DEVELOPMENT AND CHARACTERIZATION OF PROTEIN RICH MILK BASED BEVERAGE AS A MEAL REPLACEMENT DRINK

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Abstract: A meal replacement is a formulated food or beverage designed to substitute a regular meal while providing balanced amounts of essential nutrients such as proteins, carbohydrates, fats, vitamins, and minerals. Increasing busy lifestyles have created a growing demand for convenient and nutritionally balanced foods. This study aimed to develop and characterize a protein-rich milk-based ready-to-drink beverage as a balanced meal replacement. The beverage was prepared using skim milk, milk protein concentrate (MPC), and micellar casein concentrate (MCC) with added dietary fiber, stabilizers, and sweeteners. MCC contains about 80–90%, MPC contains around 70–85% protein, and skim milk contains approximately 3.3–3.5% protein**.** The research method used an experiment using a completely randomized design, Four base formulation trials were conducted, and Trial 4 (65% skim milk, 10% MPC, and 4% MCC) showed lower sedimentation and improved mouthfeel, making it the optimized formulation. Flavour optimization using lychee and ginger flavor showed that Trial 2 (4% lychee pulp) achieved the highest overall acceptability score (4.2), providing a balanced fruity flavour and mild ginger warmth. The optimized beverage exhibited physicochemical properties of pH 6.65 ± 0.01, Brix 16.2 ± 0.2, titratable acidity 0.15± 0.01%, sedimentation index 1.2 ± 0.04%, dietary fiber 1.8 ± 0.1g/100ml, with a nutritional composition of protein 12.74g/100 mL, fat 4.02g/100 ml, and carbohydrates 10g/100 ml. Based on the microbiological results, Trial 2 revealed a shelf-life of 14 days under refrigerated storage. The developed beverage showed good nutritional composition, sensory acceptance, stability provides approximately 24 g protein per 200 mL serving, meeting about 40% of the recommended daily protein intake
.

***Key words*: meal replacement, protein, skim milk, MCC, MPC, sedimentation, dietary fiber**

I. INTRODUCTION

Meal replacement beverages are formulated to provide balanced nutrition in a convenient form and are designed to substitute a regular meal while supplying essential nutrients including carbohydrates, proteins, fats, vitamins, and minerals. The popularity of these beverages has increased due to evolving lifestyles and demanding daily routines, busy schedules, and growing health awareness among consumers[1]. They are also considered a practical dietary option for individuals seeking weight management, improved nutrition, or convenient meal alternatives.

Milk proteins are widely used in the development of high-protein beverages because of their excellent nutritional value and functional properties. Dairy ingredients such as skim milk, milk protein concentrate (MPC), micellar casein concentrate (MCC), and whey proteins are valuable sources of high-quality protein and amino acids, as it plays an important role in supporting muscle maintenance and overall health [2]. In beverage formulations, these milk proteins also contribute to improving stability, mouthfeel, and texture, in addition to their nutritional benefits. However, the formulation of high-protein milk beverages presents certain challenges, particularly related to protein solubility, rehydration properties, and sedimentation during storage. The rehydration behaviour and stability of dairy protein powders significantly influence the quality and acceptability of the final product [3]. Recent developments in dairy protein ingredients, such as micellar casein powders, have improved functional characteristics and enhanced beverage formulation possibilities [4].

The development of a cost-effective, protein-rich milk-based beverage that can serve as a nutritionally balanced meal replacement is of significant interest. Such products can provide essential nutrients while offering convenience and improved dietary intake for consumers.

II. MATERIALS AND METHODS

2. 1 Procurement of Raw Materials

The materials used for the preparation of the protein-rich milk-based beverage included skim milk, milk protein concentrate (MPC), micellar casein concentrate (MCC), wheat fiber, polydextrose, palm oil, inulin, lysine, and sucralose. Stabilizers such as xanthan gum and locust bean gum, potassium citrate as a buffering agent, and soy lecithin as an emulsifier were also used. Lychee pulp along with lychee and ginger flavors were added to improve the sensory quality of the beverage. were obtained from online sources and local markets in Nilambur, Malappuram 676505.

2.2. Base Optimisation

The base formulation was optimized through four preliminary trials by varying the proportions of skim milk, milk protein concentrate (MPC), and micellar casein concentrate (MCC). Trial 1 showed good stability with minimal sedimentation, Trial 2 exhibited chalkiness due to higher MPC, and Trial 3 showed high sedimentation attributed to increased MCC. Trial 4 showed improved viscosity with lower sedimentation and was selected as the optimized base formulation for further studies. The formulation used for base optimization is shown in Table 1.

Table 1. Optimization of Base Formulation Trials

Ingredients	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Skim milk	80%	70%	70%	65%
Mpc	10%	20%	10%	10%
Mcc	5%	5%	15%	4%

2.3 Flavor Optimisation

Flavor optimization trials were conducted to evaluate the sensory characteristics of the beverage. Trial 1 showed strong lychee flavor with higher sedimentation, while Trial 2 formulation exhibited a mild fruity note with slight ginger warmth and stable pH. Trial 3 had reduced fruity notes with a dominant ginger flavor. Among formulations, Trial 2 has highest acceptability (4% lychee pulp,0.2 % lychee flavor, 0.15%ginger flavor). The flavor optimization trials are presented in Table 2.

Table 2. Optimization of Flavor Trials

Ingredients	**Trial 1**	**Trial 2**	**Trial 3**
Lychee pulp	5%	4%	3%
Lychee flavour	0.3%	0.2%	0.2%
Ginger flavour	0.15%	0.15%	0.2%

2.4 Formulation and Preparation of Beverage

The optimized formulation of beverage used in the experimental trials are summarized in Table 3.

Table 3. Optimized Formulation of beverage

Ingredients	**Quantity/100gm**
Skim Milk	64
MPC	10
MCC	4
Sucralose	0.02
Pottasium Citrate	0.15
wheat fibre	0.5
xantham gum	0.03
poludextrose	2
locus bean gum	0.07
palm oil	3.5
soy lecithin	0.2
inulin	1.5
lysein	0.1
lychee pulp	4
lychee flavor	0.2
ginger flavor	0.15

The protein-rich milk-based beverage was prepared using a standardized processing method commonly applied in dairy beverage production. Initially, skim milk was heated to 50–55 °C to facilitate proper dispersion of proteins and other dry ingredients[5]. Potassium citrate was added as a buffering agent to maintain stable pH., MPC, MCC, wheat fiber, and polydextrose they were slowly incorporated with continuous mixing to avoid lump formation and to achieve uniform distribution of the ingredients [2]. Palm oil was then slowly incorporated along with soy lecithin to promote emulsification and improve the stability. Stabilizers, including xanthan gum and locust bean gum, were incorporated under high-speed mixing at approximately 2000 rpm to improve the viscosity of the beverage and minimize sediment formation [1]. The mixture was subsequently homogenized at approximately 60 °C to achieve a uniform emulsion and improve the texture of the final product. The mixture was cooled to 4 °C, after which sucralose was added and the beverage was homogenized again to ensure uniform distribution. Then, lychee pulp and flavoring agents were incorporated into the formulation. The final beverage was cooled to approximately 8 °C, packaged, and stored at 4 °C for further physicochemical, sensory, and microbiological analysis.

Weighing of all dry ingredients separately
↓
Heating milk to 50–55°C
↓
Addition of potassium citrate and mixing
↓
Gradual addition of mpc, mcc wheat fiber and polydextrose with continuous mixing(to avoid lump formation)
↓
Slow incorporation of palm oil + addition of soy lecithin with agitation
↓
Addition of xanthan gum and locust bean gum with high-speed mixing 2000 rpm at (55–60°C)
↓
Cooling and holding in refrigerator (4°C)
↓
Addition of sucralose
↓
Homogenization (60 C)
↓
Addition of pulp and flavor
↓
Cooled to 8 C , Packed and stored in 4 C

Fig 1 Flowchart for Preparation of Beverage

III. RESULT AND DISCUSSSION

3.1 Evaluation of Physicochemical, Nutritional, and Functional Parameters

The proximate composition of formulations containing 3%, 4%, and 5% fruit pulp, along with the control sample, is presented in Table 4. The nutritional analysis results are presented as a line graph in Figure 2.

3.1.1 pH

The pH was 6.65 ± 0.01, within the acceptable range for dairy-based formulations. The increase in pH due to potassium citrate indicates effective buffering and improved protein stability, preventing coagulation during processing and storage. Maintaining pH in the range of 6.5–6.8 is critical for stability in milk-based systems.[6].

3.1.2 Brix

The total soluble solids of the optimized beverage were 16.2 ± 0.2 Brix, which was higher compared to control sample, indicating an increased concentration of dissolved constituents contributing to sweetness and mouthfeel. This higher Brix reflects improved formulation balance and enhances the overall consistency and sensory quality of the beverage.

3.1.3 Titratable Acidity (%)

The titratable acidity increased linearly from 0.11% to 0.17% across trials, directly reflecting the higher concentration of natural organic acids introduced by the increased lychee pulp. Trial 2 (4% pulp) achieved an optimal acidity of 0.15%, which provided a balanced flavor profile by complementing the ginger warmth without the excessive tartness found in Trial 1.To maintain physical stability, potassium citrate was utilized as a buffering agent, ensuring these rising acid levels did not destabilize the milk protein network or cause curdling.

3.1.4 Sedimentation Index (%)

The base was highly stable at 0.4 ± 0.1%. Higher pulp concentrations led to significantly more sedimentation, with Trial 1 (5% pulp) showing the poorest stability at 2.8 ± 0.2%, while Trial 2 (4% pulp) and Trial 3 (3% pulp) recorded much lower sedimentation levels of 1.2 ± 0.1% and 0.6 ± 0.1%, respectively. This reflects efficient dispersion of suspended particles and a stable colloidal system.

3.1.5 Dietary Fiber (%)

The dietary fiber was standardized at 1.8% using a blend of wheat fiber, polydextrose, and inulin to enhance satiety and digestive health.[7], this fiber matrix acts as a functional bulking agent that mimics a creamy mouthfeel, offsetting the natural thinness of the skim milk base. This synergy explains why Trial 2 achieved a high sensory viscosity score of 4.4, delivering a satisfyingly thick texture despite its low-fat profile.

3.1.6 Protein (%)

The protein content was standardized at 12.74% using a blend of skim milk, MPC, and MCC to provide essential amino acids that support muscle preservation and improve fullness. the specific dairy protein ratio balances high nutritional density with physical stability, preventing the "chalky" mouthfeel common in RTD beverages [1]. These results indicate that appropriate standardization is essential to achieving a high-protein profile that ensures both nutritional adequacy and consumer acceptability.

3.1.7 Carbohydrate (%)

The carbohydrate content was standardized at 10% to provide a balanced energy release from milk-derived lactose and added sucrose. the specific concentration ensures the necessary caloric density for a meal replacement without causing the excessive sweetness or syrupy texture that can reduce consumer acceptability [8].

3.1.8 Fat (%)

By blending skim milk with vegetable oils, we achieved a fat content of 4.02 % that meets RDI guidelines for a nutritionally complete meal. This specific combination ensures a smooth, creamy texture and provides the essential energy needed to aid the absorption of fat-soluble vitamins.

3.1.9 Overall interpretation

The Trial 4 formulation achieved a high-protein concentration of 12.74%, a carbohydrate level of 10 %, a fat content of 4.02%, and a dietary fiber level of 1.8% by blending skim milk, MPC, MCC, and vegetable oils. This optimized profile meets RDI guidelines, providing the balanced caloric density and amino acids required for a complete meal replacement.

Table 4 Physicochemical, Nutritional, and Functional Parameters

Parameter	**Base**	**Tria1(5% pulp)**	**Trial 2(4% pulp)**	**Trial 3(3% pulp)**
pH	6.80±0.02	6.45 ± 0.02	6.45 ± 0.02	6.75 ± 0.02
°Brix	14.8±0.2	17.5 ± 0.3	16.2 ± 0.2	15.8 ± 0.2
Titratable Acidity (% lactic acid)	0.11±0.01	0.17 ± 0.01	0.15 ± 0.01	0.13 ± 0.01
Sedimentation Index (%)	0.4±0.1	2.8 ± 0.2	1.2 ± 0.1	0.6 ± 0.1
Dietary Fibre (%)	1.8 ± 0.1	1.8 ± 0.1	1.8 ± 0.1	1.8 ± 0.1
Protein (%)	12.71	12.75	12.74	12.74
Fat (%)	4.02	4.02	4.02	4.02
Carbohydrate (%)	9.6	10.4	10	9.5

Data are expressed as mean ± standard deviation of three replicates. Means in the same column with identical letters indicate no significant difference at $p \geq 0.05$ based on Tukey's test.

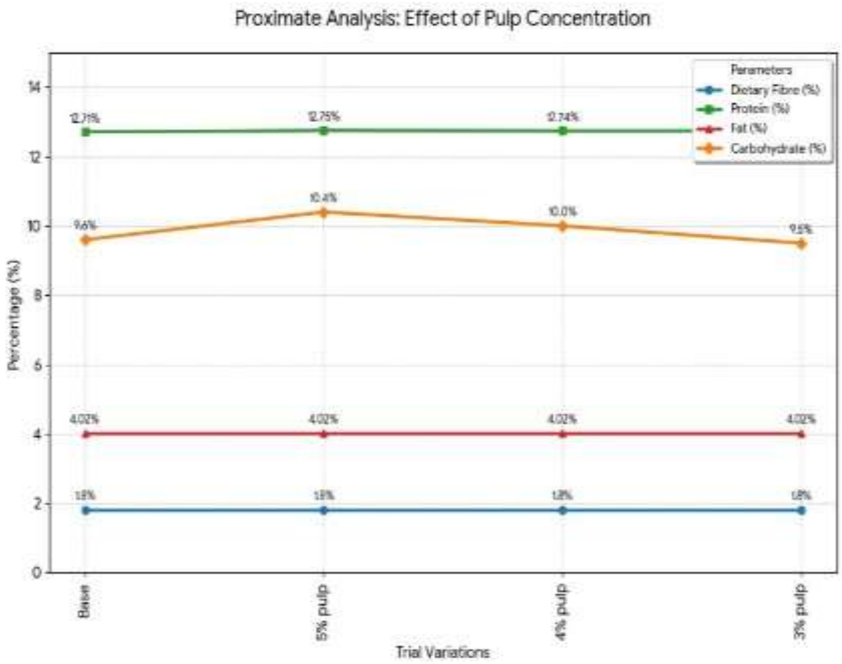

Fig 2: Nutritional analysis values for the control and the three formulations

3.2 Microbial Analysis

The microbial stability of the protein-rich milk-based beverage was monitored through Total Plate Count (TPC) analysis over a 30-day storage period at 4°C to determine its refrigerated shelf life .In microbiological safety standards for dairy-based beverages, a 6.0 log CFU/mL (or 10^6 CFU/mL) is generally considered the borderline threshold for microbial spoilage, beyond which the product is deemed unacceptable for consumption. The microbial parameters and Total Plate Count (TPC) values of the beverage recorded during the 30-day storage period at 4°C are detailed in Table 5, with the corresponding growth trends illustrated in the line graph shown in Figure 3. As shown in data , the base sample remained below this spoilage limit until the 30th day, where it reached 6.8 log CFU/g. However, the flavored trials exceeded this borderline value much earlier; specifically, Trial 1 (5% pulp) and Trial 2 (4% pulp) reached the 6.8 and 6.0 log CFU/g limit by the 14th day of storage, effectively marking the end of their shelf life . By the 21st day, all flavored formulations (T1, T2, and T3) had significantly surpassed the borderline value, with Trial 1 reaching as high as 8.5 log CFU/g. indicating that the nutrient-dense environment provided by the milk proteins and fruit sugars supports rapid proliferation after the two-week mark.

Table 5: Total Plate Count (10^4 log CFU/g) of milk-based beverage trials during 30 days of refrigerated storage).

TOTAL PLATE COUNT (1O^4 log CFU/g)				
STORAGE DAYS	**BASE**	**T1(5% PULP)**	**T2(4% PULP)**	**T3(3% PULP)**
P+0	1.5	2.5	2.2	2
P+7	2.2	4.2	3.8	3.2
P+14	3.5	6.8	6	5.2
P+21	4.8	8.5	7.5	6.5
P+30	6.8	9.2	8.4	7.6
FEEDBACK	From 0th day to 30th day the microbial load was increased at 4°C and shows a spoilage at 21st day itself			

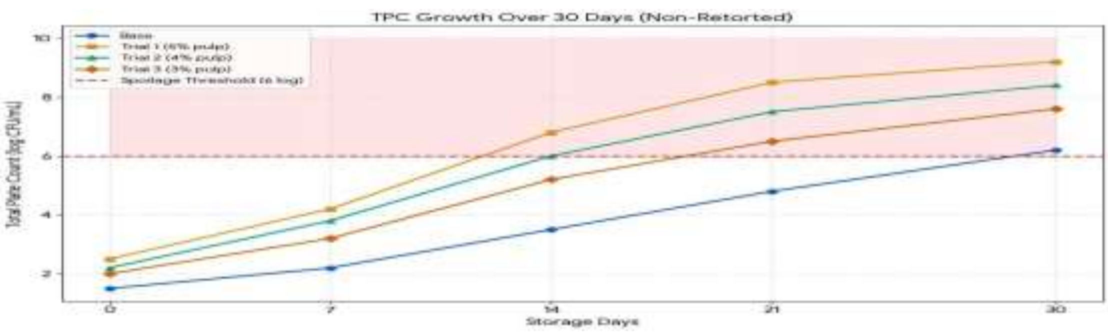

Figure 3: Effect of storage time on Total Plate Count (10^4 log CFU/g) of formulated beverage.

3.3 Sensory Analysis

The sensory profile of the protein-rich milk-based beverage was evaluated using a 9-point Hedonic scale, with detailed results for all trials provided in Table 6 and overall acceptability score illustrated in Figure 4. Among the variations, Trial 2 (4% lychee pulp) was clearly the panel's favourite, achieving the highest overall acceptability score of 4.2 due to its refreshing fruit notes and well-balanced ginger warmth. In contrast, Trial 3 (3% pulp) was overshadowed by a dominant ginger flavor (scoring 4.0), while Trial 1 (5% pulp) received the lowest score of 3.8 because it felt too thick and showed some sedimentation. These differences likely happened because the extra fruit in Trial 1 made the drink more acidic, which slightly destabilized the milk proteins and changed the texture. Ultimately, Trial 2 hit the sweet spot, providing the perfect harmony between flavor and consistency for a high-protein drink.

Table 6 Sensory Evaluation of Each Trial

Attributes	Trial 1(5% pulp)	Trial 2(4% pulp)	Trial 7(3% pulp)
Aroma	4	4	4.3
Taste	3.6	4.4	3.8
Colour	4.5	4.3	4.0
Overall mouth feel	3.5	4.3	3.6
Viscosity	3.6	4.4	4.6
Overall acceptability	3.8	4.2	4

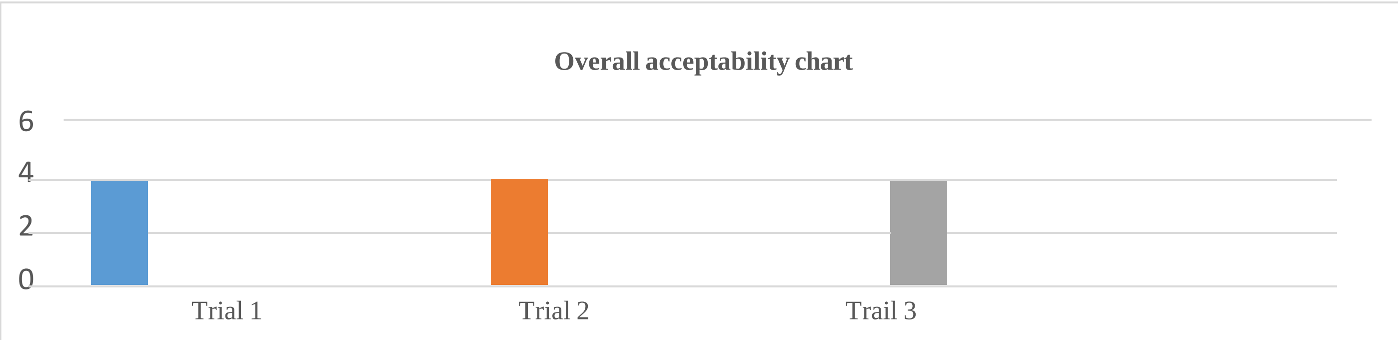

Fig 4 Overall acceptability of various formulations

IV. CONCLUSION

This study successfully developed a nutritionally dense meal replacement beverage, with Trial 2 identified as the optimized formulation. achieving a superior overall acceptability score of 4.2 due to its balanced flavor profile, providing a fruity flavour and mild ginger warmth also containing 12.74% protein, 4.0% fat, 10% carbohydrates, and 1.8% dietary fiber. Technical analysis revealed a Brix value of 16.2% pH value of 6.65 and a titratable acidity of 0.15%, reflecting a well-balanced sugar-to-acid ratio that contributed to the product's high sensory scores. Based on these values, the beverage effectively aligns with the Recommended Daily Intake (RDI) standards for a meal replacement, providing a concentrated source of high-quality proteins and essential macronutrients. However, a significant challenge remains regarding its stability; while the base sample showed extended durability, the flavored trials reached the 6.0 log CFU/g spoilage threshold by the 14th day of refrigerated storage. Therefore, Trial 2 successfully meets nutritional RDI targets, its current 14-day refrigerated shelf life indicates a need for enhanced preservation techniques to improve commercial viability

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