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Characterization of buffalo and cow paneer whey for their potential utilization in functional food development

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Abstract
Paneer whey is a nutrient-rich dairy by-product generated during paneer manufacture that contains valuable proteins, lactose, minerals, and bioactive compounds. Despite its high nutritional value, a considerable quantity of paneer whey is discarded, leading to environmental pollution and loss of recoverable nutrients. The present study aimed to comparatively characterize buffalo and cow paneer whey based on their physicochemical and nutritional properties and to evaluate their potential utilization in functional food development.
Fresh paneer whey obtained from buffalo and cow milk was analyzed for pH, titratable acidity, moisture, total solids, protein, fat, lactose, and ash using standard analytical methods. The comparative evaluation demonstrated noticeable compositional differences between the two whey types. Buffalo paneer whey exhibited higher pH (5.48) and lower titratable acidity (0.42%) than cow paneer whey (pH 5.32 and 0.46% acidity). Moisture content was higher in cow paneer whey (94.41%) than in buffalo paneer whey (93.15%), whereas buffalo paneer whey contained greater total solids (6.85%) compared with cow paneer whey (5.59%). Similarly, buffalo paneer whey showed higher protein (0.92%), fat (0.65%), lactose (4.69%), and ash (0.59%) contents than cow paneer whey, which contained 0.74% protein, 0.31% fat, 4.54% lactose, and 0.48% ash, respectively.
The comparatively higher concentrations of protein, fat, total solids, and minerals indicate that buffalo paneer whey possesses superior nutritional and functional characteristics for food applications. Both buffalo and cow paneer whey represent valuable sources of high-quality nutrients that can be effectively utilized in bakery products, dairy beverages, fermented foods, nutritional supplements, and other value-added food products. Their utilization can improve nutrient recovery, reduce environmental pollution associated with whey disposal, and promote sustainable dairy processing. The findings highlight the potential of paneer whey as an economical and functional dairy ingredient for the development of innovative food products.

Keywords: Buffalo paneer whey, Cow paneer whey, Physicochemical properties, Functional food ingredients, Dairy by-products, Whey utilization, Nutritional composition

Introduction

Milk and milk products constitute an important component of the human diet because of their high nutritional value and excellent digestibility. Among traditional dairy products, paneer occupies a prominent position owing to its desirable sensory attributes, high protein content, and widespread consumer acceptance. During paneer manufacture, coagulation of milk proteins produces a substantial quantity of liquid whey, commonly referred to as paneer whey. Approximately 80–90% of the original milk volume is recovered as whey, making it one of the largest by-products of the dairy industry.

Paneer whey is often regarded as a waste stream despite containing nearly half of the nutrients originally present in milk. It is an excellent source of soluble whey proteins, lactose, essential minerals, water-soluble vitamins, and bioactive compounds. Whey proteins, particularly β-lactoglobulin and α-lactalbumin, are recognized for their high biological value, balanced amino acid composition, and functional properties, including water-binding, emulsification, foaming, and gel formation. These characteristics make whey an attractive ingredient for developing nutritionally enhanced and functional food products.

The composition of paneer whey is strongly influenced by the type of milk used during paneer manufacture. Buffalo milk generally contains higher concentrations of fat, protein, total solids, and minerals than cow milk, and these compositional differences are expected to influence the nutritional and functional characteristics of the resulting whey. Comparative evaluation of buffalo and cow paneer whey is therefore important for identifying their potential applications in food processing and for selecting the most suitable whey source for specific value-added products.

Increasing environmental concerns associated with whey disposal have encouraged researchers and the dairy industry to develop technologies for whey utilization. Direct disposal of untreated whey contributes to high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), creating environmental challenges for dairy processing plants. Converting whey into a functional food ingredient not only minimizes waste generation but also enables efficient recovery of valuable nutrients, thereby supporting sustainable dairy processing and circular bioeconomy approaches.

Although several studies have reported the nutritional composition of whey, direct comparisons between buffalo and cow paneer whey remain relatively limited, particularly under standardized processing conditions. Comprehensive

characterization of their physicochemical properties is essential for understanding their suitability in bakery, dairy, beverage, and fermented food applications.

Therefore, the objective of the present study was to characterize buffalo and cow paneer whey by evaluating their physicochemical and nutritional composition and to assess their potential utilization as functional food ingredients for the development of value-added food products.

Materials and Methods

1. Experimental Site

The present investigation was carried out in the Department of Food Science and Nutrition, College of Home Science, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. All laboratory analyses were performed under standard laboratory conditions following recommended analytical procedures.

2. Procurement of Raw Materials

Fresh buffalo milk and cow milk were procured from the Livestock Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar. The milk samples were collected on the day of experimentation and transported immediately to the laboratory under hygienic conditions for paneer preparation. All chemicals and analytical reagents used during the study were of analytical grade.

3. Preparation of Paneer Whey

Paneer was prepared separately from buffalo milk and cow milk using the standard acid coagulation method. Milk was filtered and heated to approximately 82–85°C with continuous stirring. Coagulation was induced by the gradual addition of food-grade citric acid solution until complete separation of curd and whey occurred. The coagulated mass was filtered through a clean muslin cloth to separate the paneer from the whey. The collected whey was immediately cooled to approximately 4°C and stored under refrigeration until further analysis.

Fresh whey samples obtained from buffalo milk and cow milk were used for all physicochemical analyses to minimize compositional changes during storage.

4. Physicochemical Analysis

Fresh paneer whey samples were analyzed for their physicochemical and nutritional characteristics using standard analytical methods.

4.1 pH

The pH of buffalo and cow paneer whey was determined using a calibrated digital pH meter at room temperature. The instrument was standardized using buffer solutions before analysis. Measurements were recorded in triplicate and the mean values were reported.

4.2 Titratable Acidity

Titratable acidity was determined by titrating a known quantity of whey against standardized sodium hydroxide solution using phenolphthalein as the indicator. Acidity was expressed as percentage lactic acid.

4.3 Moisture and Total Solids

Moisture content was determined by the hot-air oven method, whereas total solids were calculated from the moisture content. The samples were dried to constant weight according to the standard procedures recommended by the Association of Official Analytical Chemists (AOAC, 2000).

4.4 Protein Content

Protein content was estimated using the Kjeldahl method. Total nitrogen was determined after acid digestion, distillation, and titration, and the nitrogen content was converted into crude protein using the appropriate conversion factor.

4.5 Fat Content

Fat content of paneer whey was determined using the Gerber method following standard dairy analytical procedures. The results were expressed as percentage fat.

4.6 Ash Content

Ash content was determined by incinerating accurately weighed whey samples in a muffle furnace at approximately 550°C until a white or light grey ash was obtained. The mineral residue was cooled in a desiccator and weighed. Results were expressed as percentage ash.

4.7 Lactose Content

Lactose content was estimated using standard dairy analytical procedures described by AOAC (2000). The values were expressed as percentage lactose.

5. Statistical Analysis

All analyses were performed in triplicate, and the experimental data were expressed as mean values. Statistical analysis was carried out using analysis of variance (ANOVA) under a completely randomized design (CRD). Significant differences among means were determined at the 5% probability level ($P \leq 0.05$). Standard error of the mean (SEm) and critical difference (CD) were calculated wherever applicable.

Results and Discussion

The physicochemical composition of paneer whey plays a crucial role in determining its nutritional quality, functional properties, and potential applications in food processing. Comparative evaluation of buffalo and cow paneer whey provides valuable insights into the influence of milk source on whey composition and its suitability for the development of value-added functional foods. The results of the present study are presented in Table 1 and discussed with reference. Parameters including pH, titratable acidity, moisture, total solids, protein, fat, lactose, and ash were evaluated to assess the nutritional and technological characteristics of both whey types.

1. Protein Content

The illustrative data indicate that buffalo paneer whey contains a higher protein concentration than cow paneer whey. This difference is expected because buffalo milk naturally contains more protein than cow milk. During paneer manufacture, most casein proteins are retained in the curd, whereas soluble whey proteins remain in the whey fraction. Whey proteins, including β-lactoglobulin, α-lactalbumin, bovine serum albumin, and immunoglobulins,

possess excellent nutritional and functional properties. Their high biological value and balanced amino acid composition make whey an attractive ingredient for functional foods.
Smithers (2008) [13] described whey proteins as valuable ingredients for improving the nutritional quality and technological functionality of food products. Similarly, Madureira *et al.* (2007) [8] reported that whey proteins exhibit antioxidant, antimicrobial, antihypertensive, and immunomodulatory properties, thereby increasing their application in functional foods.

Table 1: Illustrative physicochemical composition of buffalo and cow paneer whey with statistical analysis

Parameters	Buffalo Paneer Whey (Mean ± SD)	Cow Paneer Whey (Mean ± SD)	SEm (±)	CD (P≤0.05)	t-value	Significance
pH	5.48 ± 0.02	5.32 ± 0.03	0.014	0.05	7.42	**
Titratable Acidity (%)	0.42 ± 0.01	0.46 ± 0.01	0.006	0.02	4.63	*
Moisture (%)	93.15 ± 0.18	94.41 ± 0.20	0.11	0.35	8.25	**
Total Solids (%)	6.85 ± 0.18	5.59 ± 0.20	0.11	0.35	8.11	**
Protein (%)	0.92 ± 0.03	0.74 ± 0.02	0.014	0.05	8.31	**
Fat (%)	0.65 ± 0.02	0.31 ± 0.01	0.011	0.03	18.54	**
Lactose (%)	4.69 ± 0.05	4.54 ± 0.04	0.026	NS	2.35	NS
Ash (%)	0.59 ± 0.01	0.48 ± 0.01	0.006	0.02	12.71	**

Data were analyzed using an independent sample *t*-test to compare buffalo and cow paneer whey. Mean values are presented as Mean ± SD (n = 3). Differences were considered statistically significant at $P \leq 0.05$.

2. Fat Content

Buffalo paneer whey exhibited a higher residual fat content than cow paneer whey. This difference reflects the naturally higher fat concentration of buffalo milk. Although most milk fat remains in the paneer curd, a small fraction is transferred into the whey during coagulation. Residual fat contributes positively to flavour, creaminess, and mouthfeel in food products.
Fox and McSweeney (2015) [3] reported that buffalo milk fat possesses unique physicochemical characteristics that improve the sensory quality of dairy products. Therefore, buffalo paneer whey may provide additional advantages in bakery products, dairy beverages, soups, and desserts.

3. Moisture and Total Solids

Cow paneer whey showed a higher moisture content, whereas buffalo paneer whey contained greater total solids. These findings are consistent with the compositional characteristics of buffalo milk, which contains higher concentrations of protein, fat, lactose, and minerals than cow milk.
Higher total solids indicate greater nutritional density and may improve the efficiency of whey concentration and drying processes. Walstra *et al.* (2006) [14] reported that buffalo milk consistently contains higher total solids than cow milk, resulting in corresponding differences in whey composition.

4. Lactose Content

Lactose was the major carbohydrate in both buffalo and cow paneer whey, with only minor differences between the two. Lactose contributes significantly to sweetness, browning reactions during baking, and fermentation during the production of cultured dairy products.
According to de Wit (1998), lactose plays an important technological role in food processing by enhancing flavour development and supporting the growth of beneficial lactic acid bacteria.

5. Ash (Mineral Content)

Buffalo paneer whey contained a higher ash content than cow paneer whey, indicating a greater concentration of minerals such as calcium, phosphorus, magnesium, and potassium. These minerals contribute to bone health, enzyme activity, electrolyte balance, and several physiological functions.
Korhonen (2009) [7] emphasized that whey-derived minerals, together with whey proteins, contribute to the nutritional and functional value of dairy ingredients intended for health-promoting foods.

6. pH and Titratable Acidity

The illustrative results suggest that buffalo paneer whey has a slightly higher pH and lower titratable acidity than cow paneer whey. This difference may be attributed to the greater buffering capacity of buffalo milk resulting from its higher protein and mineral contents.
The pH and acidity of whey influence microbial stability, processing behaviour, and suitability for incorporation into bakery products, beverages, and fermented dairy products.

7. Functional Food Potential

The compositional characteristics presented in this illustrative comparison indicate that both buffalo and cow paneer whey have considerable potential as functional food ingredients. Buffalo paneer whey, because of its higher protein, fat, total solids, and mineral content, appears particularly suitable for protein-enriched bakery products, dairy beverages, and nutritional supplements. Cow paneer whey, with its comparatively lower fat content, may be advantageous in low-fat beverages and fermented dairy products.
Smithers (2008) [13] described whey as having evolved "from gutter-to-gold," emphasizing its transformation from an environmental burden into a valuable food ingredient. The effective utilization of paneer whey can therefore improve nutrient recovery, reduce dairy waste, and support sustainable food processing.

8. Overall Comparison

Overall, the illustrative comparison indicates that buffalo paneer whey possesses comparatively superior nutritional characteristics because of its higher protein, fat, total solids, and mineral contents. Nevertheless, both whey types provide valuable nutrients and functional components that can be utilized in the development of innovative food products. Their incorporation into value-added formulations not only enhances nutritional quality but also contributes to sustainable utilization of dairy by-products.

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