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Valorization of paneer whey for sustainable bakery products: Development and characterization of Whey-Enriched Cookies

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Abstract
The disposal of paneer whey, a nutrient-rich by-product of the dairy industry, poses significant environmental and economic challenges due to its high organic load despite containing valuable proteins, lactose, and minerals. The present study aimed to evaluate the feasibility of utilizing paneer whey as a complete or partial replacement for water in cookie production and to assess its effects on the sensory, nutritional, and physicochemical characteristics of the developed products. Five cookie formulations were prepared by replacing water with paneer whey at different levels (0, 25, 50, 75, and 100%), designated as T_0, T_1, T_2, T_3, and T_4, respectively. The cookies were analyzed for proximate composition, calorific value, and sensory quality using standard analytical methods.
Progressive incorporation of paneer whey significantly ($P \leq 0.05$) improved the nutritional composition of cookies. Moisture content increased from 6.11% in the control (T_0) to 11.32% in T_4, while protein content increased from 9.07% to 9.92%. Fat and ash contents also increased from 22.23% to 24.53% and 0.48% to 1.09%, respectively. In contrast, carbohydrate content decreased from 62.11% to 53.15%, resulting in a slight reduction in calorific value from 484.84 to 473.19 kcal/100 g. Sensory evaluation revealed that cookies prepared with 100% paneer whey (T_4) achieved the highest scores for colour and appearance (8.45), body and texture (8.30), taste and flavour (8.15), and overall acceptability (8.30) on a nine-point hedonic scale, indicating excellent consumer acceptance.
The findings demonstrate that paneer whey can effectively replace water in cookie formulation without compromising product quality. Its incorporation enhanced nutritional composition, improved sensory characteristics, and provided a practical strategy for the valorization of dairy by-products. The study highlights the potential of paneer whey as a sustainable functional ingredient for the development of value-added bakery products while contributing to waste reduction and resource-efficient food processing.

Keywords: Paneer whey, sustainable food processing, dairy by-product valorization, cookies, circular bioeconomy, functional bakery products, whey proteins, food waste utilization

Introduction

The dairy industry is one of the largest agro-based sectors worldwide and contributes substantially to the production of nutrient-rich foods. Along with the manufacture of milk products such as paneer, cheese, chhana, casein, and yogurt, large volumes of liquid whey are generated as a by-product. Traditionally, whey was considered a waste stream because of its high moisture content and the lack of economical utilization methods, particularly in small- and medium-scale dairy industries. Disposal of untreated whey into water bodies or on land has been recognized as an environmental concern due to its high organic load, which contributes to elevated biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Consequently, effective utilization of whey has become an important objective for both the dairy industry and sustainable food processing.
Despite being regarded as a by-product, whey possesses remarkable nutritional value. It contains high-quality proteins with an excellent amino acid profile, lactose, minerals, water-soluble vitamins, and several bioactive components. Whey proteins are particularly rich in essential amino acids, including leucine, isoleucine, and valine, which are important for growth, tissue repair, and maintenance of muscle protein synthesis. In addition to their nutritional significance, whey proteins exhibit desirable functional properties such as water-binding, emulsification, foaming, and gel formation, making them suitable ingredients for various food formulations. These characteristics provide an opportunity to convert whey from a disposal problem into a valuable food ingredient.
In India, paneer is one of the most widely consumed traditional dairy products, resulting in the generation of considerable quantities of paneer whey during its manufacture. Although large dairy industries often process whey into value-added ingredients such as whey protein concentrates and lactose, such technologies are generally beyond the economic capacity of small dairy units. As a result, a significant proportion of paneer whey remains underutilized or is discarded, representing both a loss of valuable nutrients and an environmental burden. Utilization of paneer whey in commonly consumed food products offers an economical and practical approach for improving resource efficiency while reducing waste generation.
Bakery products are among the most popular convenience foods because of their affordability, long shelf life, pleasant sensory characteristics, and widespread consumer acceptance. Cookies, in particular, are consumed by individuals of all age groups and represent an excellent

vehicle for nutritional enhancement. Conventional cookies are primarily prepared from refined wheat flour, sugar, and fat. Although highly acceptable from a sensory standpoint, they generally contain relatively low levels of high-quality protein and essential micronutrients. Incorporation of nutrient-rich ingredients into cookie formulations has therefore become an effective strategy for improving their nutritional quality without significantly affecting consumer acceptability.

The functional properties of whey make it particularly suitable for bakery applications. Lactose present in whey participates in Maillard browning during baking, contributing to improved crust colour and flavour development. Whey proteins enhance the nutritional value of baked products while influencing dough characteristics and texture. Furthermore, whey supplies minerals and other bioactive components that may improve the overall nutritional profile of bakery products. Therefore, replacing water with paneer whey during cookie preparation provides an innovative means of simultaneously improving product quality and utilizing an underexploited dairy by-product.

The concept of utilizing food processing by-products has gained increasing attention within sustainable food systems. Instead of treating by-products as waste, modern food processing emphasizes their conversion into value-added ingredients capable of generating economic, nutritional, and environmental benefits. Such approaches contribute to resource conservation, reduction of food processing waste, and improved sustainability of food production systems. Incorporating paneer whey into bakery products aligns with these objectives by promoting efficient utilization of dairy resources while minimizing environmental pollution associated with whey disposal.

Although several studies have investigated the incorporation of dairy ingredients into bakery products, information regarding the direct utilization of fresh paneer whey as a replacement for water in cookie preparation remains comparatively limited. Most previous investigations have focused on whey protein concentrates or dried whey powders, whereas utilization of fresh liquid paneer whey represents a simple and cost-effective alternative that can be readily adopted by small-scale dairy processors and local bakeries without requiring sophisticated processing technologies.

Therefore, the present study was undertaken to evaluate the feasibility of utilizing paneer whey in cookie production by replacing water at different incorporation levels. The prepared cookies were assessed for their physicochemical characteristics, proximate composition, calorific value, and sensory acceptability to determine the suitability of paneer whey as a sustainable ingredient for value-added bakery products. The study also explores the potential of paneer whey utilization as an approach for improving nutritional quality while promoting sustainable management of dairy by-products.

Materials and Methods

1. Materials

Fresh buffalo milk was procured from the Animal Husbandry Department, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India. Refined wheat flour (maida), powdered sugar, vegetable shortening, baking powder, sodium bicarbonate, common salt, and vanilla flavour were purchased from the local market. All chemicals and reagents used for analytical determinations were of analytical grade.

2. Preparation of Paneer Whey

Paneer whey was prepared following the standard acid coagulation method. Fresh buffalo milk was heated to 90°C in a stainless-steel vessel and subsequently cooled to approximately 83°C. A 2% citric acid solution was gradually added with continuous stirring until complete coagulation occurred. The coagulated paneer was separated by filtration through a clean muslin cloth, and the resulting whey was collected in a stainless-steel container. The freshly prepared paneer whey was used immediately for cookie preparation.

3. Preparation of Cookies

Cookies were prepared by the conventional creaming method. Powdered sugar, vegetable shortening, and vanilla flavour were creamed until a light and uniform mixture was obtained. Refined wheat flour, baking powder, common salt, and sodium bicarbonate were mixed separately and incorporated into the creamed mixture. Water or paneer whey was then added according to the treatment formulation to obtain a homogeneous dough.

The dough was rolled uniformly, cut into circular shapes using a cookie cutter, and baked in a preheated oven at 175°C for 10–15 minutes until light brown in colour. After baking, cookies were cooled to room temperature and stored in airtight containers until further analysis.

4. Experimental Design

Paneer whey was incorporated by replacing water at different levels while maintaining a constant quantity of refined wheat flour (150 g) in all treatments. Five formulations were prepared:

Table 1: Optimization of cookies formulation

Treatment	Refined wheat flour (g)	Paneer whey (mL)	Water (mL)
T_0 (Control)	150	0	100
T_1	150	25	75
T_2	150	50	50
T_3	150	75	25
T_4	150	100	0

The prepared cookies were evaluated to identify the optimum level of whey incorporation based on physicochemical characteristics and sensory quality.

5. Proximate Composition

Both raw materials and cookie samples were analysed using standard analytical procedures.

Moisture Content

Moisture content was determined using the hot air oven method (AOAC, 2000). Samples were dried at 100 ± 1°C until constant weight was obtained, and moisture content was expressed as percentage loss in weight.

Protein Content

Protein was determined by the Kjeldahl method (AOAC, 2000). Nitrogen content was estimated after digestion, distillation, and titration, and converted to protein using appropriate conversion factors (5.71 for wheat products and 6.38 for milk and whey).

Crude Fat
Crude fat content was determined by Soxhlet extraction using petroleum ether (40–60°C) as the extraction solvent following the AOAC (2000) procedure.

Ash Content
Total ash was determined by incinerating samples in a muffle furnace at 550 ± 15°C until white ash was obtained. Ash content was expressed as percentage of sample weight.

Carbohydrate Content
Total carbohydrate content was calculated by difference according to AOAC (2000):

Carbohydrate (%) = 100 − (Moisture + Protein + Fat + Ash + Crude Fibre)

6. Sensory Evaluation
Sensory evaluation of the cookies was carried out by a semi-trained panel comprising twenty members from the Department of Food Science and Nutrition. The panel evaluated appearance, colour, flavour, texture, taste, and overall acceptability using a nine-point hedonic scale, where a score of 9 indicated "like extremely" and a score of 1 indicated "dislike extremely."

7. Statistical Analysis
All experimental observations were analysed using analysis of variance (ANOVA) according to the completely randomized design (CRD) as described by Snedecor and Cochran. Differences among treatment means were evaluated for statistical significance at the appropriate probability level.

Results and Discussion

1. Sensory Characteristics of Whey-Incorporated Cookies

Consumer acceptability is one of the most important determinants of the successful utilization of novel ingredients in bakery products. In the present study, paneer whey was incorporated into cookie formulations by progressively replacing water, and the resulting products were evaluated for appearance, colour, flavour, texture, taste, and overall acceptability using a nine-point hedonic scale.

The sensory scores in Table 2 demonstrated that incorporation of paneer whey did not adversely affect the organoleptic quality of cookies. Instead, gradual replacement of water with paneer whey resulted in improved sensory perception for most evaluated attributes. Among the different formulations, cookies prepared with complete replacement of water by paneer whey (T_4) received the highest overall acceptability score, indicating excellent consumer preference.

The improvement in sensory quality may be attributed to the compositional characteristics of paneer whey. Whey contains lactose, whey proteins, and soluble minerals that contribute positively to baking performance. During baking, lactose actively participates in the Maillard reaction, producing desirable golden-brown colour and pleasant roasted flavour compounds. Unlike sucrose, lactose is less sweet but highly reactive during thermal processing, enhancing colour development without producing excessive sweetness.

Whey proteins also contribute to favourable textural characteristics by improving moisture retention within the baked product. Increased water-binding capacity may have reduced excessive hardness, resulting in cookies with a more desirable bite and improved mouthfeel. Furthermore, naturally occurring milk solids impart a mild dairy flavour that complements conventional cookie formulations, thereby increasing flavour acceptability.

The progressive increase in sensory scores observed with increasing levels of paneer whey indicates that the ingredient can successfully replace water without compromising product quality. Rather than functioning merely as a processing liquid, paneer whey acts as a multifunctional ingredient capable of simultaneously improving flavour, colour, texture, and overall acceptability. These findings demonstrate that utilization of paneer whey provides an effective strategy for developing value-added bakery products while reducing wastage of nutritionally valuable dairy by-products.

Table 2: Sensory evaluation scores of paneer whey-incorporated cookies

Treatment	Colour & Appearance	Body & Texture	Taste & Flavour	Overall Acceptability
T_0 (0% whey)	6.05	5.90	6.05	6.05
T_1 (25% whey)	6.80	6.55	6.65	6.70
T_2 (50% whey)	7.45	7.10	6.95	7.25
T_3 (75% whey)	8.00	7.60	7.30	7.80
T_4 (100% whey)	8.45	8.30	8.15	8.30

2. Effect of Paneer Whey on Proximate Composition

The proximate composition of the developed cookies is presented in Table 3. Replacement of water with paneer whey influenced the nutritional composition of cookies because whey contributes proteins, lactose, minerals, and other soluble solids that remain in the final baked product.

2.1 Moisture Content

Moisture content is an important quality parameter that influences the texture, palatability, and shelf stability of bakery products. The moisture content of the cookies increased progressively with increasing levels of paneer whey incorporation, ranging from 6.11% in the control (T_0) to 11.32% in the formulation prepared with 100% paneer whey (T_4). The increase was statistically highly significant ($P \leq 0.05$), indicating that replacement of water with paneer whey markedly influenced moisture retention in the baked product.

The higher moisture content observed in whey-incorporated cookies can be attributed to the functional properties of whey proteins and lactose. Whey proteins possess a high water-holding capacity and interact with gluten proteins and starch during dough development, thereby retaining more bound water throughout baking. Lactose, being hygroscopic in nature, also contributes to moisture retention, resulting in cookies with a softer texture and improved eating quality. This mechanism is consistent with the higher sensory scores obtained for body and texture in the whey-incorporated formulations.

The present findings agree with Towler (1982) [19], who reported that incorporation of whey into noodle formulations increased water retention and produced dough with higher moisture content. Similarly, Richeut (1993) observed that cakes prepared with whey exhibited improved tenderness and moisture compared with conventional

formulations. These observations suggest that whey functions not merely as a replacement for water but also as a functional ingredient capable of modifying the hydration characteristics of bakery products.

A similar trend was reported by O'Brien *et al.* (2003) [15], who attributed increased moisture retention in whey-containing bakery products to the greater amount of bound water within the food matrix. Likewise, Gallagher *et al.* (2005) [7] demonstrated that biscuits enriched with whey protein concentrate possessed significantly higher moisture content than control samples because of the superior water-binding properties of milk proteins.

From a technological perspective, moderate moisture retention is advantageous because it contributes to improved softness and consumer acceptability. However, increased moisture may also influence the storage stability of bakery products and should therefore be considered during product packaging and shelf-life evaluation. Overall, the results demonstrate that paneer whey effectively enhances moisture retention while simultaneously improving the sensory characteristics of cookies, supporting its utilization as a functional dairy ingredient in bakery applications.

2.2 Protein Content

Protein enrichment is one of the principal nutritional advantages associated with the incorporation of dairy-derived ingredients into bakery products. In the present investigation, protein content increased progressively with increasing levels of paneer whey incorporation, rising from 9.07% in the control cookies (T_0) to 9.92% in cookies prepared with complete replacement of water by paneer whey (T_4). Intermediate treatments (T_1–T_3) also exhibited gradual increases in protein content, indicating a positive relationship between whey incorporation level and protein enrichment. Statistical analysis revealed that the differences among treatments were highly significant ($P \leq 0.05$), confirming that paneer whey exerted a measurable influence on the protein composition of the developed cookies. The observed increase in protein content is primarily attributed to the presence of soluble whey proteins, including β-lactoglobulin and α-lactalbumin, which remain in the whey fraction following coagulation during paneer manufacture. Unlike water, paneer whey contributes nutritionally valuable milk proteins to the cookie dough. During baking, these proteins are retained within the product, thereby increasing the overall protein concentration. Although the numerical increase was modest, it represents an important nutritional improvement because whey proteins possess a superior amino acid profile and high biological value compared with cereal proteins.

The gradual increase in protein content with increasing whey incorporation demonstrates that paneer whey functions as a natural protein fortifier without requiring commercial protein concentrates or synthetic nutritional supplements. This finding is particularly relevant for sustainable food processing, where low-cost by-products can be converted into value-added ingredients while simultaneously improving the nutritional quality of widely consumed foods.

The present findings are consistent with those reported by Munaza *et al.* (2012) [14], who observed significantly higher protein content in biscuits fortified with whey protein concentrate. Similarly, Visalakshi and Mohansundari (2001) [20] reported progressive increases in protein content in whey-incorporated bakery products, including biscuits, cheese biscuits, and pizza, with increasing levels of whey addition. These authors concluded that whey serves as an effective source of high-quality protein capable of enhancing the nutritional profile of cereal-based foods.

From a product development perspective, improvement in protein content without compromising sensory quality is particularly desirable because bakery products are generally recognized as energy-dense foods with comparatively limited protein quality. Incorporation of paneer whey therefore offers an economical strategy to improve nutritional quality while maintaining consumer acceptability. Moreover, utilizing paneer whey for protein enrichment contributes to efficient recovery of milk nutrients that might otherwise be lost through disposal, thereby supporting sustainable utilization of dairy by-products.

Overall, the results demonstrate that replacement of water with paneer whey significantly enhanced the protein content of cookies while maintaining desirable product quality. These findings confirm the suitability of paneer whey as a functional ingredient for the development of nutritionally improved bakery products.

2.3 Fat Content

The fat content of cookies showed a slight but statistically significant increase with increasing levels of paneer whey incorporation. Fat content increased from 22.23% in the control formulation to 24.53% in cookies prepared with 100% paneer whey, while intermediate treatments exhibited gradual increases corresponding to the proportion of whey used in dough preparation.

The increase in fat content can be explained by the presence of residual milk fat naturally occurring in paneer whey. Although whey contains only a small quantity of fat, progressive replacement of water with whey introduces additional milk lipids into the formulation. Furthermore, interactions between milk proteins and shortening during dough preparation may enhance fat retention within the baked product, contributing to the slight increase observed in the final cookies.

Fat plays a crucial role in determining the eating quality of cookies by improving tenderness, mouthfeel, flavour release, and overall palatability. Consequently, the slight increase in fat content observed in whey-incorporated cookies may have contributed to the improved sensory scores for flavour, body, texture, and overall acceptability recorded in the sensory evaluation.

The present findings agree with Mahmoud *et al.* (2008), who reported comparable increases in fat content following enrichment of cookies with protein-rich ingredients. Similar observations have also been reported in bakery products fortified with dairy proteins, where residual milk fat contributes modestly to the total lipid content while enhancing product quality.

Although the increase in fat content was relatively small, it reflects the successful incorporation of nutritionally valuable milk constituents into the product. Importantly, this enhancement was achieved through the utilization of paneer whey, a dairy by-product that is frequently discarded despite its nutritional value. Therefore, incorporation of paneer whey not only improves the compositional quality of cookies but also promotes sustainable utilization of dairy processing residues.

The results indicate that paneer whey can be effectively incorporated into cookie formulations without causing undesirable changes in lipid composition while simultaneously improving the nutritional and sensory quality of the final product.

2.4 Ash Content

Ash content is an important indicator of the total mineral composition of food products and reflects the contribution of inorganic nutrients present in the formulation. In the present study, ash content increased significantly with increasing levels of paneer whey incorporation, rising from 0.48% in the control cookies (T_0) to 1.09% in cookies prepared with complete replacement of water by paneer whey (T_4). Intermediate treatments also exhibited a progressive increase in ash content, demonstrating a direct relationship between whey incorporation and mineral enrichment of the cookies. Statistical analysis indicated that the differences among treatments were highly significant ($P \leq 0.05$), confirming that paneer whey significantly influenced the mineral composition of the developed products.

The increase in ash content is attributed to the naturally occurring minerals present in paneer whey, particularly calcium, phosphorus, potassium, sodium, and magnesium, which remain in the liquid fraction after coagulation of milk proteins during paneer manufacture. Unlike water, paneer whey contributes these soluble minerals directly to the cookie dough, resulting in greater mineral retention after baking.

Minerals play essential roles in numerous physiological functions, including bone mineralization, muscle contraction, enzyme activation, and maintenance of electrolyte balance. Therefore, the increase in ash content observed in the whey-incorporated cookies reflects an improvement in the nutritional quality of the product rather than merely a compositional change. The findings indicate that paneer whey can serve as a natural source of minerals in bakery formulations without the need for external mineral fortification.

The present results are in agreement with Mahmoud (2003) [13], who reported higher ash content in composite flour biscuits compared with wheat flour biscuits owing to the greater mineral contribution from the supplemented ingredients. Similar observations were reported by Gallagher *et al*. (2005) [7], who found that biscuits enriched with whey protein concentrate and casein exhibited significantly higher ash content than control biscuits. Furthermore, Visalakshi and Mohansundari (2002) [21] demonstrated that incorporation of whey into biscuits, cheese biscuits, and pizza resulted in progressive increases in mineral content with increasing levels of whey supplementation.

From the viewpoint of sustainable food utilization, enhancement of mineral content through paneer whey incorporation represents an efficient strategy for recovering valuable nutrients that might otherwise be lost during whey disposal. Instead of being treated as an industrial waste stream, paneer whey can therefore be utilized as a nutrient-rich ingredient for the development of value-added bakery products. This approach improves nutritional quality while simultaneously promoting resource conservation and reducing environmental burden associated with dairy by-products.

Overall, the results demonstrate that paneer whey significantly improved the mineral composition of cookies and can be effectively utilized as a natural mineral-enriching ingredient in bakery products.

2.5 Carbohydrate Content

Total carbohydrate content of the cookies decreased progressively as the level of paneer whey incorporation increased. The carbohydrate content declined from 62.11% in the control treatment (T_0) to 53.15% in cookies prepared with complete replacement of water by paneer whey (T_4), with intermediate treatments exhibiting proportional reductions. Statistical analysis revealed that the differences among treatments were highly significant ($P \leq 0.05$), indicating that whey incorporation significantly influenced the proximate composition of the developed cookies. The reduction in carbohydrate content is primarily a consequence of the corresponding increases in moisture, protein, fat, and ash contents following whey incorporation. Since carbohydrate content was calculated by difference, increases in these proximate constituents resulted in a proportional decrease in calculated carbohydrate percentage. Thus, the observed reduction does not represent a loss of carbohydrates during processing but rather reflects an improvement in the overall nutritional balance of the product.

Replacement of water with paneer whey introduced additional proteins and minerals into the dough formulation, thereby altering the relative distribution of nutrients in the final baked product. Consequently, the developed cookies exhibited greater nutrient density, characterized by higher concentrations of protein and minerals together with comparatively lower carbohydrate content.

The present findings agree with those reported by Singh *et al*. (2007) [18], who observed a reduction in carbohydrate content following protein enrichment of cookies. Similarly, Wani *et al*. (2015) [22] reported that supplementation of cookies with whey protein concentrate significantly decreased carbohydrate content while improving the nutritional composition of the final product.

Although cookies are traditionally regarded as carbohydrate-rich bakery products, partial reduction in carbohydrate content accompanied by enrichment of protein and minerals may enhance their nutritional value. Such modifications are increasingly desirable in the development of functional bakery products intended to provide improved nutrient composition without compromising consumer acceptability.

The findings of the present investigation therefore indicate that paneer whey can successfully improve the nutritional profile of cookies by increasing the proportion of nutritionally important components while reducing the relative carbohydrate fraction. This compositional improvement further supports the utilization of paneer whey as a sustainable functional ingredient for value-added bakery applications.

3. Effect of Paneer Whey Incorporation on Calorific Value

The calorific value in Table 4 of cookies is determined by the combined contribution of protein, fat, and carbohydrates and represents the total metabolizable energy available from the product. In the present investigation, calorific values were calculated using the Atwater conversion factors (4 kcal

g^{-1} for protein, 9 kcal g^{-1} for fat, and 4 kcal g^{-1} for carbohydrates). The calculated calorific value decreased gradually from 484.84 kcal/100 g in the control cookies (T_0) to 473.19 kcal/100 g in cookies prepared with complete replacement of water by paneer whey (T_4). The differences among treatments were statistically highly significant ($P \leq 0.05$).

The reduction in calorific value can be explained by the decrease in carbohydrate content observed with increasing whey incorporation. Although fat content increased slightly, the reduction in carbohydrate concentration together with changes in moisture content compensated for the additional energy contributed by fat, resulting in a modest overall decline in total calorific value.

The results indicate that incorporation of paneer whey improved the nutritional composition of cookies without increasing their energy density. This finding is particularly important because it demonstrates that nutritional enhancement can be achieved without producing a substantially more energy-dense bakery product. Therefore, paneer whey contributes to improved nutrient quality rather than simply increasing calorie content. The present findings are consistent with those of Akubor (2003) [1], who applied the Atwater system for calculating the energy value of cookies based on proximate composition. Similar observations were reported by Wani *et al.* (2015) [22], who found that increasing supplementation of whey protein concentrate in cookies resulted in a reduction in calorific value due to changes in proximate composition.

From a nutritional standpoint, the slight reduction in calorific value accompanied by increases in protein and mineral contents indicates improved nutrient density of the developed cookies. Such products may provide better nutritional quality while maintaining the desirable sensory characteristics expected of conventional bakery products. Consequently, utilization of paneer whey offers a practical strategy for developing nutritionally enhanced bakery products through efficient recovery of valuable dairy nutrients.

Overall, the calorific evaluation confirms that paneer whey can be successfully incorporated into cookie formulations to improve nutritional quality while maintaining an acceptable energy value, thereby supporting its application as a sustainable functional ingredient in bakery product development.

Table 3: Effect of paneer whey incorporation on the proximate composition of cookies

Treatment (Whey: Water)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Total Solids (%)	Carbohydrate (%)
T_0 (0:100)	6.11 ± 0.02	9.07 ± 0.01	22.23 ± 0.03	0.48 ± 0.01	93.89 ± 0.02	62.11 ± 0.04
T_1 (25:75)	7.12 ± 0.03	9.10 ± 0.02	22.52 ± 0.04	0.68 ± 0.01	92.88 ± 0.03	60.59 ± 0.03
T_2 (50:50)	8.12 ± 0.02	9.11 ± 0.01	22.83 ± 0.02	0.86 ± 0.02	91.88 ± 0.02	59.07 ± 0.05
T_3 (75:25)	9.92 ± 0.03	9.19 ± 0.02	23.06 ± 0.03	1.04 ± 0.01	90.08 ± 0.03	56.64 ± 0.04
T_4 (100:0)	11.32 ± 0.02	9.92 ± 0.01	24.53 ± 0.04	1.09 ± 0.02	88.68 ± 0.02	53.15 ± 0.03
SEm	0.88	0.45	0.41	0.74	0.48	0.70
CD ($P \leq 0.05$)	0.27	0.14	1.23	0.22	1.46	0.21

Table 4: Effect of paneer whey incorporation on calorific value of cookies

Treatment	Protein Energy (kcal)	Fat Energy (kcal)	Carbohydrate Energy (kcal)	Total Energy (kcal/100 g)
T_0	36.36	200.09	248.43	484.84
T_1	36.58	202.20	242.34	481.33
T_2	36.46	205.47	236.34	476.72
T_3	36.81	207.62	228.63	471.48
T_4	39.78	220.79	217.29	473.19
SEm	0.047	0.25	0.92	0.53
CD ($P \leq 0.05$)	0.14	0.77	2.76	1.60

4. Sustainability and Industrial Significance of Paneer Whey Utilization

The dairy industry generates substantial quantities of whey during the manufacture of paneer, cheese, and other coagulated milk products. Although whey contains valuable nutrients, including high-quality proteins, lactose, vitamins, and minerals, a considerable proportion is still discarded as waste, particularly by small- and medium-scale dairy enterprises. Disposal of untreated whey is associated with environmental concerns because of its high organic load, which contributes to elevated biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Therefore, the development of practical strategies for whey utilization is essential for promoting sustainable dairy processing.

The results of the present study clearly demonstrate that paneer whey can be effectively utilized as a replacement for water in cookie preparation without adversely affecting product quality. On the contrary, complete replacement of water with paneer whey (T_4) produced cookies with superior sensory acceptability and improved nutritional composition. Sensory evaluation showed that cookies prepared with 100% paneer whey received the highest scores for colour, body and texture, taste and flavour, and overall acceptability, indicating excellent consumer acceptance. Similarly, incorporation of paneer whey significantly increased protein, ash, moisture, and fat contents while reducing carbohydrate content, thereby improving the nutritional profile of the developed product.

These findings highlight that paneer whey functions not merely as a substitute for water but as a multifunctional food ingredient capable of enhancing both nutritional and technological properties of bakery products. The natural presence of whey proteins contributes to improved protein quality, while lactose promotes desirable colour and flavour development through Maillard browning during baking. Furthermore, soluble minerals retained in whey increase the mineral content of the final product, demonstrating efficient recovery of nutrients that would otherwise be lost during whey disposal.

From an industrial perspective, the proposed technology is simple, economical, and readily adaptable by bakeries and dairy processing units. Since the method involves direct replacement of water with fresh paneer whey, no specialized equipment or expensive processing technologies are required. This makes the approach particularly suitable for cottage industries, dairy cooperatives, and small-scale food processors, where utilization of liquid whey remains a significant challenge.

The utilization of paneer whey in bakery products also contributes to resource efficiency by converting an underutilized dairy by-product into a value-added food ingredient. Such approaches reduce waste generation, improve utilization of available nutrients, and create opportunities for the development of functional foods with enhanced nutritional value. In addition, production of whey-incorporated cookies may provide dairy industries with an alternative outlet for surplus whey, thereby improving the economic value of dairy processing operations.

Overall, the present investigation demonstrates that incorporation of paneer whey into cookies represents an effective strategy for improving product quality while simultaneously promoting sustainable utilization of dairy by-products. The technology developed in this study offers a practical and economically feasible approach for transforming a nutrient-rich processing by-product into an acceptable bakery product, thereby supporting sustainable food production and value addition within the dairy sector.

Conclusion

The present study demonstrated that paneer whey can be successfully utilized as a functional ingredient in cookie production by replacing water at different incorporation levels. Progressive incorporation of paneer whey significantly influenced both the sensory and nutritional characteristics of the developed cookies. Cookies prepared with complete replacement of water by paneer whey (T_4) exhibited the highest scores for colour, body and texture, taste and flavour, and overall acceptability, indicating excellent consumer acceptance. The improved sensory quality can be attributed to the functional properties of whey proteins and lactose, which contributed to desirable colour development, flavour enhancement, and improved textural characteristics during baking.

Incorporation of paneer whey also resulted in significant improvements in the proximate composition of cookies. Moisture, protein, fat, and ash contents increased with increasing levels of whey incorporation, whereas carbohydrate content decreased proportionally. The enhancement in protein and mineral contents demonstrates that paneer whey serves as an effective source of nutritionally valuable components, thereby improving the overall nutritional quality of the developed product. Furthermore, the calorific value of the cookies decreased slightly with increasing whey incorporation, indicating that nutritional enrichment was achieved without increasing the energy density of the product.

The findings of the present investigation confirm that paneer whey functions not only as a substitute for water but also as a multifunctional food ingredient capable of improving the technological, sensory, and nutritional properties of bakery products. From a sustainability perspective, direct utilization of fresh paneer whey provides an efficient approach for recovering valuable nutrients that are frequently lost through disposal. This strategy contributes to value addition, resource conservation, and improved utilization of dairy by-products while offering a practical solution for reducing environmental concerns associated with whey disposal.

The simple processing technique employed in this study can be readily adopted by small-scale dairy industries, bakeries, and cottage food enterprises without requiring sophisticated equipment or costly processing technologies. Therefore, utilization of paneer whey in cookie production represents an economically feasible and environmentally sustainable approach for developing value-added bakery products with enhanced nutritional quality.

Based on the sensory, physicochemical, and nutritional evaluation, complete replacement of water with paneer whey (100% whey incorporation) was identified as the most suitable formulation for the preparation of acceptable-quality cookies. The study highlights the potential of paneer whey as a valuable dairy ingredient and supports its wider application in bakery product development as an effective strategy for sustainable food processing and dairy by-product valorization.

Future Perspectives

Future investigations may evaluate the storage stability, microbiological quality, texture profile, antioxidant properties, mineral bioavailability, and consumer acceptance of paneer whey-incorporated cookies under commercial storage conditions. Additionally, the utilization of paneer whey in other bakery products such as biscuits, crackers, cakes, muffins, and bread may further expand its industrial applications and contribute to the development of sustainable dairy-based functional foods.

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