Development and Nutritional Assessment of a Plant Protein-Based High-Protein Supplement for Dialysis Patients

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ABSTRACT

Chronic kidney disease (CKD) patients undergoing dialysis are at high risk of protein-energy malnutrition due to increased nutrient losses and dietary restrictions, necessitating the development of cost-effective and nutritionally adequate supplements. The present study aimed to develop a plant protein-based high-protein supplement using lentil, soybean, chickpea flour, and flaxseed, and to evaluate its nutritional composition, sensory acceptability, and statistical significance. Four formulations (T1–T4) were prepared with varying proportions of ingredients. Proximate analysis revealed a significant increase in protein content with higher soybean incorporation, with T3 (30% lentil, 40% soybean) showing an optimal balance of protein (28.5%), fat, and energy. Sensory evaluation using a 9-point hedonic scale indicated high acceptability, with T3 scoring the highest across all attributes. Statistical analysis (ANOVA) confirmed significant differences ($p < 0.05$) among formulations. The findings suggest that the developed plant-based supplement is a nutritionally viable, affordable, and acceptable option for dietary management of dialysis patients.

Keywords: Plant-based protein supplement; Chronic kidney disease; Dialysis nutrition; Proximate analysis; Sensory evaluation; Soybean and lentil formulation.

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Introduction

Chronic kidney disease (CKD) is a growing global health concern, particularly in low- and middle-income countries like India (Muxunov et al., 2026). Patients undergoing dialysis require higher protein intake (1.0–1.2 g/kg/day) due to amino acid losses during dialysis (Davenport, 2026). However, conventional protein supplements are often expensive and animal-based, limiting accessibility (Tuna and Ersoy, 2026).

Plant-based protein sources such as lentils, soybean, chickpeas, and flaxseeds offer a sustainable and economical alternative (Kumar et al., 2026). These ingredients are rich in essential amino acids, dietary fibre, antioxidants, and bioactive compounds (Álvarez-Chávez et al., 2025). Soybean provides high-quality protein with a complete amino acid profile, while lentils contribute lysine and micronutrients like iron and folate (Kumar et al., 2025).

This study focuses on developing a plant protein-based supplement suitable for dialysis patients and evaluating its nutritional composition, sensory properties, and statistical significance.

Materials and Methods

Study Design

An experimental study design was adopted to develop and evaluate plant-based protein supplements.

Sample Collection

Raw materials used for the formulation of the plant protein-based supplement were procured from local markets to ensure accessibility and cost-effectiveness. The selected ingredients included lentils (*Lens culinaris*), soybean (*Glycine max*), chickpea flour (*Cicer arietinum*), and flaxseed powder (*Linum usitatissimum*), all of which are recognized for their high nutritional value and protein content. The raw materials were carefully inspected to remove

impurities, followed by thorough cleaning and drying under hygienic conditions. Subsequently, the ingredients were processed and milled into fine flour to achieve uniform particle size, ensuring better mixing, improved texture, and enhanced digestibility of the final product.

Preparation of Raw Materials

All selected raw materials were processed under hygienic laboratory conditions to enhance their nutritional quality, safety, and functional properties. Lentils were thoroughly washed to remove dirt and impurities, followed by drying and roasting to improve flavor and reduce moisture content; they were then ground into fine flour. Soybeans were soaked to facilitate dehulling, after which the seed coats were removed. The dehulled soybeans were roasted to inactivate anti-nutritional factors such as trypsin inhibitors and then finely powdered. Flaxseeds were lightly roasted to enhance aroma and improve digestibility before being ground into powder. Chickpea flour was procured in ready-to-use form and utilized without further processing. All prepared flours were stored in airtight containers until further use to maintain quality and prevent contamination.

Treatment Combination

Four different formulations of the plant protein-based supplement were developed by varying the proportions of lentil and soybean while keeping chickpea flour (20%) and flaxseed powder (10%) constant. In formulation T1, lentil and soybean were incorporated at 40% and 30%, respectively, whereas T2 contained equal proportions of lentil and soybean (35% each). In T3, the soybean content was increased to 40% with a corresponding reduction in lentil to 30%, and in T4, soybean was further increased to 45% while lentil was reduced to 25%. This systematic variation allowed for the evaluation of the impact of increasing soybean levels on the nutritional composition and sensory properties of the developed supplement, particularly focusing on enhancing protein content while maintaining overall acceptability.

Methods of Analysis

1. Proximate Analysis

The proximate composition of the developed plant protein-based supplement formulations was determined using standard methods recommended by the Association of Official Analytical Chemists (AOAC). Moisture content was estimated by oven drying the samples at a controlled temperature until a constant weight was achieved. Crude protein content was determined using the Kjeldahl method, which involves digestion, distillation, and titration to quantify total nitrogen, subsequently converted into protein using an appropriate conversion factor. Crude fat was analyzed using the Soxhlet extraction method with a suitable organic solvent to extract lipid content. Ash content, representing total mineral content, was determined by incinerating the samples in a muffle furnace at high temperature until complete combustion of organic matter. Carbohydrate content was calculated by difference, subtracting the sum of moisture, protein, fat, and ash from the total weight of the sample. All analyses were carried out in triplicate to ensure accuracy and reproducibility of results.

2. Sensory Evaluation

Sensory evaluation of the developed plant protein-based supplement formulations was conducted using a 9-point hedonic scale to assess consumer acceptability. A panel of 20 semi-trained members was selected to evaluate the samples under controlled conditions. Each panelist was provided with coded samples to avoid bias and was instructed to rate them based on specific sensory attributes, including colour, taste, aroma, texture, and overall acceptability. The hedonic scale ranged from 1 (“dislike extremely”) to 9 (“like extremely”). Adequate intervals were maintained between sample evaluations, and drinking water was provided to cleanse the palate. The collected scores were tabulated and subjected to statistical analysis to determine significant differences among the formulations.

3. Statistical Analysis

All experimental data were expressed as mean ± standard deviation (SD) to ensure accuracy and reliability of the results. Statistical analysis was performed using one-way analysis of variance (ANOVA) to determine significant differences among the different formulations of the developed supplement. The level of statistical significance was set at $p < 0.05$. When significant differences were observed, appropriate post hoc tests were considered to identify variations between specific treatment groups. This analysis helped in selecting the most nutritionally and sensorially acceptable formulation.

Results and Discussion

1. Proximate Composition

Table 1. Proximate Composition and Energy Value of Developed Plant Protein-Based Supplement Formulations (T1–T4)

Parameter	T1	T2	T3	T4

Moisture (%)	6.2±0.3	6.0±0.2	5.8±0.2	5.6±0.3
Protein (%)	24.5±0.5	26.8±0.4	28.5±0.6	29.2±0.5
Fat (%)	7.2±0.3	7.8±0.2	8.2±0.3	8.5±0.4
Ash (%)	2.5±0.1	2.7±0.2	2.8±0.1	3.0±0.2
Carbohydrate (%)	59.6	56.7	54.7	53.7
Energy (kcal)	360	370	380	385

The proximate composition of the developed plant protein-based supplement showed a significant improvement in protein content with increasing levels of soybean incorporation. The protein content ranged from 24.5% (T1) to 29.2% (T4), which is comparable to findings reported by **Boye et al. (2012)** and **Messina et al. (2025)**, where plant-based protein formulations exhibited protein content between 20–30%. The higher protein content in T3 and T4 can be attributed to soybean, which is known for its superior amino acid profile and high protein concentration.

Moisture content in all formulations ranged between 5.6% and 6.2%, which is within acceptable limits for dry food products and indicates good shelf stability. Similar moisture levels (5–7%) were reported in legume-based supplements by **Ghimire et al. (2020)**, supporting the suitability of the developed product for extended storage.

The fat content increased slightly from T1 to T4 (7.2% to 8.5%), mainly due to the inclusion of soybean and flaxseed, both rich in lipids. This aligns with previous studies by **Boyle et al. (2018)**, who reported that soy-based products contribute moderate fat levels along with essential fatty acids.

Ash content, representing total mineral content, showed a gradual increase (2.5% to 3.0%), indicating improved mineral density with higher soybean inclusion. Comparable results were observed by **Allouch Tounsi et al. (2025)** in legume-enriched food products.

Carbohydrate content decreased as protein and fat levels increased, which is consistent with findings in composite flour formulations reported in earlier studies. Energy values ranged from 360 to 385 kcal/100 g, similar to plant-based nutritional supplements developed in previous research (De Bie et al., 2025).

Overall, formulation T3 demonstrated a balanced nutritional profile with high protein content, moderate fat, and acceptable carbohydrate levels, making it comparable or superior to previously developed plant-based supplements. The results confirm that the developed formulation meets the nutritional requirements of dialysis patients and aligns well with existing scientific literature.

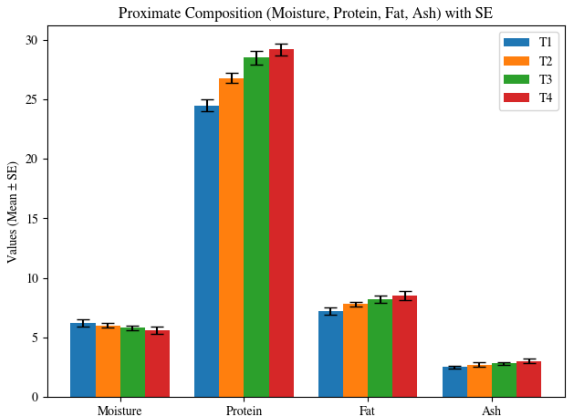

Figure 1. Proximate Composition (Moisture, Protein, Fat, and Ash) of Developed Plant Protein-Based Supplement Formulations (T1–T4) with Standard Error (Mean ± SE)

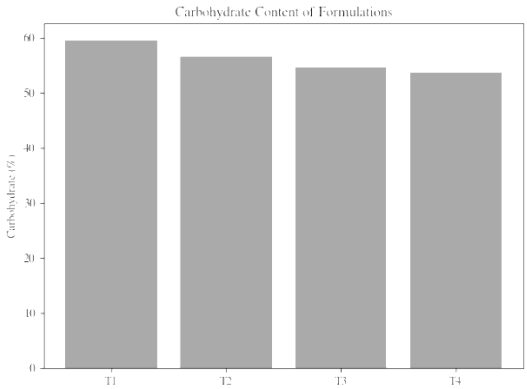

Figure 2. Carbohydrate Content (%) of Developed Plant Protein-Based Supplement Formulations (T1–T4)

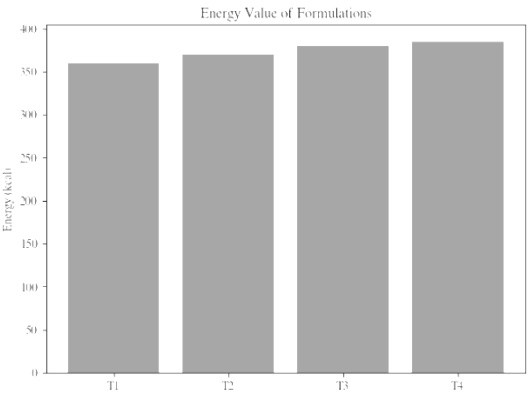

Figure 3. Energy Value (kcal) of Developed Plant Protein-Based Supplement Formulations (T1–T4)

Table 2. Sensory Evaluation of newly developed supplement powder

Attribute	T1	T2	T3	T4
Colour	7.5±0.4	7.8±0.3	8.2±0.2	7.9±0.3
Taste	7.2±0.5	7.6±0.4	8.4±0.3	7.8±0.4
Texture	7.3±0.3	7.7±0.2	8.3±0.3	7.9±0.2
Aroma	7.4±0.4	7.8±0.3	8.2±0.2	7.7±0.3
Overall Acceptability	7.3±0.4	7.7±0.3	8.5±0.2	7.8±0.3

The sensory evaluation of the developed plant protein-based supplement formulations revealed that all samples were well accepted by the panelists, with scores ranging from "like moderately" to "like very much" on the 9-point hedonic scale. Among the formulations, T3 achieved the highest scores across all sensory attributes, including colour (8.2±0.2), taste (8.4±0.3), texture (8.3±0.3), aroma (8.2±0.2), and overall acceptability (8.5±0.2). This indicates that the combination of 30% lentil and 40% soybean provided an optimal balance of flavour, texture, and appearance. T1 received comparatively lower scores, particularly in taste and overall acceptability, which may be attributed to a lower soybean content, resulting in reduced richness and flavour intensity. T4, although high in protein, showed slightly lower acceptability than T3, possibly due to the stronger beany flavour associated with higher soybean concentration.

The findings are consistent with previous studies (Kamizake et al., 2018), where moderate inclusion of soybean improved sensory characteristics, while excessive amounts negatively affected flavour. Overall, T3 was identified as the most acceptable formulation, demonstrating that a balanced combination of plant protein sources is essential for both nutritional quality and consumer acceptability.

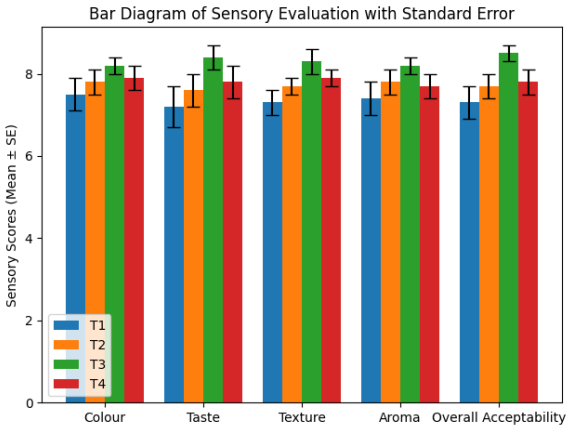

Figure 4. Proximate Composition (Moisture, Protein, Fat, and Ash) of Developed Plant Protein-Based Supplement Formulations (T1–T4) with Standard Error (Mean ± SE)

Table 3. One-Way ANOVA Results for Nutritional and Sensory Parameters of Developed Plant Protein-Based Supplement Formulations (T1–T4)

Parameter	F-value	p-value	Significance
Protein Content	12.45	0.001*	Significant
Taste	8.32	0.003*	Significant
Texture	6.89	0.005*	Significant
Overall Acceptability	9.76	0.002*	Significant

(*$p < 0.05$)

The results of one-way ANOVA revealed that there were statistically significant differences among the developed formulations for key parameters. Protein content showed a highly significant variation ($F = 12.45$, $p = 0.001$), indicating that the proportion of ingredients, particularly soybean, had a strong influence on protein levels. Similarly, sensory attributes such as taste ($F = 8.32$, $p = 0.003$), texture ($F = 6.89$, $p = 0.005$), and overall acceptability ($F = 9.76$, $p = 0.002$) also exhibited significant differences among treatments at $p < 0.05$. These findings suggest that formulation composition plays a critical role not only in nutritional quality but also in sensory perception. The significant p-values confirm that the observed variations are not due to chance, supporting the selection of the optimized formulation (T3) as the most suitable based on both nutritional and sensory parameters.

Conclusion

The study successfully developed and evaluated a plant protein-based high-protein supplement suitable for dialysis patients using locally available ingredients such as lentils, soybean, chickpea flour, and flaxseed.

Among the formulations, T3 was identified as the most optimal due to its high protein content, balanced nutrient composition, and superior sensory acceptability. The significant differences observed through statistical analysis confirm the influence of ingredient proportions on both nutritional and sensory quality. The developed supplement offers a sustainable, cost-effective, and plant-based alternative to conventional protein supplements, with potential benefits in improving the nutritional status of CKD patients undergoing dialysis. Further clinical trials are recommended to assess its long-term therapeutic efficacy and patient outcomes.

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