by households (percent)				
Farmers – cooperatives and formal channels	35.7	89.3	52.8	59.3
Farmers – milk vendors, processors, hotels, etc.	17.4	2.9	29.3	16.5
Farmers – households	16.5	5.8	1.6	8.0
Does not sell	33.9	15.5	20.3	23.2
Number of farmers using different channels (percent)				
Only one channel	88.7	79.6	83.7	84.1
Two channels	11.3	18.5	13.8	14.4
Three channels	-	1.9	2.5	1.5
Access to information (percent)				
Household member	31.3	70.2	78.8	59.9

Particulars	Bihar	Punjab	Uttar Pradesh	Overall
Friends	66.1	74.5	21.1	51.8
Institutions/ Others	3.4	6.3	0.8	3.3
Attended training (percent)	3.5	41.5	2.4	13.8
Number of observations	115	103	123	341

Source: Author's calculations based on field survey

5.2 Adoption of food safety practices

Indices were formulated for each dairy household to measure the extent of adoption. Table 5 reveals that farmers are adopting 48 to 58 percent of food safety measures at the farm level. While Punjab exhibited a slightly higher FSI value (0.58) compared to Uttar Pradesh (0.54) and Bihar (0.48), it is worth noting that the range reflects both minimum and maximum indices within Punjab. Bihar, on the other hand, displayed the narrowest range. The coefficient of variation was most pronounced in Punjab, indicating a greater level of dispersion around the mean. Though the range is moderately wide, especially in Bihar and Uttar Pradesh, it marks an improvement as Kumar *et al*. (2011) reported 0.42 and 0.45 FSI for these states in 2011.

Table 5: Status of adoption of food safety practices

Particulars	Bihar	Punjab	Uttar Pradesh	Overall
FSI	0.48	0.58	0.54	0.53
Range	0.36-0.74	0.02-0.81	0.33-0.73	0.02-0.81
Standard Deviation (±)	0.07	0.20	0.08	0.13
Coefficient of variation (%)	14.6	34.5	14.8	24.5
Herd size category				
≤2 animals	0.47	0.55	0.53	0.51
2-4 animals	0.55	0.65	0.58	0.61
>4 animals	0.48	0.67	0.62	0.65

Source: Author's calculations based on field survey

FSI values exhibit marginal variations across states, yet the adoption rate demonstrated a positive correlation with herd size in all the states except Bihar. A slight deviation observed in Bihar warrants further examination to understand the unique factors influencing the relationship between herd size and FSI. Figure 2 shows the relationship between herd size and FSI across the three key states. The data suggests that as herd size increases, there is an inclination towards higher adoption rates of food safety practices, providing insight into the interplay between herd management and the commitment to food safety measures.

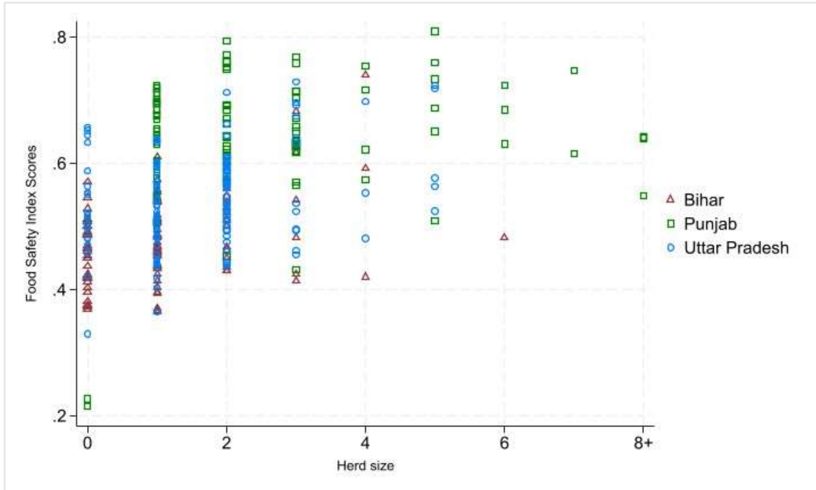

Figure 2: Relationship between herd size and food safety index score

Table 6 provides a comprehensive overview of the adoption status of different elements within food safety practices, specifically focusing on microbiological, physical, and chemical safety. The data presented in Table 6 reflects the perspective of farmers regarding their concerns related to food safety. Punjab is ahead of Bihar and Uttar Pradesh in compliance with the highest standards across three dimensions of food safety practices, highlighting its advanced commitment to ensuring clean and compliant food safety practices. Furthermore, adherence within the state reveals that the primary area of concern for dairy farmers in Punjab revolves around both microbiological and chemical safety. However, Bihar farmers are particularly mindful of and engaged with practices that address the physical safety of food products. In Uttar Pradesh, farmers are notably more apprehensive about microbiological safety, implying a heightened awareness and emphasis on measures to control and manage microbiological risks in dairy products. These distinct concerns across the three states underscore the regional variations and priorities within the agricultural community concerning food safety practices.

Table 6: Adoption of different components of food safety practices

Components	Microbiological safety (Utensils, farmers & animal/ milk hygiene)	Physical safety (Shed hygiene & waste management)	Chemical safety (Proper usage of medicines & chemicals)
Bihar			
Mean	0.49	0.50	0.42
Range	0.39-0.78	0.24-0.87	0.19-0.66
SD (±)	0.06	0.14	0.10
CV (%)	13.3	27.3	24.1
Punjab			
Mean	0.66	0.57	0.67
Range	0.18-0.87	0.13-0.84	0.37-0.78
SD (±)	0.12	0.16	0.09
CV (%)	17.8	27.4	13.8
Uttar Pradesh			
Mean	0.56	0.52	0.49
Range	0.33-0.75	0.19-0.84	0.15-0.80
SD (±)	0.08	0.13	0.18
CV (%)	15.6	25.2	35.8
Overall			
Mean	0.54	0.53	0.58
Range	0.18-0.87	0.13-0.87	0.15-0.80
SD (±)	0.14	0.16	0.22
CV (%)	25.9	30.2	37.9

Source: Author's calculations based on field survey

5.3 Determinants of the intensity of adoption of food safety practices

The determinants affecting FSI adoption were analyzed using multiple linear regression (OLS method) and ordered logistic regression. The results provide information about the relationship between the intensity of the adoption of food safety practices and the characteristics of dairy farms. Before applying the regression models, we check for multicollinearity and heteroscedasticity. Variance Inflation Factors (VIF) indicated an average value of 1.64, suggesting no significant multicollinearity. A Breusch–Pagan/Cook–Weisberg test was used to identify heteroscedasticity. However, the non-significance of the chi-square (3.51) at the 5-percent level indicated that the model is not threatened by heteroscedasticity. Using one specific value as a baseline for comparison, we were able to quantify the impact of dummy variables.

The findings from the regression models presented in Table 7 illustrate the relationship between the adoption of food safety practices and various characteristics of dairy farms. OLS column results indicate that for every extra year of schooling, the adoption rate increases by 0.003 units. The adoption rate among the general category is 3.2 percent more than the SC/ST and 3.3 percent more than the OBC category. This suggests that individuals in the general category have greater access to resources, education, awareness, and similar factors compared to other segments of society. Punjab and Uttar Pradesh have higher adoption rates—11.9 percent and 9.3 percent, respectively—than Bihar. The income earned from the dairy sector also positively influences the adoption rate. Higher income empowers farmers to enhance animal husbandry, invest in quality feed, and maintain proper sanitation in dairy operations, collectively fostering a safer and more reliable food supply chain. Training programs related to dairy farming and awareness of modern dry cow therapy positively influenced the adoption rate of food safety practices. Enhanced awareness and understanding empower farmers to implement effective measures in their operations, which ultimately contribute to a higher adoption rate of food safety practices. Farmers that use piped public water supply instead of on-farm well/bore have high adoption intensity. Piped public water supply systems often ensure a more reliable and consistent source of water, reducing the risk of contamination and thus resulting in a higher index. Farmers using Artificial Insemination (AI) breeding techniques compared to natural breeding also have high adoption intensity. This can be attributed to the potential benefits of AI in enhancing breeding precision, efficiency, and overall quality of livestock. The likelihood estimates of the model show a significant F-statistic, indicating robust explanatory power. The correlation between predicted and observed values of the dependent variable is 0.7780. Squaring this value yields multiple squared correlations, indicating that predicted values share about 60 percent of their variance with the dependent variable. The R-squared value indicates that the model fits 61 percent of the variation in the data.

With ordered logistic regression, we assess the likelihood of adopting food safety practices, with corresponding coefficients detailed in columns 3 through 6 of Table 7. The ordered logistic regression model results also show that the general category has a higher adoption rate—Punjab and Uttar Pradesh both have higher adoption rates than Bihar. Also, dairy farmers selling milk to households have a lower adoption rate than those selling to cooperatives. Cooperatives often provide farmers with a structured and organized platform, facilitating adherence to the best dairy practices. Using a piped water supply for cleaning animals is better than using on-farm well/bore and river/stream water. With a one percent increase in the share of dairy income, the adoption rate increases by 2.8 percent. Furthermore, the findings indicate that farmers with an awareness of contamination risks exhibit a high adoption index. Cutoff points in the model signify the transition values of the latent variable across three observed groups. This shows the propensity to adopt, discerning movement from low to medium (cutoff point 1) and from medium to high (cutoff point 2). In the iteration log, software initially fits a null model at iteration 0, progressing to the full model until the log-likelihood difference between successive iterations becomes negligible. The log pseudolikelihood (-87.54) can be used for nested model comparisons.

Table 7: Factors affecting the adoption of the Food Safety Index among dairy farmers

Variables	OLS	Ordered Logistic Regression			
		Coefficient	Marginal Effect		
			Low	Medium	High
Age	-0.000	-0.018	0.001	0.001	-0.001
	(0.000)	(0.017)	(0.001)	(0.001)	(0.001)
Education	0.003**	0.059	-0.002	-0.002	0.003
	(0.001)	(0.049)	(0.002)	(0.002)	(0.003)
Family size	0.001	0.037	-0.001	-0.001	0.002
	(0.001)	(0.062)	(0.002)	(0.002)	(0.004)
Caste (w.r.t General category)					
OBC	-0.033**	-1.009*	0.029	0.029	-0.057
	(0.010)	(0.577)	(0.019)	(0.019)	(0.035)
SC/ST	-0.032**	-2.266**	0.064***	0.064**	-0.129***
	(0.011)	(0.685)	(0.022)	(0.029)	(0.041)
State (w.r.t Bihar)					
Punjab	0.119***	2.717*	-0.077**	-0.077*	0.154**
	(0.015)	(1.521)	(0.034)	(0.040)	(0.065)
Uttar Pradesh	0.093***	2.827**	-0.080***	-0.080**	0.160***
	(0.012)	(0.990)	(0.030)	(0.036)	(0.054)
Herd size	0.001	0.042	-0.001	-0.001	0.002
	(0.002)	(0.086)	(0.003)	(0.003)	(0.005)
Cross bred animals	0.002	0.124	-0.004	-0.004	0.007
	(0.002)	(0.086)	(0.003)	(0.003)	(0.005)
Share of dairy on total income	0.001***	0.028**	-0.001**	-0.001**	0.002**
	(0.000)	(0.013)	(0.000)	(0.000)	(0.001)
Marketing channel (Base: households)					
To cooperatives	0.010	1.703**	-0.048	-0.048	0.097
	(0.014)	(0.866)	(0.034)	(0.035)	(0.064)
To vendors/ hotels/ institution	-0.018	0.906	-0.026	-0.026	0.051
	(0.017)	(0.909)	(0.035)	(0.036)	(0.070)
Does not sell	-0.007	0.617	-0.017	-0.017	0.035
	(0.016)	(0.908)	(0.031)	(0.031)	(0.061)
Training attended	0.027**	-0.156	0.004	0.004	-0.009
	(0.012)	(0.586)	(0.017)	(0.017)	(0.034)
Awareness of contamination risk	0.009	1.333*	-0.038*	-0.038	0.076*
	(0.012)	(0.721)	(0.022)	(0.025)	(0.043)
Awareness of milking gap after medicines	-0.016	-0.579	0.016	0.016	-0.033
	(0.011)	(0.596)	(0.017)	(0.017)	(0.034)
Awareness of modern dry cow therapy	0.023**	0.599	-0.017	-0.017	0.034
	(0.010)	(0.722)	(0.019)	(0.020)	(0.039)
Source of water (Base: farm well/ bore)					
Piped Public water supply	0.034**	1.888**	-0.054**	-0.054**	0.107***
	(0.011)	(0.875)	(0.022)	(0.023)	(0.036)
River/ stream	-0.092**	-3.067***	0.087	0.087	-0.174
	(0.046)	(0.725)	(0.161)	(0.162)	(0.320)
Source of breeding (Base: natural)					
AI	0.038**	1.231	-0.035	-0.035	0.070

Variables	OLS	Ordered Logistic Regression			
		Coefficient	Marginal Effect		
			Low	Medium	High
	(0.015)	(0.823)	(0.030)	(0.031)	(0.059)
Both	0.017	0.085	-0.002	-0.002	0.005
	(0.021)	(1.137)	(0.039)	(0.039)	(0.078)
Constant	0.393^{***}				
	(0.034)				
R-squared	0.61				
Adjusted R-squared	0.58				
F (21, 279)	20.37^{***}				
LR χ^2 (21)		114.10^{***}			
Pseudo R^2		0.395			
Log pseudolikelihood		-87.54			
Cutoff point 1		0.511			
		(1.985)			
Cut off point 2		10.137			
		(2.578)			

Source: Author's calculations based on field survey

Note: Figures in parentheses presents standard error. ***, **, * presents significance at 1, 5 and 10 percent

5.4 Impact of compliance with food safety measures

The first step in the GPS estimation procedure involves calculating the propensity score for each household in the sample. This score indicates the likelihood of each household receiving the treatment. The GPS estimation is presented in Table 8. A Kolmogorov-Smirnov normality test was used to assess the normality assumption of the treatment variable. The treatment variable satisfied the normal distribution assumption at a 5-percent level. Based on the visual examination from Figure 3, it is determined that the treatment variable approximates a normal distribution, which means no further transformations are necessary to meet the normality assumption.

Table 8: Regression of an adoption intensity over the covariates: The estimated Generalized Propensity Score (GPS)

Covariates	Coefficient	Standard Error
Age	0.001	0.000
Education	0.004***	0.001
Family size	0.002	0.002
Bihar	-0.035*	0.020
Uttar Pradesh	0.031*	0.018
Milch animals	0.005	0.003
Crossbred animals	0.001	0.002
Share of dairy in total income	0.001***	0.000
Selling milk to cooperatives	0.043***	0.013
Training attended	0.059***	0.018
Awareness of contamination risk	0.060***	0.016
Awareness of milking gap after medicine	0.014	0.015
Awareness of modern dry cow therapy	0.051***	0.014
Piped source of water	0.058***	0.015
AI source of breeding	0.028	0.019
Constant	0.246***	0.040

Source: Author's calculations based on field survey
Note: ***, **, * presents significance at 1, 5 and 10 percent

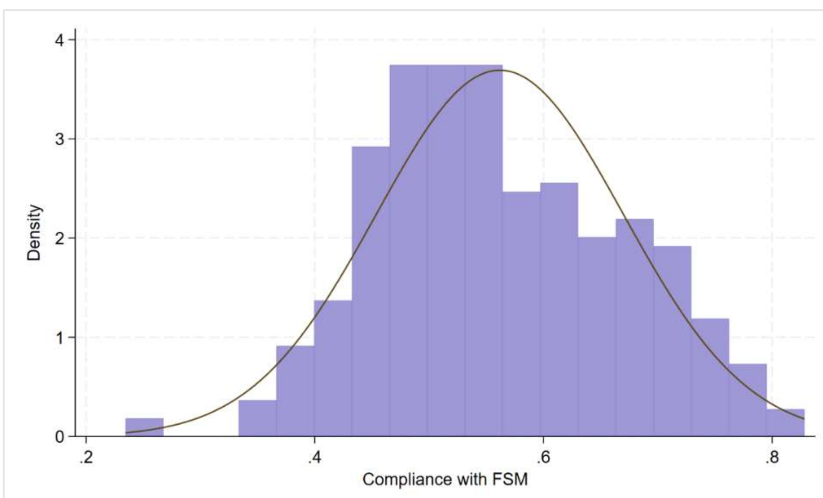

Figure 3: Distribution of compliance with food safety measures

Achieving balance in covariates between the treatment and control groups is essential for ensuring the validity of causal inference. The estimated GPS serves as a tool for assessing the balance of covariates between the treatment and control groups. To assess covariate balance using the estimated GPS, the sample households were categorized into four treatment intervals with comparable sizes. Further, the balance was investigated by testing whether the mean in one of the groups was different from the mean in the other groups combined. Table 9 reports the t-tests for each of the sixteen covariates and four groups. The results indicate that of the 64 covariates included, the t-values of 40 covariates were significant (greater than 1.68). The GPS unadjusted covariates indicate the existence of a 67 percent covariate imbalance. GPS can reduce the covariate imbalance (Kassie *et al*., 2014), thus, the households were matched using the estimated GPS and covariate balancing property. The adjusted GPS reveals the reduction of covariate imbalance by 15 percent. Also, checking the region of common support is vitally important before proceeding to the next step.

Table 9: Balancing check of covariates before and after adjusting GPS

Covariates	[0.02-0.49]		[0.49-0.59]		[0.59-0.69]		[0.69-0.83]	
	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.
Age	1.38	0.97	0.50	0.51	-1.13	-1.19	-0.55	-0.98
Education	3.75*	4.21***	-2.49*	-2.73**	-2.06*	-2.34**	1.15	1.24
Family size	-0.06	-0.82	-2.83*	-3.00**	0.94	1.27	1.71	2.70*
Bihar	-5.93*	-8.92***	-1.19	-1.53	5.07*	5.71***	3.53*	4.95***
Punjab	3.81*	6.99***	5.63*	6.08***	-3.84*	-4.72***	-7.07*	-10.06***
Uttar Pradesh	1.58	1.66*	-4.06*	-4.12***	-1.24	-1.00	2.30*	3.81***
Milch animals	4.52*	4.37***	1.34	1.53	-4.50*	-4.76***	-3.43*	-3.42***
Crossbred animals	1.31	0.62	0.59	0.46	-1.00	-0.94	-1.05	-1.38
Share of dairy in total income	2.37*	1.34	3.01*	3.05**	-1.42	-1.91**	-3.04*	-6.07***
Selling milk to cooperatives	4.64*	4.78***	1.24	1.44	-2.19*	-3.84**	-3.09*	-5.32***
Training attended	4.30*	4.69***	2.73*	3.34***	-3.35*	-4.62***	0.26	-5.84***
Awareness of contamination risk	2.46*	0.17	1.27	0.76	-0.10	-1.41	-1.77*	-2.74**
Awareness of milking gap after medicine	4.78*	5.51***	0.86	1.25	-3.65*	-4.97***	-3.34*	-3.68***
Awareness of modern dry cow therapy	4.91*	4.48***	-0.31	0.61	-0.82	-2.44**	-2.96*	-4.21***
Piped source of water	0.07	0.95	4.32*	4.39***	0.73	0.36	-4.59*	-9.43***
AI source of breeding	0.93	1.14	2.43*	2.39**	-1.29	-1.71*	-1.91*	-2.61**

Source: Author's calculations based on field survey
Note: Values presents t-stat for comparisons of means ***, **, * presents significance at 1, 5 and 10 percent

The common support region is a fundamental concept in propensity score matching and analysis. It refers to the range of propensity scores where both treated and control units exist in other words, the area of overlap in propensity scores between treated and control groups. This overlap is crucial because it ensures that there are comparable individuals across both groups, allowing for a valid comparison of treatment effects. The common support test (Figure 4) revealed that the GPS of groups have a significant overlap with the same distribution of the rest of the observations.

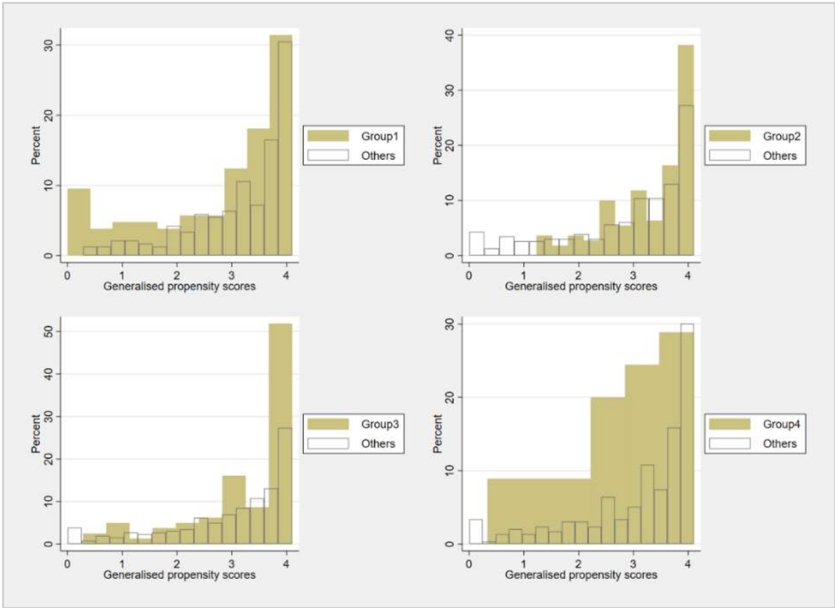

Figure 4: Common support test

In the second step, the conditional expectations of the outcome variables were calculated based on the observed treatment (T_i), the estimated GPS ($\widehat{R}_i$), along with their squares and interactions, detailed in Table 10. The results reveal that both productivity and price outcomes play significant roles in influencing the degree to which individuals comply with FSM. Productivity calculated as the total production by milch animals indicates the daily yield of milk. The price outcome represents the income in Indian rupees earned by selling a liter of milk through various channels in a day. Higher productivity and increased prices typically lead to higher profits. However, the equation becomes more complex when the cost of adopting new measures, such as Food Safety Measures, is substantial. Even if milk productivity increases and a higher price is received due to improved quality, the initial and ongoing expenses of implementing these measures can offset these gains. Profit outcome is determined by the difference between total revenue and costs per liter. The costs considered in the analysis encompass labor costs, costs related to good dairy practices, breeding practices, vaccination, and feed. The coefficients of profitability were not significant with the FSM compliance. This may be attributed to the substantial upfront costs required to adhere to good dairy practices. FSM compliance may not yield immediate financial gains, but it is crucial for ensuring the long-term sustainability and regulatory adherence of the dairy sector. The GPS and its squared term were significant in the case of productivity, suggesting that the relationship between the likelihood of receiving the treatment and productivity exhibits some curvature or non-linearity.

Table 10: Estimated conditional expectations of outcome variables: OLS

Particulars	Productivity	Price	Profitability
Compliance with Food Safety Measures (FSM)	31.40**	123.12**	4.61
	(11.43)	(49.06)	(4.78)
Compliance with FSM square	-20.18	-54.58	-0.70
	(13.82)	(59.34)	(3.67)
Generalized Propensity Score (GPS)	-16.90*	-62.50	-1.07
	(9.36)	(40.19)	(2.66)
GPS square	12.90*	38.76	1.34
	(7.02)	(30.14)	(1.42)
Compliance with FSM*GPS	1.36	20.96	-1.24
	(9.44)	(40.53)	(2.62)
Constant	-0.53	-2.41	1.27
	(1.49)	(6.38)	(1.89)
Observations	341	341	232
F- value	8.01	19.65	10.61
Prob F	0.00	0.00	0.00
R-squared	0.11	0.23	0.22
Adj. R-sq.	0.09	0.21	0.20

Source: Author's calculations based on field survey
Note: Figures in parentheses presents standard error. ***, **, * presents significance at 1, 5 and 10 percent

The final step of GPS estimation involves determining the average dose-response function (DRF) across various treatment intervals. Utilizing the "dose-response" Stata package, the average DRF and average treatment effect function (TEF) are estimated, accompanied by a 95 percent confidence interval and bootstrapping of the standard errors through 100 replications (Bia & Mattei, 2008). The estimated average DRFs and TEFs are presented in Figures 5, 6, and 7. These figures visually represent the relationships between FSM compliance and three important outcomes: milk productivity, milk prices, and profitability within the dairy sector. Each graph comprises three distinct lines, in which the dose-response or treatment effect lines occupy the middle position, with upper and lower bound lines denoting the 95-percent confidence intervals.

Figure 5 illustrates the impact of adherence to FSM compliance on milk productivity. We observed a non-linear impact of the compliance, suggesting that the effect on milk productivity is not uniform across all compliance levels. Notably, there was no positive response at the lower treatment levels of compliance. However, between the treatment levels of 40 and 60 percent, a distinct shift occurred. The average DRF began to increase, indicating that within this range of compliance, there was a noticeable improvement in milk productivity. This finding suggests that there might be a threshold level of compliance necessary to elicit a positive response in milk productivity. The average TEF on the right side of Figure 5 also supports this observation, showing an increasing marginal effect of FSM compliance on milk productivity.

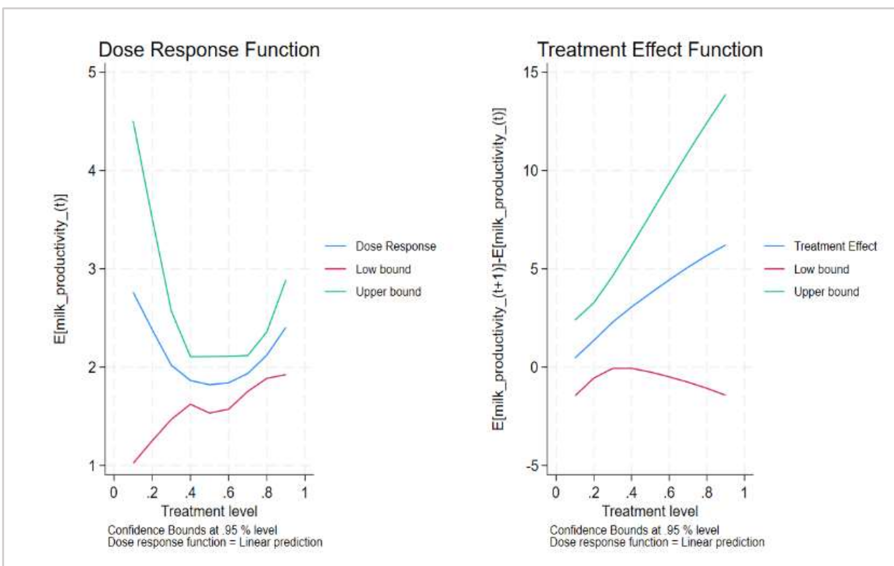

Figure 5: DRF and TEF of compliance with FSM on milk productivity

Figure 6 presents the impact of FSM compliance on average prices fetched by dairy farmers. We observed an increasing linear impact of compliance on this outcome. This linear relationship suggests that there is a direct and positive impact of adherence to FSM on the prices farmers receive for their dairy products. Additionally, while the average TEF shows a slight decrease, it remains positive throughout the observed range of compliance levels, indicating that although there may be some variability, the overall trend still supports the notion that compliance with FSM has a moderate but positive effect on the prices farmers can command for their products.

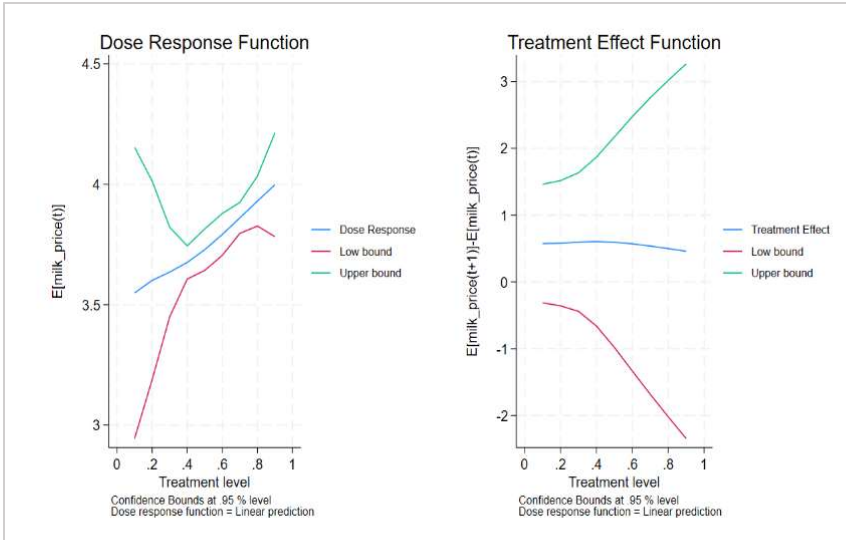

Figure 6: DRF and TEF of compliance with FSM on average prices

The impact of FSM compliance on profit earned per unit (Figure 7) also showed that though the average TEF is slightly decreasing, it has remained positive. The DRF has been increasing throughout the treatment levels. Despite the lack of significance in the statistical analysis (Table 10), the graphical representation revealed a positive relationship between adherence to food safety measures and profitability. This suggests that while direct influence might not have been apparent, a tangible link between them exists. This underscores the importance of investing in maintaining food safety standards in the dairy sector.

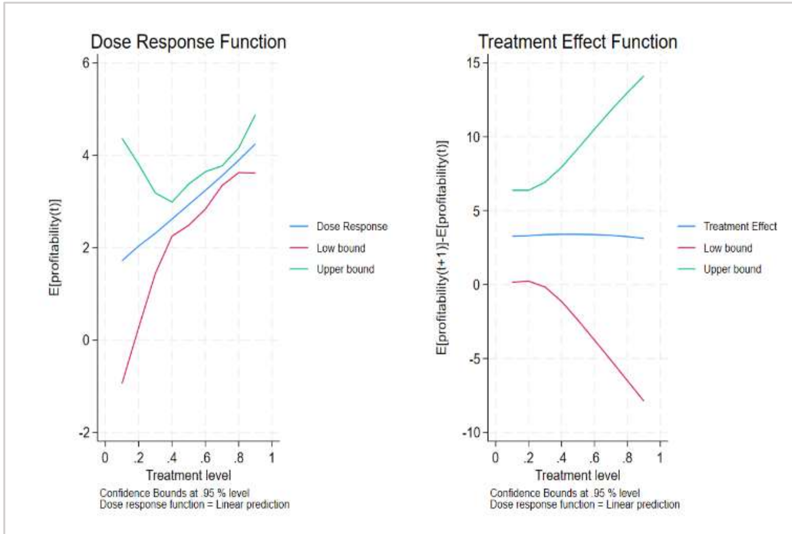

Figure 7: DRF and TEF of compliance with FSM on profitability

6 Conclusion and policy implications

The study systematically examined the adoption of food safety practices among dairy farmers in three key states in the Indo-Gangetic plains of India. We explored a comprehensive set of good production practices undertaken by dairy farmers and developed a robust food safety index to quantify the same. The index is derived from 71 distinct practices which serves as a quantitative measure of the level of FSM compliance in milk production. The factors influencing adoption intensity were assessed using an ordinary least square and ordered logistic model. Furthermore, the impact of FSM compliance on farm-level performance indicators was estimated using a generalized propensity score. The dose-response function was employed for visual illustrations of the impact of adoption intensity.

On average, only 53 percent of the prescribed measures are being followed by dairy farmers in the study area, a less-than-optimal scenario. The food safety index varied across states: Bihar had the lowest adoption of FSM at 48 percent, Punjab had 58 percent, and Uttar Pradesh had 54 percent. Punjab exhibits a notably higher food safety index compared to Uttar Pradesh and Bihar. This variation is attributed to a spectrum of influential factors, including educational attainment, caste, income derived from dairying, marketing channels, training exposure, awareness of contamination, awareness of modern dry cow therapy, source of water and breeding practices. Dairy farmers engaged in formal channels (e.g. cooperatives) have a high adoption intensity of FSM compared to dairy farmers associated with informal channels. This signifies the pivotal role of cooperatives in enhancing food safety standards within the dairy sector. The findings also revealed that the use of piped water sources was associated with a higher food safety index compared to open water sources. Additionally, the integration of Artificial Insemination in breeding practices demonstrated a positive impact on the index, surpassing the outcomes of natural breeding methods.

Moreover, the impact analysis revealed that compliance with FSMs is correlated with milk price, milk productivity, and profitability. However, the impact on milk productivity suggests that while lower levels of compliance may not yield significant improvements in milk productivity, maintaining a certain threshold of compliance can lead to tangible enhancements in production efficiency. The impact on price and profit also advocates that investing in and maintaining compliance contributes to economic benefits for dairy farmers.

The study highlights key policy implications for boosting food safety measures in the dairy sector. Firstly, there is a need to incentivize the farmers through reforms in the pricing system and the inclusion of quality parameters into milk, which would be beneficial for enhancing the adoption of FSM in milk production. Secondly, improving infrastructure, such as access to clean water and AI breeding facilities, should be emphasized. Thirdly, conducive policies should be promoted for strengthening formal marketing channels like cooperatives. Lastly, there should be an increased emphasis on the sensitization of farmers to the potential benefits of the adoption of food safety measures.

References

Amenu, K., Wieland, B., Szonyi, B., Grace, D. 2019. Milk handling practices and consumption behavior among Borana pastoralists in Southern Ethiopia. J. Health Popul. Nutr. 38, 1–12. https://doi.org/10.1186/s41043-019-0163-7

André Feil, A., Schreiber. D., Haetinger, C., Haberkamp, A.M., Inês Kist, J., Rempel, C., Maehler, A.E., Gomes, M.C., Rodrigo da Silva, G. 2020. Sustainability in the dairy industry: A systematic literature review. Environ. Sci. Pollut. Res. 27, 33527–33542 https://doi.org/10.1007/s11356-020-09316-9

Annual Report, 2022-23. Ministry of Cooperation, Government of India. https://www.cooperation.gov.in/sites/default/files/2023-08/Annual%20Report-2022-23_c.pdf

Ariningsih, E., Saliem, H.P. Erwidodo. 2019. Sales and Marketing of Fresh Milk by Smallholder Dairy Farmers in West Java. IOP Conf. Ser.: Earth Environ. Sci. 372, 012056 https://doi.org/10.1088/1755-1315/372/1/012056

Azanaw, J., Gebrehiwot, M., Dagne, H. 2019. Factors associated with food safety practices among food handlers: facility-based cross-sectional study. BMC Res. Notes. 12, 1–6 https://doi.org/10.1186/s13104-019-4702-5

Bai, Z., Liu, C., Wang, H., Li, C. 2023. Evolution characteristics and influencing factors of global dairy trade. Sustainability. 15, 931 https://doi.org/10.3390/su15020931

Bhatt, S.R., Singh, A., Bhatt, S.M. 2008. Assessment of synthetic milk exposure to children of selected population in Uttar Pradesh, India. Indian J. Med. Res. 7, 22–34

Bia, M., Mattei, A. 2008. A Stata package for the estimation of the dose-response function through adjustment for the generalized propensity score. Stata J. 8, 354–373 http://dx.doi.org/10.1177/1536867X0800800303

Birthal, P.S., Chand, R., Joshi, P.K., Saxena, R., Rajkhowa, P., Khan, M.T., Khan, M.A., Chaudhary, K.R. 2017. Formal versus informal: efficiency, inclusiveness and financing of dairy value chains in Indian Punjab. J. Rural Stud. 54, 288–303 https://doi.org/10.1016/j.jrurstud.2017.06.009

Bisht, A., Kamble, M.P., Choudhary, P., Chaturvedi, K., Kohli, G., Juneja, V.K., Sehgale, S., Taneja, N.K. 2021. A surveillance of food borne disease outbreaks in India: 2009-2018. Food Control. 121, 107630 https://doi.org/10.1016/j.foodcont.2020.107630

Cardoso, C.S., Hötzel, M.J., Weary, D.M., Robbins, J.A., Keyserlingk, M.A.G. 2016. Imagining the ideal dairy farm. J. Dairy Sci. 99, 1663–1671 https://doi.org/10.3168/jds.2015-9925

CBC News. 2008. Adulterated milk kills 6 children in eastern India. https://www.cbc.ca/news/science/adulterated-milk-kills-6-children-in-eastern-india-1.694024 (accesses 17 November 2023).

Chattu, V.K. 2015. Food safety as an integral part of Food Security: Addressing the governance issues and the critical role of climate change. Int. J. Adv. Res. 3, 1472–1474 https://www.journalijar.com/uploads/218_IJAR-8295.pdf

Chaudhary, H., Sharma, N. 2024. Milk adulterants: Serious impact on human health. J. Med. Evid. 5, 124-128. https://doi.org/10.4103/JME.JME_145_23

Chauhan, C., Dhir, A., Akram, M.U., Salo, J. 2021. Food loss and waste in food supply chains. A systematic literature review and framework development approach. J. Clean. Prod. 295, 1264138 http://dx.doi.org/10.1016/j.jclepro.2021.126438

Chavas, J.P., Läpple, D., Barham, B., Dillon, E. 2022. An economic analysis of production efficiency: Evidence from Irish farms. Can. J. Agric. Econ. 70, 153–173 https://doi.org/10.1111/cjag.12314

Cole, M.B., Augustin, M.A., Robertson, M.J., Manners, J.M. 2018. The science of food security. npj Sci. Food. 2, 14 https://doi.org/10.1038/s41538-018-0021-9

Cronbach, L.J. 1951. Coefficient alpha and the internal structure of tests. Psychometrika. 16, 297-334 https://doi.org/10.1007/BF02310555

DAHD, 2019. 20th Livestock Census, Department of Animal Husbandry and Dairying, Ministry of Fisheries, Government of India https://dahd.nic.in/documents/statistics/livestock-census

DAHD, 2022. How to produce quality, hygienic milk on your farm. Department of Animal Husbandry and Dairying. Ministry of Fisheries, Government of India https://dahd.nic.in/sites/default/filess/2928-MilkBooklet-F-Web.pdf

DAHD, 2023. Basic Animal Husbandry Statistics. Department of Animal Husbandry and Dairying, Ministry of Fisheries, Government of India https://dahd.nic.in/sites/default/filess/BasicAnimalHusbandryStatistics2023.pdf

Dhanalakshmi, M., Balakrishnan, S., Sangeetha, A., Manimaran, K., Jayalalitha, V. 2020. Assessment of milk adulteration in the commercially available milk for the consumers in Cauvery delta region of Tamil Nadu, India. Indian J. Dairy Sci. 73, 131–135 https://doi.org/10.33785/IJDS.2020.v73i02.005

Dhanashekar, R., Akkinepalli, S., Nellutla, A. 2012. Milk-borne infections. An analysis of their potential effect on the milk industry. Germs. 2, 101–109 https://doi.org/10.11599%2Fgerms.2012.1020

Ferens, W.A., Hovde, C.J. 2011. Escherichia coli O157:H7: Animal reservoir and sources of human infection. Foodborne Pathog. Dis. 8, 465–487 https://doi.org/10.1089/fpd.2010.0673

Feyisa, B.W., Haji, J., Mirzabaev, A. 2023a. Determinants of food and nutrition security: Evidence from crop-livestock mixed farming households of central and eastern Ethiopia. J. Agric. Food Res., 12, 100556 https://doi.org/10.1016/j.jafr.2023.100556

Feyisa, B.W., Haji, J., Mirzabaev, A. 2023b. The impact of adoption of milk safety practices on food and nutrition security: Evidence from smallholder dairy farmers in Ethiopia. Res. Glob. 7, 100157 https://doi.org/10.1016/j.resglo.2023.100157

Fraser, D. 2008. Animal welfare and the intensification of animal production, in: Korthals, M., Thompson, P.B. (Eds.), The Ethics of Intensification. The International Library of Environmental, Agricultural and Food Ethics, Springer, Dordrecht, pp. 167–189. https://doi.org/10.1007/978-1-4020-8722-6_12

Garcia, S.N., Osburn, B., Jay-Russell, M.T. 2020. One Health for food safety, food security, and sustainable food production. Front. Sustain. Food Syst. 4, 1–9 https://doi.org/10.3389/fsufs.2020.00001

Gayathri, S.L., Bhakat, M., Mohanty, T.K. 2023. An outlook on commercial dairy farming in India: A review. Indian J. Animal Prod. Manag. 37, 45–56 http://dx.doi.org/10.48165/ijapm.2023.37.1.6

Girma, K., Tilahun, Z., Haimanot, D. 2014. Review on milk safety with emphasis on its public health. World J. Dairy Food Sci. 9, 166–183 https://idosi.org/wjdfs/wjdfs9(2)14/11.pdf

Gossner, C.M., Schlundt, J., Ben Embarek, P., Hird, S., Lo-Fo-Wong, D., Beltran, J.J., Teoh, K.N. Tritscher, A. The melamine incident: Implications for international food and feed safety. Environ Health Perspect. 117, 1803-1808. https://doi.org/10.1289/ehp.0900949

Gwandu, S.H., Nonga, H.E., Mdegela, R.H., Katakweba, A.S., Suleiman, T.S., Ryoba, R. 2018. Assessment of raw cow milk quality in smallholder dairy farms in Pemba Island Zanzibar, Tanzania. Vet. Med. Int. 2018, 1031726 https://doi.org/10.1155/2018/1031726

Handford, C.E., Campbell, K., Elliott, C.T. 2016. Impacts of Milk Fraud on Food Safety and Nutrition with Special Emphasis on Developing Countries. Compr. Rev. Food Sci. Food Saf. 15, 130–142 https://doi.org/10.1111/1541-4337.12181

Henchion, M.M., Regan, A., Beecher, M., MackenWalsh, A. 2022. Developing 'Smart' Dairy Farming Responsive to Farmers and Consumer-Citizens: A Review. Animals. 12, 360 https://doi.org/10.3390/ani12030360

Hernández-Castellano, L.E., Nally, J.E., Lindahl, J., Wanapat, M., Alhidary, I.A., Fangueiro, D., Grace, D., Ratto, M., Bambou, J.C., Almeida, A.M. 2019. Dairy science and health in the tropics: Challenges and opportunities for the next decades. Trop. Anim. Health Prod. 51, 1009–1017 https://doi.org/10.1007/s11250-019-01866-6

Hirano, K., Imbens, G.W. 2004. The propensity score with continuous treatments, in Gelman, A., Meng, X.L. (Eds.), Applied Bayesian modelling and causal inference from incomplete-data perspectives: An essential journey with Donald Rubin's statistical family. John Wiley & Sons, Ltd, pp. 73–84. http://dx.doi.org/10.1002/0470090456.ch7

IDSP, 2024. Weekly Outbreak Surveillance, Integrated Disease Surveillance Program, National Center for Disease Control, Directorate General of Health Services. Ministry of Health and Family Welfare, Government of India https://idsp.mohfw.gov.in/index4.php?lang=1&level=0&linkid=403&lid=3685

Jaffee, S., Henson, S., Unnevehr, L., Grace, D., Cassou, E. 2019. The safe food imperative: accelerating progress in low- and middle- income countries. Agriculture and Food Series, World Bank Group, Washington DC https://documents1.worldbank.org/curated/en/484371545400065950/pdf/133154-PUB-PUBLIC-9781464813450.pdf

Kandpal, S.D., Srivastava, A.K., Negi, K.S. 2012. Estimation of quality of raw milk (open and branded) by milk adulteration testing kit. Indian J. Community Health. 24, 188-192. https://www.iapsmupuk.org/journal/index.php/IJCH/article/view/248/248

Kassie, M., Jaleta, M., Mattei, A. 2014. Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. Food Secur. 6, 217–230 http://dx.doi.org/10.1007/s12571-014-0332-x

Kemitare, G., Kabuye, F., Olyanga, A.M., Rudaheranwa, N. 2020. Value chain, productivity, and trade performance in the dairy industry. Mod. Supply Chain Res. App. 3, 24-40 https://doi.org/10.1108/MSCRA-05-2020-0009

Kena, D., Golicha, D., Jemal, E., Kanu, B., Gayo, G. 2022. Smallholder dairy producers' participation in dairy marketing in Southern Omo Zone, Ethiopia. Pastor. Res. Policy. Prac. 12, 1–13 https://doi.org/10.1186/s13570-022-00262-4

Korale-Gedara, P., Weerahewa, J., Roy, D. 2023. Food safety in milk: Adoption of food safety practices by small-scale dairy farmers in Sri Lanka and their determinants. *Food Control, 143*: 109274 https://doi.org/10.1016/j.foodcont.2022.109274

Kousta, M., Mataragas, M., Skandamis, P., Drosinos, E.H. 2010. Prevalence and sources of cheese contamination with pathogens at farm and processing levels. Food Control. 21, 805–815 https://doi.org/10.1016/j.foodcont.2009.11.015

Kristkova, Z., Grace, D., Kuiper, M. 2017. The economics of food safety in India: A rapid assessment. Amsterdam, Netherlands: Wageningen University and Research https://edepot.wur.nl/431795

Kumar, A., Mishra, A.K., Saroj, S., Sonkar, V.K., Thapa, G., Joshi, P.K. 2020. Food safety measures and food security of smallholder dairy farmers: Empirical evidence from Bihar, India. Agribus. Int. J. 36, 363–384. https://doi.org/10.1002/agr.21643

Kumar, A., Saroj, S., Thapa, G., Joshi, P.K., Roy, D. 2017a. Compliance with food safety practices among smallholder dairy farmers in Bihar, India: Drivers and impact. IPFRI Discussion Paper 01689 https://www.ifpri.org/cdmref/p15738coll2/id/131561/filename/131763.pdf

Kumar, A., Thapa, G., Roy, D., Joshi, P.K. 2017b. Adoption of food safety measures on milk production in Nepal: Impact on smallholders' farm-gate prices and profitability. Food Policy, 70, 13–26 https://doi.org/10.1016/j.foodpol.2017.05.002

Kumar, A., Wright, I.A., Singh, D.K. 2011. Adoption of food safety practices in milk production: implications for dairy farmers in India. J. Int. Food Agribus. Mark. 23, 330–344 http://dx.doi.org/10.1080/08974438.2011.621855

Lemma, D.H., Mengistu, A., Kuma, T., Kuma, B. 2018. Improving milk safety at farm-level in an intensive dairy production system: Relevance to smallholder dairy producers. Food Qual. Saf. *2*, 135–143 https://doi.org/10.1093/fqsafe/fyy009

Lindahl, J.F., Deka, R.P., Melin, D., Berg, A., Lunden, H., Lapar, M.L., Asse, R., Grace, D. 2018. An inclusive and participatory approach to changing policies and practices for improved milk safety in Assam, northeast India. Glob. Food Secur. 17, 9–13 https://doi.org/10.1016/j.gfs.2018.03.002

Montgomery, H., Haughey, S.A., Elliott, C.T. 2020. Recent food safety and fraud issues within the dairy supply chain (2015–2019). Glob. Food Secur. 26, 100447 https://doi.org/10.1016/j.gfs.2020.100447

MoSPI, 2023. National Accounts Statistics 2023. Ministry of Statistics & Program Implementation, Government of India. https://www.mospi.gov.in/publication/national-accounts-statistics-2023.

Mudgil, D., Barak, S. 2013. Synthetic milk: A threat to Indian dairy industry. Carpathian J. Food Sc. Tech. 5, 64-68

Nicolini, G., Guarin, A., Deka, R.K., Vorley, B., Alonso, S., Blackmore, E., Grace, D. 2022. Milk quality and safety in the informal sector in Assam, India: governance, perceptions, and practices. Cogent Food Agri. 8, 2137897 https://doi.org/10.1080/23311932.2022.2137897

Nordhagen, S., Lambertini, E., Smith, DeWaal., C., McClafferty, B., Neufeld, L.M. 2022. Integrating nutrition and food safety in food systems policy and programming. Glob. Food Secur. 32, 1–7 https://doi.org/10.1016/j.gfs.2021.100593

Nyokabi, N.S., Korir, L., Lindahl, J.F., Phelan, L., Gemechu, G., Berg, S., Mihret, A., Wood, J.L. N, Moore, H.L. 2024. Exploring the adoption of food safety measures in smallholder dairy systems in Ethiopia: Implications for food safety and public health. Food Secur., *16*: 423–435. https://doi.org/10.1007/s12571-024-01439-y

Nyokabi, S., Luning, P.A., de Boer, I.J.M., Korir, L., Muunda, E., Bebe, B.O., Lindahl, J., Bett, B., Oosting, S.J. 2021. Milk quality and hygiene: Knowledge, attitudes, and practices of smallholder dairy farmers in central Kenya. Food Control. 130, 108303 https://doi.org/10.1016/j.foodcont.2021.108303

Nyokabi, S.N., de Boer, I.J.M., Luning, P.A., Korir, L., Lindahl, J., Bett, B., Oosting, S.J. 2021. Milk quality along dairy farming systems and associated value chains in Kenya: An analysis of composition, contamination, and adulteration. Food Control. 119, 107482 https://doi.org/10.1016/j.foodcont.2020.107482

Pal, M., Devrani, M., Pinto, S. 2018. Significance of hygienic processing of milk and dairy products. Madridge J. Food Technol. 3, 133–137 https://doi.org/10.18689/MJFT-1000120

Peterson, C.B., Mitloehner, F.M. 2021. Sustainability of the dairy industry: Emissions and mitigation opportunities. Front. Anim. Sci. 2, 760310 https://doi.org/10.3389/fanim.2021.760310

Poczta, W., Sredzinska, J., Chenczke, M. 2020. Economic situation of dairy farms in identified clusters of European Union countries. Agriculture. 10, 92 https://doi.org/10.3390/agriculture10040092

Ponnusamy, K., Lal, S.P. 2015. Review of Challenges and opportunities in promoting good dairy farming practices. Indian J. Dairy Sci. 68, 305–320 http://dx.doi.org/10.5146/ijds.v68i4.47958

Rathod, P.K., Dixit, S. 2020. Precision dairy farming: Opportunities and challenges for India. Indian J. Anim. Sci. 90, 1083–1094 http://dx.doi.org/10.56093/ijans.v90i8.109207

Rosenbaum, P.R., Rubin, D.B. 1983. The central role of the propensity score in observational studies for causal effects. Biometrika. 70, 41–55 https://doi.org/10.1093/biomet/70.1.41

Segerkvist, K.A., Hansson, H., Sonesson, U. Gunnarsson, S. 2020. Research on Environmental, Economic, and Social Sustainability in Dairy Farming: A Systematic Mapping of Current Literature. Sustainability. 12, 5502 https://doi.org/10.3390/su12145502

Simelane, K.S., Worth, S. 2020. Food and nutrition security theory. Food Nutr. Bull. 41, 367–379 https://doi.org/10.1177/0379572120925341

Sundram, P. 2023. Food Security in ASEAN: Progress, challenges and future. Front. Sustain. Food Syst., 7, 1260619 https://doi.org/10.3389/fsufs.2023.1260619

Sushma, M. 2019. Carcinogen Aflatoxin detected in FSSAI milk survey samples. Down to Earth. https://www.downtoearth.org.in/news/health/carcinogen-aflatoxin-detected-in-fssai-milk-survey-samples-67327#:~:text=The%20final%20results%20of%20the,have%20aflatoxins%20beyond%20permissible%20limits (accessed 18 December 2023).

The Hindu Bureau 2023. Aflatoxin detected in milk samples in Kerala. https://www.thehindu.com/news/national/kerala/aflatoxin-detected-in-milk-samples-in-kerala/article66517444.ece#:~:text=An%20official%20statement%20issued%20by,samples%20tested%20by%20the%20department (accessed 12 February 2024).

Unnevehr, L. 2015. Food safety in developing countries: Moving beyond exports. Glob. Food Secur. 4, 24–29 https://doi.org/10.1016/j.gfs.2014.12.001

Vemula, S.R., Kumar, R.V., Polasa, K. 2012. Foodborne diseases in India – A review. Br. Food J. 114, 661–680 http://dx.doi.org/10.1108/00070701211229954

White, H., Raitzer, D.A. 2017. Impact evaluation of development interventions: A practical guide. Asian Development Bank, Metro Manila, Philippines. http://dx.doi.org/10.22617/TCS179188-2

Yadav, D., Dutta, G., Kumar, S. 2021. Food safety standards adoption and its impact on firms' export performance: A systematic literature review. J. Clean. Prod. 329, 129708. https://doi.org/10.1016/j.jclepro.2021.129708

Yilmaz, H., Gelaw, F., Speelman, S. 2020. Analysis of technical efficiency in milk production: A cross-sectional study on Turkish dairy farming. Rev. Bras. Zootec. 49, e20180308. https://doi.org/10.37496/rbz4920180308

Yu, Z., Liu, H., Peng, H., Xia, Q., Dong, X. 2023. production efficiency of raw milk and its determinants: Application of combining data envelopment analysis and stochastic frontier analysis. Agriculture. 13, 370. https://doi.org/10.3390/agriculture13020370

Appendix

Table A1: Percentage for compliance with food safety measures

UTENSILS HYGIENE

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
1. Type of containers used for bulking milk				**8.** Cleaning utensils before milking	100	89.3	96.7
i. Steel	54.5	46.7	63.9	**9.** Source of water for washing containers and utensils			
ii. Aluminum	9.1	33.3	22.2	i. Piped/tap	32.2	50.5	60.9
iii. Plastic	36.4	18.7	11.1	ii. Private ground pump/ well	9.6	30.1	39.1
iv. Iron and others	0	1.3	2.8	iii. Others	58.2	19.4	0
2. Bulking containers are without joints	9.5	45.6	24.3	**10.** Type of utensils used for milking			
3. Washing containers before bulking milk	9.5	71.8	28.4	i. Steel	88.7	84.4	91.1
4. Frequency				ii. Aluminum	13.9	9.7	9.7
i. Same day	81.8	77	34.3	iii. Plastic and others	0.1	5.7	9.7
ii. A day before	18.2	13.5	11.4	**11.** Mode of cleaning milking utensils			
iii. One hour before	0	9.5	54.3	i. Water	51.3	42.7	85.4
5. Mode of cleaning bulking containers				ii. Water and soap/ detergent/ disinfectant	44.3	46.6	13
i. Water	54.6	33.3	74.4	iii. Water and sand ash	4.4	10.7	1.6
ii. Water and soap/ detergent/ disinfectant/ sand ash	45.4	66.7	25.6	**12.** Milking utensils are washed before milking each animal	13	66.1	66.7
6. Milking utensils are without any joints	86.1	37.9	61.8	**13.** Milking utensils are sanitized before milking	0.8	53.4	19.5
7. Drying utensils before milking	89.6	69.9	66.7				

FARMER'S HYGIENE

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
1. Milking with hand	100	96.1	98.4	**5.** Drying hands before milking	30.4	72.4	44.3
2. Washing hands before milking	100	87.9	95	**6.** Sanitize hands before milking	0.9	48.5	5.8
3. Washing hand before milking each animal	17.4	54	62.6	**7.** Wear suitable clean clothes	100	91.3	95.9
4. Mode of washing hands				**8.** Clean hands and arms of workers during milking	100	88.3	98.4
i. Cold water only	86.1	66.7	90.4	**9.** Smoking/eating/drinking at milking/ storage area	15.6	12.6	36.6

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
ii. Cold water and soap/ detergent/ disinfectant	13.9	33.3	9.6	**10.** Nails are trimmed regularly	100	71.8	99.2
				11. Cuts and wounds are covered with appropriate dressing	100	90.3	98.4

ANIMAL AND MILK HYGIENE

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
1. Bulking of milk after milking	9.6	72.8	29.3	**11.** Source of water for washing animals			
2. Mode of bulking milk				i. Pipe/tap	28.7	44.7	60.2
i. By supplier type	9.1	34.7	5.6	ii. Community ground water	9.6	9.7	0.8
ii. By milk type	90.1	34.7	83.3	iii. Private ground pump/ well	59.1	35.9	38.2
iii. By source location	0	8	5.6	iv. Other	2.6	9.7	0.8
3. Method of transferring milk from milking to bulking containers	9.5	72.8	16.3	**12.** Wash animals in summer	100	90.3	99.2
i. Pouring directly	100	100	55.6	**13.** Frequency of washing			
ii. Using scoop with handle	-	-	44.4	i. Daily	57.4	49.5	36.9
4. Keep diseased animals separately	20	57.3	43.9	ii. Two times a day	5.2	29	30.3
5. Store milk of diseased animals separately	29.6	56.3	38.2	iii. Alternate day	27	17.2	30.3
6. Cleaning of udder and teats before milking	97.4	86.9	94.2	iv. Weekly	10.4	4.3	2.5
7. Mode of washing udder and teats				**14.** Wash animals in winter	90.4	90.3	90.2
i. water only	100	80.8	99.2	**15.** Frequency of washing			
8. Drying of udder and teats before milking	6.1	45	37.5	i. Daily or alternate day	1.9	21.6	66.7
9. Sanitize udder and teats before milking	0	25.3	3.3	ii. Weekly	11.4	35.3	18.9
10. Mode of washing animals				iii. Fortnightly	23.8	31.4	11.7
i. Water	88.7	56.3	88.6	iv. Monthly	62.9	11.7	2.7
ii. Water and soap/ detergent/ disinfectant	11.3	43.7	11.4				

SHED MANAGEMENT

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
1. Separate milk storage area	80	45.6	36.6	**8.** Drained floor of milk storage area	86.9	74.8	42.3
2. Milk storage area is free from birds, vermin, cats, and dogs	100	54.4	92.7	**9.** Cleaning of milking area floor	96.5	75.7	94.3
3. Condition of milk storage area				**10.** Frequency of cleaning floor in a day			
i. Damaged	0	1.9	2.4	i. Once	44.1	21.8	48.3

ii.	Partially damaged	41.7	40.8	28.5
iii.	Undamaged and others	58.3	57.3	69.1
4. Mode of cleaning floor of milk storage area				
i.	Water	86.1	84.5	92.7
ii.	Spray disinfectant/ detergent/ disinfectant/ phenyl	3.5	4.8	5.7
iii.	Others	10.4	10.7	1.6
5. Mode of washing milk storage area				
i.	Water	86.9	72.8	96.8
ii.	Spray disinfectant/ detergent/ disinfectant/ phenyl	2.6	15.5	0.8
iii.	Others	10.4	11.7	2.4
6. Mode of cleaning milking area floor				
i.	Sweeping	95.6	65.1	87.8
ii.	Washing	24.4	66	50.4
iii.	Use ash	2.6	9.7	8.9
7. Mode of washing floor				
i.	Water	50.4	75.7	92.6
ii.	Spray disinfectant/ detergent/ disinfectant/ phenyl	1.7	15.6	3.3
iii.	Others	47.8	8.7	4.1

ii.	Twice	50.4	70.5	47.4
iii.	More than twice	0.9	6.4	0.9
iv.	Every alternate day and others	4.5	1.3	0.9
11. Frequency of washing floor in a day				
i.	Once	28.7	46.6	60.9
ii.	Twice	5.2	36.9	30.1
iii.	Every alternate day	6	4.9	3.3
12. Floor of milking area				
i.	Pucca (Concrete and Slats/Bricks)	81.1	95.2	92.6
ii.	Kutcha	18.9	4.8	7.4
13. Well drained floor of dairy area		65.2	78.6	47.2
14. Cattles are milked in separate place from stall		46.1	40.8	21.9
15. Floor of stall-feeding area				
i.	Pucca (Concrete and Slats/Bricks)	61.7	90.3	81.8
ii.	Kutcha	38.3	9.7	18.2
16. Condition of dairy floor area				
i.	Damaged	13	6.8	4.1
ii.	Partially damaged	67	41.8	41.4
iii.	Undamaged	20	51.5	54.5

WASTE MANAGEMENT

Particulars	Bihar	Punjab	UP
1. Dispose dung	98.3	90.3	88.6
2. Dispose dung immediately after excretion	7.9	51.6	44
3. Drying dung cake inside the animal shed	0.9	5.8	3.2

Particulars	Bihar	Punjab	UP
4. Drain Urine	60	83.5	48.8
5. Drained urine immediately after excretion	36.5	51.5	53.3

PROPER USAGE OF MEDICINES

Particulars	Bihar	Punjab	UP
1. Keep veterinary medicines	0	38.8	47.9
2. Source of prescription			

Particulars	Bihar	Punjab	UP
5. Used anthelmintic (deworming) in last 12 months	64.3	91.3	60.2
6. Preventive measures used			

		Bihar	Punjab	UP			Bihar	Punjab	UP
i.	Vet doctor	38.5	86.4	67.5	i.	None	44.3	3.9	7.3
ii.	Quack/ chemist	34.6	1.9	3.3	ii.	Curative medication	36.5	8.7	64.2
iii.	Paravet/ pvt cooperative	19.2	2.9	28.4	iii.	Vaccination	12.2	90.3	53.7
iv.	Fellow farmers/others	7.7	8.7	0.8	iv.	Grazing restriction	0	15.5	28.5
3. Lubricants used in udder and teats for milking		72.2	68.7	66.1	v.	Hand picking	4.3	0	26.8
4. Additives used in udder and teats					vi.	Isolation	0	3.9	27.6
i.	Ghee	2.4	25	7.5	vii.	Traditional measures	30.4	7.8	2.4
ii.	Mustard Oil	47	7.4	17.5					
iii.	Milk	50.6	67.6	75					

PROPER USAGE OF CHEMICALS

Particulars	Bihar	Punjab	UP	Particulars	Bihar	Punjab	UP
1. Use chemicals/ drugs as per instructions	98.3	89.3	72.4	**4.** Mix powder/ baking soda before selling milk	0	1.9	2.4
2. Chemicals stored in lockable area away from dairy	85.2	82.5	58.5	**5.** Use oxytocin	0.9	8.7	39.8
3. Use chemicals in storage area	0	17.5	45.5				

Source: Author's calculations based on field survey

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