Research Article

Assessment of Raw Milk Quality, Adulteration, and Public Health Risks in Peshawar District

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Abstract | Milk is a crucial nutritional resource in Pakistan, where small-scale dairy farms significantly contribute to national production. However, the dairy sector faces serious quality and safety issues due to inadequate infrastructure, substandard feed, and outdated processing methods. This study examined the impact of adulteration on raw milk composition in three districts of the Peshawar Division (Peshawar, Charsadda, Nowshera). A total of 110 raw milk samples (from farms and retail shops) were analyzed using the Lacto Scan 860 and the UVAS adulteration kit for fat, protein, solids-not-fat (SNF), lactose and added water. Statistical analyses (ANOVA, Chi-square, effect sizes and Pearson correlation) revealed that farm milk generally met nutritional standards except for SNF, whereas shop milk—especially from Charsadda and Nowshera—had lower nutrient content and higher levels of adulteration, mainly by water dilution. Farm-milk variations across districts in fat ($p = 0.037$), SNF ($p = 0.019$) and lactose ($p = 0.016$) reflect differences in management; shop milk exhibited significant fat variation ($p = 0.002$), indicating routine skimming or dilution. Common adulterants included sodium chloride and quaternary ammonium compounds; carbonate and formalin occurred only once ($n = 1$) in Charsadda. Urea showed strong negative correlations with SNF ($r=-0.97$), lactose ($r=-0.82$) and protein ($r=-0.77$); water dilution strongly depressed SNF, protein and lactose ($r=-0.92$ to -0.99). Sodium chloride and QACs also negatively correlated with protein and lactose. These findings confirm a significant link between adulteration and reduced milk nutritional quality, posing community health and economic concerns. To ensure safe, nutritious milk in Pakistan, improved regulatory measures, infrastructure investment and farmer training are essential.

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Introduction

Milk is a vital nutritional resource in Pakistan, where small-scale dairy farms contribute significantly to the country's status as one of the world's leading milk producers (APP, 2019). However, the industry faces persistent quality and safety challenges due to inadequate infrastructure, substandard feed, and outdated processing techniques (FAO, 2022). These issues often result in contamination and adulteration, compromising both nutrition and public health.

A primary concern is the adulteration of milk through water dilution or the addition of harmful substances such as urea, detergents, and formalin (Mohammed, 2018). Globally, milk adulteration poses particularly severe consequences in developing nations with weak regulatory frameworks. Food adulteration — the addition, removal, or substitution of food components for economic gain — yields consumer nutrition deficits, health hazards, and financial losses (Banti, 2020).

A comprehensive 2023 Pakistani study analyzing 190 raw milk samples found 77.89% contained added water, 32.9% detergents, 16.8% caustic soda, and 9.4% formalin; 2.63% were classified as semi-synthetic milk (Ibrahim *et al*., 2023). Azad and Ahmed (2016) documented a wide range of adulterants including urea, detergents and formalin, noting the increasing sophistication of methods to evade detection. The health implications are grave: Choudhary and Sharma (2024) linked adulterants like melamine and formaldehyde to kidney failure, cancer and acute poisoning, especially in children.

Current detection methods include rapid field kits (e.g., Eat Right India's DART kit) and advanced spectroscopic techniques, but their efficacy hinges on widespread implementation. Addressing this crisis requires urgent policy interventions, including strict penalties for adulteration and comprehensive farmer training to improve practices throughout the dairy value-chain.

This study offers Pakistan's first comprehensive examination of milk adulteration, providing precedent-setting data on the physical, chemical and biological contamination affecting consumer health. Its findings are particularly relevant for developing countries with inadequate food-safety regulation, guiding authorities in enhancing monitoring systems and advising policy on milk safety standards.

Materials and Methods

Study design

This experimental study used both qualitative and quantitative approaches to assess the quality (composition and adulteration) of milk samples from selected farms and milk shops in the Peshawar Division (districts: Peshawar, Nowshera, Charsadda) between September 2023 and December 2024.

Sampling technique

A probability cluster sampling technique was applied. The population was divided into clusters (dairy farms); 105 clusters were randomly selected and one milk sample collected from each. An equal number (105) of milk samples were collected from retail milk shops in the three districts.

Sample collection and handling

Fresh buffalo milk samples were aseptically collected in sterilised plastic bottles (≈100 mL) from randomly selected dairy farms and shops. Each sample was assigned a unique alphanumeric code (e.g., 1PS, 2PF, 3CS, 4NF) to maintain confidentiality. Samples were transported in a thermos box kept at 4 °C to the laboratory. Upon arrival, samples were homogenised at room temperature before analysis. A list of registered dairy farms was obtained from the District Diagnostic Laboratory, Veterinary Hospital, Peshawar. Information such as milking times and supply schedules was collected to ensure representative and unbiased sampling. The sampling protocol was designed to minimise contamination, preserve physicochemical properties, and comply with international dairy-sample collection standards (FAO; AOAC).

Analytical methods

Milk composition (fat, protein, lactose, SNF, added water) was assessed using the Lacto-Scan 860 analyser. Adulterants were identified using the UVAS Milk Adulteration Testing (MAT) kit that detects twelve adulterants: starch, urea, soap, hydrogen peroxide (H_2O_2), sorbitol, boric acid, sugarcane, sodium chloride (NaCl), carbonate, formalin, quaternary ammonium compounds (QAC), and hypochlorite.

Statistical analysis

Data were coded and analysed using SPSS. Descriptive statistics (mean ± SD) were calculated. Chi-square, Fisher's exact test, and effect size (Cramer's V) were used to determine associations between adulteration, milk source and district. Pearson correlation was computed using Microsoft Excel to assess the impact of adulteration on milk composition. One-way ANOVA was used to test district-wise differences.

Table 1: *Comparison of composition of raw milk across sources and districts (Percentage%)*

Districts	Peshawar (P)		Charsadda (C)		Nowshera N)		Standard 2022*
Farm /Shop	Farm	Shop	Farm	Shop	Farm	Shop	Buffalo milk
Nutrient	n=35	n=35	n=35	n= 35	n=35	n=35	
Fat	5.98+2.05	5.13+0.94	7.33+2.22	6.00+1.42	7.32+2.43	5.18+0.96	6.7
Snf	8.75+1.25	8.29+ 0.89	8.48+1.26	7.80+1.25	7.71+2.01	7.88+1.10	10
Lactose	4.19+0.71	3.90+0.96	3.80+0.58	3.58+0.63	3.74+0.54	3.54+0.52	4.6
Protein	4.12+0.62	3.88+0.44	3.98+0.63	3.66+0.63	3.90+0.59	3.73+0.50	4.7
Water	4.83+7.08	10.78+10.11	9.10+12.95	15.98+14.18	9.99+12.02	16.08+12.85	83.2

Results and Discussion

Composition of raw milk

Table 1 displays the composition of raw milk samples collected across the three districts using the Lacto-Scan 860. Farm milk generally approached the standard fat level (6.7%) with mean values of Peshawar (5.98 ± 2.05 %), Charsadda (7.33 ± 2.22 %) and Nowshera (7.32 ± 2.43 %). In contrast, shop-milk fat values were lower: Peshawar (5.13 ± 0.94 %), Nowshera (5.18 ± 0.96 %) and Charsadda (6.00 ± 1.42 %). These deviations likely reflect skimming or water dilution. Similar patterns were reported by Arif *et al*. (2024); Nawaz *et al*. (2022).

Solid-not-fat (SNF) content was generally below the required standard. Farm milk: Peshawar (8.75 ± 1.25 %), Charsadda (8.48 ± 1.26 %), Nowshera (7.71 ± 2.01 %); Shop milk: Peshawar (8.29 ± 0.89 %), Charsadda (7.80 ± 1.25 %), Nowshera (7.88 ± 1.10 %). The low SNF values likely result from water dilution or inadequate feed. Arif *et al*. (2024) reported SNF ranging between 7.7 % and 8.5 %.

Lactose content in Peshawar samples (farm 3.90 ± 0.96 %, shop 4.19 ± 0.71 %) approached the expected value (4.6 %), but was lower in other districts. Microbial activity or adulteration may explain the reduction. Arif *et al*. (2024) found lactose as low as 3.2 % in Multan.

Protein levels were acceptable in farm milk (3.90–4.12 ± 0.6 %) but lower in shop milk (Peshawar 3.88 ± 0.44 %, Charsadda 3.66 ± 0.63 %, Nowshera 3.73 ± 0.50 %). Nawaz *et al*. (2022) reported similar values in Mardan (3.03–3.34 %).

Added water ranged from 5 % to 116 %, especially in shop milk, significantly reducing the nutritional content and increasing health risks. Arif *et al*. (2024) documented dilutions up to 92 %.

ANOVA of core nutritional parameters

One-way ANOVA showed significant differences in fat content for both farm ($p=0.037$, $\eta^2=0.063$) and shop milk ($p=0.002$, $\eta^2=0.111$). Farm milk SNF differed significantly ($p=0.019$, $\eta^2=0.070$), while shop milk SNF variation was non-significant ($p=0.094$). Lactose in farm milk varied ($p=0.016$, $\eta^2=0.078$); shop milk lactose variation was non-significant ($p=0.073$). Protein and water content showed non-significant variation ($p>0.1$). These findings reflect small-to-medium variability in farm milk (management differences) and medium variation in shop milk (indicating frequent manipulation).

Prevalence of adulterants

Sodium chloride was nearly ubiquitous in samples (Peshawar n=50, Charsadda n=60, Nowshera n=63), consistent with the use of NaCl to mask dilution and increase density (Tipu *et al*., 2012; Saeed *et al*., 2024). QAC was also highly prevalent (Nowshera n=57, Charsadda n=46, Peshawar n=34). These compounds, used as disinfectants, can cause gastrointestinal irritation, kidney damage, and liver toxicity (Nasir *et al*., 2022; Burham *et al*., 2014). Urea was detected (Nowshera n=35; Charsadda n=17; Peshawar n=8) — often added to mask low protein but can damage kidneys, liver and gut (Khomane *et al*., 2024; Azad and Ahmad, 2016). Sorbitol and hypochlorite were detected but less common; carbonate and formalin were found only once (n=1) in Charsadda — formalin is banned due to carcinogenic and organ-damaging properties (Barham *et al*., 2007; Abbas *et al*., 2024). According to the Khyber Pakhtunkhwa Food Safety & Halal Food Authority, 2.91% of milk samples tested contained formalin while 93% were below the standard (Anas *et al*., 2025).

Association of milk adulteration with source and district

Chi-square and Cramer's V analysis revealed strong

Table 2: *One-way anova of core nutritional parameters by sources and districts*

S#	Source	Nutrient	Source of variation	Sum of squares	df	Mean square	F-Test	p-Value	η^2	interpretation
1	Farm	Fat	Between groups	35.258	2	17.629	3.407	0.037	0.063	SM,SIG
			Within groups	527.708	102	5.174				
			Total	562.966	104					
2		SNF	Between groups	19.647	2	9.823	4.098	0.019	0.07	SM,SIG
			Within groups	244.517	102	2.397				
			Total	264.164	104					
3		Lactose	Between groups	3.643	2	1.821	4.293	0.016	0.078	M. SIG
			Within groups	43.282	102	.424				
			Total	46.925	104					
4		Protein	Between groups	1.327	2	.664	1.661	0.195	0.032	S, NSIG
			Within groups	40.756	102	.400				
			Total	42.084	104					
5		Water	Between groups	591.538	2	295.769	2.356	0.100	0.044	S , NSIG
			Within groups	12804.19	102	125.531				
			Total	13395.728	104					
6	Shop	Fat	Between groups	18.106	2	9.053	6.391	0.002	0.111	M, SIG
			Within groups	144.481	102	1.416				
			Total	162.587	104					
7		SNF	Between groups	6.225	2	3.112	2.419	0.094	0.045	S, NSIG
			Within groups	131.224	102	1.287				
			Total	137.449	104					
8		Lactose	Between groups	2.917	2	1.459	2.681	0.073	0.05	S-M, NSIG
			Within groups	55.499	102	.544				
			Total	58.416	104					
9		Protein	Between groups	1.501	2	.751	2.211	0.115	O.O42	S,NSIG
			Within groups	34.622	102	.339				
			Total	36.123	104					
10		Water	Between groups	755.180	2	377.590	2.318	0.104	.044	S, NSIG
			Within groups	16614.607	102	162.888				
			Total	17369.787	104					

district-level effects for urea (p=0.000, V=0.56), sorbitol (p=0.000, V=0.30), QAC (p=0.000, V=0.28) and hypochlorite (p=0.000, V=0.46). Moderate association was found for sodium chloride (p=0.01, V=0.20). At source level (farm vs shop), sorbitol (p=0.04, V=0.20) and QAC (p=0.00, V=0.35) were significantly higher in shop milk, suggesting poor handling and chemical contamination. Adulterants like soap, boric acid, carbonate and formalin showed no significant association, likely due to rare or accidental occurrence.

Effect of adulteration on milk composition

Pearson correlation analysis: urea was strongly negatively correlated with SNF (r=-0.97), lactose (r=-0.82) and protein (r=-0.77), and positively with water addition, confirming that urea increases non-protein nitrogen but reduces true protein. Sodium chloride and QAC showed strong negative correlations with protein (r=-0.89 to -0.98) and lactose (r=-0.92 to -0.99). Boric acid had strong positive correlations with fat, SNF, lactose and protein — likely because it preserves milk by inhibiting microbes but does not alter baseline nutrient levels (Nasir *et al*., 2022). Formalin exhibited strong positive correlation with fat, but weak negative correlations with SNF, lactose and protein — indicating composition stabilisation but serious toxicity. Water adulteration correlated very

Table 3: *Association of milk adulteration analysis with source and districts: chi square, fisher's exact test and effect of size*

S #	Adulterant	χ^2 (Chi-square)	X^2	df	p-value	Fisher Exact test	Effect Size (Cramer's V)	Interpretation
1	UREA	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction)	0.021 66.4866. 480	122	0.886 0.000 0.000	1.00 ✕	0.0100.56 0.563	NS Significant, V. .Strong Significant
2	STARCH							Not Detected
3	H2O2							Not Detected
4	SORBITOL	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction)	8.515 19.604 19.604	122	0.004 0.000 0.000	0.06 ✕	0.2010.3060 .306	Significant , weak Significant .strong Significant
5	QAC	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	25.722 16.672 16.674	122	0.000 0.000 0.000	0.000 ✓	0.3500.282 0.282	Highly significant strong Significant Significant
6	SOAP	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	0.000 1.010 1.010	122	1.0 0.604 0.604	1.000 - ✕	0.000.64 0.069	NS NS NS
7	BORIC ACID	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	0.520 1.040 1.040	122	0.471 0.595 0.585	0.721 ✕	0.0500.070 0.070	NS NS NS
8	CANE SUGAR							Not Detected
9	SODIUM CHLORIDE	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	0.033 9.120 9.120	122	0.858 0.010 0.136	1.00 ✕	0.0120.208 0.208	NS Significant, Moderatte Ns
10	CARBONATE	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	1.005 2.010 2.010	122	0.315 0.366 0.366	1.00 ✕	0.0690.098 0.098	NS NS NS
11	FORMALIN	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	1.005 2.010 2.019	122	0.316 0.366 0.366	1.00 ✕	0.0690.098 0.098	NS NS NS
12	HYPO CHLORIDE	Shop vs Farm (Overall) Districts (Overall) District × Source (Interaction	3.262 45.920 45.972	122	0.071 0.000 0.000	0.095 - ✕ -	0.1250.468 0.468	Borderline NS Highly significant,v strog Highly significant

strongly negatively with SNF, lactose and protein (r=-0.92 to -0.99), confirming dilution severely reduces nutrient content (Azhar *et al.*, 2024; Somoro et al., 2014). Overall, higher adulteration was linked to poorer nutrition.

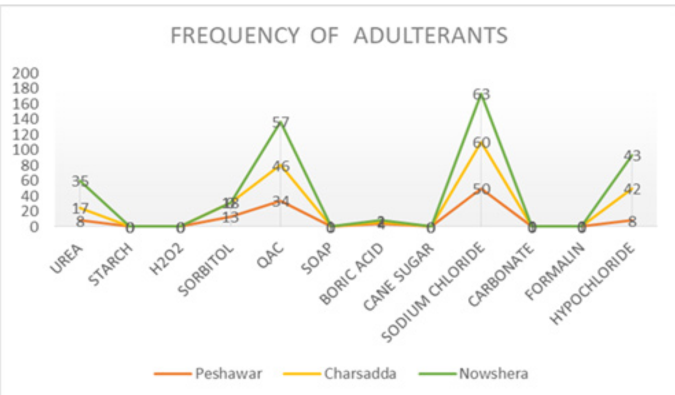

Figure 1: *Prevalence of adulteration in available raw milk*

Conclusions and Recommendations

This study confirms that while farm milk samples closely aligned with nutritional standards, shop milk exhibited significant adulteration and nutrient loss — primarily via water dilution and fat removal. The most common adulterants were urea, sodium chloride and QACs, all of which significantly reduced protein, lactose and SNF levels. A statistically significant relationship between adulteration and nutritional quality was evident.

These findings highlight vulnerabilities in the dairy value-chain resulting from both mishandling and deliberate fraud. To safeguard milk quality.

Implement farmer education programmes promoting hygienic milking, handling and nutrition. Invest

Table 4: *Pearson Correlation analysis of Adulteration and Nutritional Composition*

	UREA	Qsorbitol	QAC	Boric acid	Sodium Chl	Formaum	Hypochl	Fat	Snf	Lactose	Protein	Water
Urea	1											
Sorbitol	-0.82094	1										
QAC	0.976253	-0.67775	1									
Boric acid	-0.75467	0.244899	-0.87888	1								
Sodium Chl	0.880701	-0.45253	0.9624	-0.9754173	1							
Formaum	-0.19087	0.717204	0.026314	-0.5	0.296866125	1						
Hypochl	0.770572	-0.26866	0.890345	-0.9996977	0.980540253	0.478557128	1					
Fat	0.45838	0.131183	0.64003	-0.9290434	0.824675965	0.784925834	0.919666594	1				
Snf	-0.97592	0.67661	-1	0.87961984	-0.962819473	-0.027861262	-0.89104876	-0.64122	1			
Lactose	-0.8241	0.353095	-0.92724	0.99357017	-0.994094898	-0.398735396	-0.99605337	-0.88118	0.927819	1		
Protein	-0.77002	0.267828	-0.88995	0.99971864	-0.980369917	-0.479317156	-0.99999963	-0.92001	0.890655	0.995976	1	
Water	0.808133	-0.32711	0.91654	-0.9963192	0.990716918	0.423923065	0.9981125525	0.893909	-0.91716	-0.99962	-0.99807	1

in infrastructure, milk collection centres, cold-chain transport, and storage facilities. Strengthen regulatory enforcement, conduct routine monitoring, and impose meaningful penalties for adulteration. Increase consumer awareness about adulteration risks and encourage demand for certified milk sources. Without concerted action, raw milk will continue to present preventable health risks especially for children, the elderly and nutritionally vulnerable populations.

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Novelty Statement

This study provides the first integrated assessment of raw milk quality, adulteration practices, and associated public health risks in Peshawar District. It offers comprehensive, district-specific evidence on milk safety. The findings generate locally relevant data to support targeted regulatory actions and public health interventions.

Author's Contribution

Sumbla Yousaf: Data collection, write-up, lab work and analysis

Farhat Shehzad: Major supervisor who provided guidance in research.

Mohammad Shakir Khan: Helped and guided in laboratory work

Zahin Anjum: Helped in manuscript writing and submission

Generative AI or AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors declare no conflict of interest regarding this study.

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