

By addressing the challenges identified in these studies, such as controlling livestock diseases, implementing targeted interventions, and improving supply chain coordination, the economic and environmental sustainability of dairy farming in Pakistan can be enhanced.

Materials and Methods

Data Sources and Methodology

The study area was chosen due to its significant livestock population and proximity to urban markets. Following [41], [42], a multistage random sampling technique was used to select a sample of 100 respondents from rural and peri-urban areas of Lahore. A survey instrument was developed and administered by a team of expert enumerators to collect data on livestock management practices, production costs, and revenues. The livestock farmers in the sample were categorized into two groups: rural and peri-urban farmers. The data was analyzed using descriptive statistics and farm budgeting techniques to calculate the farm gate prices and gross margins for dairy and meat production.

This study collected primary data from a sample of livestock farmers operating within the Lahore district of Punjab province, Pakistan. A sample size of 100 farmers, with equal representation from rural (50) and peri-urban (50) areas, was chosen to ensure a balanced representation of both production environments. This sample size was considered adequate for the exploratory nature of the study, which aimed to identify key factors influencing the economic and environmental sustainability of dairy farming in the region [43, 44]. Sampling targeted five towns – Ravi Town, Aziz Bhatti Town, Wahga Town, Nishtar Town, and Iqbal Town – chosen for their geographic distribution around the major urban center of Lahore.

To ensure balanced data collection, each town contributed 20 respondents, with an equal split between rural and peri-urban farms.

Peri-urban areas are transitional zones between urban and rural landscapes, characterized by a mixture of agricultural and non-agricultural land uses. These areas often experience rapid land-use changes, driven by urban expansion and increasing demand for agricultural products from nearby cities [45]. In the context of Lahore, peri-urban dairy farming has grown in response to the city's increasing demand for fresh milk and dairy products, with farmers adapting their production practices to the unique challenges and opportunities presented by their proximity to urban markets [46].

Before analyzing the data, the livestock farmers in the sample were categorized into two groups: rural and peri-urban farmers. This categorization was based on the location of the farm and the availability of land resources. Rural farmers typically have more land resources and cultivate their own fodder, while

peri-urban farmers may have limited land resources and rely more on purchased feed.

Descriptive Statistics

Descriptive statistics were used to summarize the characteristics of the sample and the livestock production practices in the study area. The mean, median, standard deviation, and range were calculated for relevant variables such as farm size, herd size, and milk and meat production.

Economic Analysis of Fixed and Variable Costs in Milk Production and Estimation of Gross Margins

In the context of evaluating the economic sustainability of dairy farming within peri-urban settings in Lahore, Pakistan, this study employs a comprehensive econometric approach to delineate the fixed and variable costs associated with milk production, subsequently estimating the gross margins. This analysis is pivotal for understanding the financial viability of dairy enterprises, taking into account the diverse economic pressures they face.

Fixed Costs (FC)

Fixed costs encompass expenditures that remain constant regardless of the level of production. In this study, fixed costs include the depreciation (*Dep*) of dairy infrastructure (*DInfra*) and livestock (*LS*), as well as the interest (*Int*) on invested capital in livestock and dairy facilities. The inclusion of depreciation in the fixed costs allows for a more accurate representation of the long-term financial sustainability of dairy farming in the study area, as it accounts for the cost of replacing assets over time [47]. The depreciation of dairy assets is calculated as a percentage of their initial value, adjusted annually, while the interest reflects the opportunity cost of capital invested in these assets. The formula for estimating fixed costs is articulated as:

$$FC = Dep_{LS} + Dep_{DInfra} + Int_{LS} + Int_{DInfra} \quad (1)$$

where Dep_{LS} and Dep_{DInfra} are the depreciations on livestock and dairy infrastructure, respectively, calculated at a rate of 5.5% per annum, and Int_{LS} and Int_{DInfra} represent the interest on the average value of livestock and dairy infrastructure, estimated at an opportunity cost rate of 12-14%.

Variable Costs (VC)

Variable costs are directly correlated with the level of production and include expenditures on fodder (both self-grown (SGF) and purchased (PF)), concentrates (C), healthcare (HC), labor (L), breeding (B), and electricity (E). The aggregate variable cost is a function of the

