International Journal of Agriculture and Food Science 2025; 7(1): 95-101

ISSN Print: 2664-844X
ISSN Online: 2664-8458
IJAFS 2025; 7(1): 95-101
www.agriculturaljournals.com
Received: 25-10-2024
Accepted: 29-11-2024

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Technical efficiency and its determinants of milk production in South Gujarat

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DOI: https://doi.org/10.33545/2664844X.2025.v7.i1b.244

Abstract
This study investigated the technical efficiency and its determinates of milk production in South Gujarat. The Data Envelopment Analysis (DEA) approach to evaluate technical efficiency and Tobit model use for identify determinants. The multiple random sampling method used for selection dairy household. At first stage 4 districts were selected purposively, then 2 talukas from each district at second stage, then 2 dairy cooperatives from each selected taluka at third stage and at the last stage 20 respondents from each dairy cooperative were selected and finale sample was 320 respondents. Primary data were collected from 320 respondents with the pretested interview schedule in August to December 2023. The study revealed an average technical efficiency score of 0.741 under the CRS model, indicating significant scope for reducing inputs by 25.90% without affecting output. Under the VRS model, efficiency improved to 0.842, highlighting scale inefficiencies as a key factor. Determinants such as access to scientific animal sheds, education, dairy farming experience, area under green fodder, and climate change adaptation positively influenced efficiency. Conversely, larger landholdings, older livestock, and logistical challenges like distant input markets reduced efficiency. Tobit regression identified price received for milk as a significant factor, with efficiency improving by 0.52% per unit price increase. Recommendations include promoting scientific animal sheds, enhancing dairy training programs, and addressing logistical inefficiencies to improve productivity and resource utilization.

Keywords: Technical efficiency, Tobit model, milk production

1. Introduction

Dairying has been an integral part of rural households, providing essential food, income and employment, especially for marginal and small farmers. India's dairy industry has grown substantially, partly due to the Operation Flood project, positioning India as the world's leading milk producer. In 2022-23, India produced 759.96 Million Tonnes (MT) of milk, with a per capita availability of 459.63 grams per day. Dairy cooperatives have played a pivotal role in this achievement, with significant contributions from regions such as Uttar Pradesh, Rajasthan, Andhra Pradesh, Gujarat, and Punjab. The Indian Council of Medical Research (ICMR) recommends a daily intake of 240 grams of milk for a healthy diet. Gujarat exceeds this recommendation with a per capita milk availability of 670 grams per day, reflecting a satisfactory status.

The Gujarat state is supported by 17 cooperative dairy unions and 25 private dairy plants, collecting 3.45 billion liters of milk from over 3 million producers associated with more than 15,000 primary milk cooperative societies. Mil k production accounts for 22 per cent of Gujarat's agricultural GDP, serving as a vital sector for livelihood support. According to state census data, 43 lakh households out of 102 lakh in Gujarat engage in dairy and animal husbandry as a primary or secondary income source. The South Gujarat region, renowned for its successful dairy and agriculture cooperatives, includes seven districts: Bharuch, The Dangs, Narmada, Navsari, Surat, Valsad, and Tapi. In terms of milk production, Surat leads with 502.67 lakh kilograms, followed by Navsari with 357.15 lakh kilograms, Tapi with 331.52 lakh kilograms and Valsad with 279.95 lakh kilograms

2. Methodology

Methodology outlines the study area profile, the nature and sources of data collected and the analytical tools and techniques employed to achieve the study's objectives. The selection of the study area mainly based on the highest milk production in the South Gujarat, four districts *viz,* Surat, Navsari, Valsad and Tapi were the significant contributors of milk production in the South Gujarat. Multistage random sampling technique was adopted for the sampling. At first stage 4 districts were selected purposively, then 2 talukas from each district at second stage, then 2 dairy cooperatives from each selected taluka at third stage and at the last stage 20 respondents from each dairy cooperative were selected and finale sample was 320 respondents. Primary data were collected from 320 respondents with the pretested interview schedule in August to December 2023.

2.1 Analytical Techniques

2.1.1 Technical efficiency

Farm technical efficiency refers to a farmer's capacity to achieve maximum output given a specific production technology and level of inputs. This efficiency can be broken down into two components: technical efficiency and allocative efficiency, as outlined by Farrell (1957) [28]. Later, Farrell and Fieldhouse (1962) [29] introduced a third component, scale, as a potential source of inefficiency. Technical efficiency signifies the ability to attain the highest possible performance (Output) from a given set of inputs, while allocative efficiency pertains to the optimal allocation of inputs, considering their respective prices and utilized technologies. Both components contribute to a total economic efficiency measure.

There are four main approaches to measuring and estimating efficiency. The first is the non-parametric programming approach (Charnes *et al*., 1978) [30], followed by the parametric programming approach (Ali and Chaudhry, 1990) [4], the deterministic statistical approach (Richmond, 1974; Greene, 1980) [21, 10] and the stochastic frontier production function approach. Among these, the most widely recognized approaches are the stochastic frontier production function and non-parametric programming, commonly known as Data Envelopment Analysis (DEA) (Alam *et al.,* 2011) [31]. In the present study, Data Envelopment Analysis (DEA) was utilized to assess technical efficiency.

2.1.2 Data Envelopment Analysis (DEA)

For this study, a non-parametric approach, Data Envelopment Analysis (DEA) was employed to assess the technical efficiency of dairy cooperative members. DEA was chosen over parametric methods due to its inherent advantages. Unlike parametric approaches, DEA does not require a specific functional form for the frontier, thereby avoiding the imposition of unnecessary structure on technology and preventing potential distortions in efficiency measures. Additionally, DEA enables the disaggregation of technical efficiency into pure technical efficiency, congestion efficiency and scale efficiency.

DEA was originally developed by Charnes Cooper and Rhodes (1978) [30], building upon the pioneering work of Farrell (1957) [28]. They introduced a model known as the CCR (Charnes, Cooper and Rhodes) model, which is input-oriented and assumes constant returns to scale. DEA is a linear programming-based technique where the production frontier is constructed using sample observations.

Under the assumption of constant returns to scale (CRS),

$\text{Min } \theta, \lambda\ \theta$
Subject to- $y_i + Y\lambda \geq 0$
$\theta x_i - X\lambda \geq 0$
$\lambda \geq 0 \ldots$ (1)

Where,
y_i is a vector (m×1) of milk production output of the ith Milk Producing Farms (MPF),
x_i is a vector (k × 1) of inputs of the ith MPF,
Y is a milk output matrix (n × m) for n MPFs, X is the milk production input matrix (n × k) for n MPFs,
θ is the efficiency score, a scalar whose value was the efficiency measure for the ith MPF.
If θ = 1, MPF was efficient; otherwise, it was inefficient and λ is a vector (n × 1) whose values are calculated to obtain the optimum solution. For an inefficient MPF, the λ values was the weights used in the linear combination of other, efficient, MPFs, which influence the projection of the inefficient MPF on the calculated frontier.
Under the assumption of Variable Return to Scale (VRS),

$\text{Min } \theta, \lambda\ \theta$
Subject to- $y_i + Y\lambda \geq 0$
$\theta x_i - X\lambda \geq 0$
$N1\ \lambda = 1$
$\lambda \geq 0 \ldots$ (2)

Where,
N1 is a vector (n × 1) of ones.
When there are differences between the values of efficiency scores in the models CRS and VRS, scale inefficiency is confirmed, indicating that the return to scale is variable, i.e. it can be increasing or decreasing. The scale efficiency values for each analysed unit can be obtained by the ratio between the scores for technical efficiency with constant and variable returns as follow,

$$\theta s = \frac{\theta CRS\ (XK, YK)}{\theta VRS\ (XK, YK)}$$

Where,
θCRS (XK, YK) = Technical efficiency for the model with constant returns,
θVRS (XK,YK) = Technical efficiency for the model with variable returns
θs = Scale efficiency.

Non – increasing returns:	Non-decreasing returns
$\text{Min } \theta, \lambda\ \theta$ Subject to– $y_i + Y\lambda \geq 0$ $\theta x_i - X\lambda \geq 0$ $N_1\ \lambda \leq 1$ $\lambda \geq 0$ … (14)	$\text{Min } \theta, \lambda\ \theta$ Subject to - $y_i + Y\lambda \geq 0$ $\theta x_i - X\lambda \geq 0$ $N_1\ \lambda \geq 1$ $\lambda \geq 0$ … (15)

2.1.3 Determinants of Milk Production

The technical efficiency values derived from the DEA model, considering the Constant Returns to Scale (CRS) input-oriented model, was utilized to explore the relationship between technical efficiency and its influencing factors. The technical efficiency score obtained from the CRS model was selected as the dependent variable due to its higher accuracy in discriminating efficiency compared to variable returns to scale.

Tobit Regression Model: A Tobit regression model was employed to investigate this relationship. There are two main approaches to study the relationship between farm inefficiency and various socio-economic and farm-specific factors. The first approach involves computing correlation coefficients or conducting simple non-parametric analyses. The second approach, known as the 'two-step procedure,' entails measuring inefficiency and then using a regression model in which inefficiency is expressed as a function of socio-economic and farm-specific factors. This latter approach, which is commonly utilized, was adopted for this study.

The technical efficiency scores were obtained by subtracting the efficiency scores from 1, representing technical inefficiency. These scores were then regressed on socio-economic and farm-specific variables to identify sources of technical inefficiency. However, it's important to note that technical inefficiency scores are bounded between 0 and 1, meaning that the dependent variable in the regression model does not follow a normal distribution. Consequently, Ordinary Least Squares (OLS) regression is not appropriate, as estimation with OLS regression could yield biased parameter estimates. Greene (1980) [10] suggests that it is more convenient to have data censored at zero rather than at 1. As the distribution of estimated inefficiency scores is censored at zero, a tobit regression model was specified for the present study.

Tobit model was used to analysed censored sample. This can be expressed as, (Shivaswamy *et al.*, 2019) [32].

$Y = X\beta + u$ If $\beta' X + u > 0;$

Y= 0 otherwise

Such that the residual, $u \sim N(0, \sigma^2)$

Where Y, (n X 1) vectore of dependent variable, $\beta(kX1)$ vectore of unknown parameter and X vectore of exogenous variables. This model can be estimated using maximum likelihood method or Heckman two step procedure. The simplified Tobit regression model represented by Equation was used in present study.

$$TE_i = E^* = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + b_{13}X_{13} + b_{14}X_{14} + b_{15}X_{15} + b_{16}X_{16} + e_i$$

If $E^* > 0$

E = 0 if $E^* <= 0$

Where,

TE_i = Represents the technical efficiency of the i^{th} farm

E^* = Latent variable,

X_1 = Herd size (No. of animal),

X_2 = Availability of Scientific shed (Kachcha, Pakka),

X_3 = Age of Animals (Years),

X_4 = Age of the Respondent (Years),

X_5 = Type of Bred (Crossbreed, Local cow, Buffalo),

X_6 = Experience in Dairy Farming (Years),

X_7 = Education of the Respondent (Years),

X_8 = Size of Land Holding (ha),

X_9 = Area under Green Fodder (ha),

X_{10}= Dairy Training (No.),

X_{11}= Climate change effect (Yes =0, No = 1),

X_{12} = Awareness of Mobile app (Yes =0, No = 1),

X_{13} =Distance to access Credit Facility (Km),

X_{14} = Distance of Input Market (Km),

X_{15}= Proportion of milk sold (Litre),

X_{16} = Price Received (₹/litres),

b_0 = Intercept term,

$b_1.b_{16}$ = Coefficients of respective factors influencing the technical efficiency,

e_i = Random error term

3. Results and Discussion

3.1 Technical Efficiency of Milk Production

Technical efficiency of the individual milk production unit measured as efficiency score was expressed in relation to this unit as the relative parameter. It numerically expressed the distance of the given dairy production unit to the efficiency limit. It was assumed that all production units were lying either on the efficiency limit or under it. The coefficient (Scores) of technical efficiency ranged from 0 to 1.

Table 1 shows the frequency distributions of technical efficiency scores obtained with DEA model of household as classified. On an average, 22.19 per cent of the analysed herds reached the TE value higher than 0.90 and had higher effect on milk production during the evaluated period.

Average value of TE of milk production was 0.741. It means that the evaluated farms achieved 74.10 per cent technical efficiency in the study period similar results were found by Bardhan and Sharma (2013) [6] for dairy households. They should reduce the inputs by 25.90 per cent to reach the efficiency at the given level of milk yield. Scores ranging from 0-99 per cent showed that the estimation of the CRS for dairy households was only 22.19 per cent households under assumption of constant returns to scale performed with efficiency level equal to 0.90 or greater, i.e., 71 of the total 320 households. It could be inferred that remaining 249 households, which did not operate at the maximum efficiency level, could reduce the input use level by 25.90 per cent and maintain the same level of milk production as achieved by 22.19 per cent of the households.

Table 1: Frequency distribution of technical efficiency scores obtained with DEA model (n= 320)

Efficiency Score	CRSTE	VRSTE	Scale Efficiency
Below 0.50	45	19	5
0.51 to 0.60	29	15	8
0.61 to 0.70	23	17	21
0.71 to 0.80	74	30	51
0.81 to 0.90	78	109	61
0.91 to 0.99	71	130	174
Total No. of Respondents	320	320	320
Mean	0.741	0.842	0.872
Minimum	0.321	0.458	0.332
Maximum	0.965	0.999	0.999
Standard Deviation	0.181	0.134	0.123

Note: CRSTE = Technical efficiency from CRS DEA, VRSTE = Technical efficiency from VRS DEA, Scale = Scale efficiency = CRSTE / VRSTE

When the assumption of constant scale was relaxed and the model with variable returns to scale was calculated, the impact of production scale on technical efficiency level is visible. This relaxation was necessitated, as all the dairy producing households did not operate at the optimum scale due to imperfect competition, constraint in finance, etc. The number of efficient households increased to 40.63 per cent and the average technical efficiency score increased to 0.842. These better results from the model with variable returns were mainly due to the inclusion of scale efficiency. Further, the lower value of standard deviation of mean in model with variable returns suggested concentration of households in the higher efficiency levels. As regards to the scale efficiency, 54.37 per cent of households (174 households) either performed at the optimum scale or were close to the optimum scale (households having scale efficiency values equal to or more than 0.90). The VRS technical efficiency is used to measure the relative decline in output that was not a result of the constant return to scale. The scores of technical efficiencies in CRS and VRS were to determine whether the household operating at increasing return to scale or decreasing return to scale. If the score of technical efficiency at VRS was larger than CRS, it means that the households were increasing their scale of returns. Meanwhile, scale efficiency measures the relative loss of output due to the constant's returns to scale represented by the value of one or close to one. The results showed that the technical efficiency scores under VRS were higher than the average efficiency scores under CRS. The different in mean efficiency scores under the two different returns to scale assumptions highlighted that scale inefficiency was present. The cause of inefficiency may have either inappropriate scale or misallocation of resources. Inappropriate scale suggests that the households were not taking advantage of economies of scale, whereas misallocation of resources refers to inefficient input combinations. The results indicated that scale efficiencies were relatively high; therefore, it seems that efficiencies were mainly because of improper input use. This result of the study was consistent with Bardhan and Sharma (2013) [6], Kelly *et al.*, (2013) [14], Michalickova *et al.* (2013) [17], Bahta *et al.*, (2021) [5], and Hearth and Thayaparan (2024) [11].

Hypothesis

- **H0:** There is no significant difference in technical efficiency among dairy households
- **H1:** There is significant difference in technical efficiency among dairy households

With reference to the previous table 1, it showed the frequency distribution of technical efficiency scores of the dairy households in the study area during the study period. From the above table it was showed 22.19 per cent households under assumption of constant returns to scale performed with efficiency level equal to 0.90 or greater, *i.e.*, 71 of the total 320 households remaining 249 households does not operate at maximum efficiency level. So, the null hypothesis of no significant difference in technical efficiency among dairy households was rejected and alternative hypothesis of significance difference in technical efficiency among dairy households was accepted.

Inputs slacks

The inputs slacks and excess input were given in Table 2. Slack indicated excess of an input; the households can reduce its production cost on an input by the amount of slack without reducing its output. The greatest slack was in Livestock shed, veterinary care cost, annual maintenance cost and dry fodder cost. The reason behind excess livestock shed was due to high construction cost which affects animal. A large amount of veterinary care cost and maintenance cost was needed for high yield of animals.

Table 2: Distribution of input slacks of dairy farms households

Sr. No.	Input	Number of Farms	Mean Input Slack
1	Green fodder (₹)	47	1.55
2	Dry fodder (₹)	69	2.01
3	Concentrates (₹)	32	1.60
4	Labour (₹)	83	1.29
5	Veterinary care charges (₹)	80	28.77
6	Annual maintenance cost (₹)	94	15.26
7	Livestock Shed (₹)	68	88.46
8	Equipment Charges (₹)	104	3.29

3.2 Determinants of Technical Efficiency in Milk Production

The technical efficiency of individual households was analyzed in the first step by the DEA model. The production frontier in the DEA approach was deterministic, the resulting efficiencies include noise from data. Therefore, in the second stage of the present study, the determinants of inefficiency were work out using Tobit Regression Model. The Tobit was a statistical model proposed by James Tobin (1958) [33] to describe the relationship between a non-negative dependent variable and a set of exogenous variables. The Tobit model was called a censored regression model, designed to estimate linear relationships between variables when there was either left-or-right-censoring in the dependent variable. The estimates of the Tobit regression coefficients of the explanatory variables on technical inefficiency were shown in Table 3. Tobit regression was run to identify the determinants of technical inefficiency among households. In this analysis, the score of technical efficiency of CRS of the households were used as the dependent variable for its high accuracy in discriminating efficiency as compared to variable returns to scale, while the independent variables consist of the variable of herd size, availability of scientific animal shed, age of animals, age of the respondents, year of experience in dairy farming, year of education, type of bred they had, size of land holding, area under fodder, dairy training, climate change effect, awareness of mobile app, access to credit facility, distance of input market, price received, proportion of milk sold etc. Those defined variables were shown in Table 3. The E-view 12 programs were used to analyze and the model estimated was as follows:

Technical inefficiency = β0 + β1 Herd size + β2 Animal shed + β3 Age of animals + β4 Age of the respondents + β5 Type of bred+ β6 Experience in dairy farming + β7 Education + β8 land holding + β9 Area under fodder + β10 Dairy training + β11 Climate change + β12 Awareness of mobile app + β13 Access to credit facility + β14 Distance of input market + β15 Price received + β16 Proportion of milk sold

Table 3 illustrated that the Tobit regression result that examined the relationship between technical inefficiency score and herd size, availability of scientific animal shed, age of animals, age of the respondents, year of experience in dairy farming, year of education, type of bred they had, size of land holding, area under fodder, dairy training, climate change effect, awareness of mobile app, distance to access credit facility, distance of input market, price received, proportion of milk sold *etc.*

As seen from Table 3, animal herd size was found negatively related with household efficiency though it was non-significant. This result was similar with previous study of Lal *et al.*, (2020) [15] and Rathva *et al.*, (2020) [34]. Existance of scientific animal shed had a positive and significant relationship with dairy household technical efficiency at 1 per cent significance level. The result indicated that animal shed led to increase in the probability level of technical efficiency by 38 per cent. The reason behind this was that as the animal facilitate with the scientific animal shed directly affect the animal health and increase the milk production of the animal. Age of the animal showed negative effect on technical inefficiency of the household but the relationship was not significant. The results suggested that an increase in animals' age by one year increased the level of probability of technical inefficiency by 0.25 per cent. The reason behind was that as animal grow older their milk production capacity decreased with time.

Table 3: Determinants of technical efficiency of dairy farming

Variables	Coefficients	Standard Error
C	1.02**	3.70E-02
Herd size (X_1)	-0.01	1.00E-03
Availability of Scientific animal shed (X_2)	0.04**	7.00E-03
Age of animals (X_3)	0.00	2.00E-03
Age of Respondents (X_4)	0.00**	3.00E-04
Type of bred (X_5)	-0.01	6.00E-03
Experience in Dairy Framing (X_6)	0.00**	3.00E-04
Education (X_7)	0.02**	3.00E-03
Size of land holding (X_8)	0.00	1.40E-03
Area under green fodder (X_9)	0.03*	1.30E-02
Dairy training (X_{10})	0.01**	1.00E-03
Climate change effect (X_{11})	0.03**	7.00E-03
Awareness of mobile app (X_{12})	0.03**	6.00E-03
Distance to access credit facility (X_{13})	-0.01**	2.00E-03
Distance of input market (X_{14})	-0.00**	2.00E-03
Proportion of milk sold (X_{15})	-0.00	3.00E-04
Price received (X_{16})	-0.01**	6.00E-04

Note: *,** Significant at 5 and 1 per cent level of significance, respectively.

Age of the household head showed a negative effect on technical inefficiency of the households but the relationship was significant at significance of one per cent level. The results suggested that an increase in the household respondent's age by one year increased the level of probability of technical inefficiency by 0.11 per cent. This implied that aged households were technically efficient than younger counterparts. These results were similar with previous studies *viz.*, Padilla-Fernandez and Nuthall, (2009) [19], Singh (2020) [22].

Type of breed had negative and non-significant relationship with the technical efficiency of the household. As the crossbred animal has high milk production capacity but has low fat percentages as well as buffalo has high fat content in milk.

Households experience in dairy farming has positive and significant relationship with the technical efficiency of the dairy households at one per cent level of significance. As the year of experience increase the dairy households gain more practical knowledge in milk production activities. They use balance nutrition and efficient management practices gained by experience throughout their lives.

Education was found to be positively related to farm inefficiency and the relationship was significant at one per cent level. The calculated results suggested that one year of increase in schooling will increase the farm inefficiency by 1.70 per cent. More educated was more inclined towards adopting technically efficient practices. Similar results were reported by Adane *et al.*, (2016) [1], Umamageswari *et al.*, (2016) [26] and Singh (2020) [22].

Size of Land holding (ha) had negatively related to the dairy household but the relationship was not significant on technical inefficiency level of the households. The results suggest that an increase in the land holdings increased the level of probability of technical inefficiency by 0.024 per cent. This implied that households with more land were engaged in the farming activity other than dairy farming. Similar results were reported by Singh (2020) [22]. But Area under fodder has positive and significant relationship with the technical efficiency of the dairy household at the 5 per cent level of significance. This was directly related to the availability of fodder which increases the productivity of the animal and efficient working of dairy household by reducing the cost of fodder.

Dairy training attended by dairy households had positive and significant impact on increase in household efficiency at level of one per cent significance. This suggested that access to dairy training enabled producers to obtain information on animal diseases and their control methods as well as insights on innovative farming techniques that guarantee higher productivity of animals.

Climate change effect and awareness of mobile app had a positive and significant relationship with household efficiency as well as distance to access credit facility and distance of input market had a negative relationship with the household efficiency at one per cent and non-significance respectively. It showed that as the distance increase in the credit facility as well as input market it had negative impact on the efficiency of the household.

Proportion of milk sold to dairy cooperatives and milk retain for home consumption had a negative impact on technical inefficiency. The results indicated that the proportion of milk sold was negative and non-significant. The results showed that increase in probability level of technical efficiency by 0.01 per cent.

Price of the milk and milk product was an important factor which influences the milk production. The results showed that the price received was found to have a negative effect on technical inefficiency and it was significant at one per cent. The results indicated that price received by households led to increase in the probability level of technical efficiency by 0.52 per cent. The plausible reason for this could be that the more the price of milk more will be technical efficiency.

Hypothesis

H0: There is no significant relationship between dairy farming and the socio-economic characteristics of the dairy households

H1: There is significant relationship between dairy farming and the socio-economic characteristics of the dairy households

With reference to the previous table 3, it showed the determinants of technical efficiency of dairy farming. From the above table it was showed socio economic characteristics such as age of respondents, experience, education of respondents, area under green fodder, dairy training, climate change, awareness of mobile app, access of credit facility and price received has significant effect on the technical efficiency of dairy households. So, the null hypothesis of no significant relationship between dairy farming and the socio-economic characteristics of the dairy households was rejected and alternative hypothesis of the significant relationship between dairy households and socio-economic characteristics of dairy households was accepted.

4. Conclusion

The study reveals an average technical efficiency (TE) score of 0.741 under the CRS model, indicating that dairy households operate at 74.10 per cent efficiency. This implies that input use can be reduced by 25.90 per cent without impacting milk production. A mere 22.19 per cent of the households achieved a TE score of 0.90 or higher under CRS, suggesting substantial room for improvement in resource utilization. When accounting for VRS, the average TE score increased to 0.842, with 40.63 per cent of households performing efficiently. This highlights scale inefficiencies as a key contributor to suboptimal performance, emphasizing the need for targeted interventions to enhance operational scale and resource allocation. Key factors positively affecting technical efficiency include access to scientific animal sheds (+38 per cent probability), years of experience in dairy farming, education, area under green fodder, dairy training, awareness of mobile apps, and climate change adaptation. Dairy training emerged as particularly impactful, underscoring its role in disseminating best practices. Increased distance to credit facilities and input markets negatively impacted efficiency, highlighting logistical challenges. Additionally, inefficiencies were linked to larger landholdings and higher livestock ages. Input slacks analysis identified significant inefficiencies in veterinary care costs, annual maintenance costs, and livestock shed investments. Addressing these slacks can substantially reduce costs without compromising output. Price received for milk significantly influenced efficiency, with a 0.52% improvement for every unit increase in price. This underscores the critical role of fair pricing mechanisms in enhancing productivity. Promote dairy training programs and scientific animal shed adoption to enhance productivity and animal health. Improve access to credit facilities and input markets to reduce logistical inefficiencies. Develop targeted subsidies or incentives to optimize resource use, particularly in veterinary care and infrastructure. Encourage cooperative frameworks to increase operational scale and reduce input costs.

5. Acknowledgements

I express my heartfelt gratitude to my Major Guide, Dr. Narendra Singh, whose unwavering support, insightful guidance and fatherly presence have been invaluable throughout my study. I also extend my sincere appreciation Umang, Parul and Anjali didi for their unwavering encouragement, moral support and for fostering a positive and collaborative work environment. Finally, I am deeply thankful to the Government of Gujarat for providing the Shodh Scholarship (Scheme for Developing High-Quality Research) during my research period.

6. Competing Interests

"Authors have declared that no competing interests exist".

7. Authors' Contributions

"Author A designed the study, performed the statistical analysis, developed the protocol and drafted the manuscript. Author B guided the entire study, while Authors C, D and E managed and reviewed the statistical analyses.

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