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Development and Nutritional Evaluation of High-Protein Millet-Based Snack Products Fortified with Pea Protein and Soy Protein

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Abstract: The purpose of the current study was to develop high-protein millet-based snack products fortified with pea protein and soy protein. Millet is well known for its high dietary fiber and mineral contents; however, it has relatively low amounts of bioactive compounds and poor protein quality which can be improved by incorporating complementary plant protein sources. Therefore, the objective of the study was to use millet flour as the base ingredient and add varying levels of pea protein and soy protein to produce high-protein, nutritionally-enhanced millet-based snack formulations. Four fortified treatment formulations were developed and tested along with a control formulation for both the physical and functional characteristics (e.g., bulk density, hardness, water absorption capacity, and oil absorption capacity) and the sensory characteristics (i.e., taste, color, and appearance) of the formulations. Results from the study demonstrated a statistically significant increase in the protein content of the fortified formulations when compared to the control formulation; conversely, a statistically significant decrease in the carbohydrate proportion occurred because of the partial substitution of millet flour with the added protein ingredients. The addition of protein resulted in some changes to the physical properties (e.g., bulk density, hardness, water absorption capacity, and oil absorption capacity) of the formulations, although moderate additions of protein to the millet flour resulted in formulations with desirable textures and expansion characteristics. The results of the sensory evaluations of the formulations, which used a nine-point hedonic scale, indicated that the optimal formulation had the highest overall acceptability based on the responses of the panelists. Overall, the study demonstrates that millet-based snack products that have been fortified with both pea and soy proteins are nutritious, plant-based, high-protein snack options that have good sensory qualities and may provide opportunities for the development of functional foods.

Keywords: Pea protein, Soy protein, High-protein snack, Fortification, Nutritional evaluation, Sensory analysis

I. INTRODUCTION

While it is true that both oats and barley are ancient grains that have been grown for thousands of years, and while oats are currently experiencing a resurgence in popularity as a "superfood," both of these grains continue to be relatively underutilized as whole grain ingredients. The unique ability of each of these grains to thrive in challenging environmental conditions, as well as their low water requirements and resistance to drought make them very useful for food systems that may be impacted by climate variability and change. Each type of whole grain has different nutritional advantages as well; oats are a good source of soluble fiber (beta-glucan), barley is a rich source of selenium, and each type of grain is also a good source of B vitamins and other minerals. However, when compared to rice or wheat, neither oat nor barley contains as much gluten, which limits their potential for use in bread making and baking. In addition, neither oat nor barley is a complete protein, lacking one or two of the nine essential amino acids necessary for optimal protein utilization by the body. As a result, researchers have become increasingly interested in using combinations of whole grains to create more complete and nutritious foods. The combination of cereals and legumes represents a particularly promising strategy, as legumes, such as lentils, peas, and chickpeas, contain complementary amino acid

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profiles that can enhance the biological value of cereal proteins. Cereal-legume combinations offer the opportunity to develop a wide range of high protein foods that incorporate a number of key benefits, including reduced cost, enhanced nutrition, and increased food choice. Additionally, there is a growing trend toward plant based, nutrient dense snack foods as more people adopt a healthy lifestyle and seek out more environmentally sustainable options. Therefore, incorporating legume proteins into oat- or barley-based snack foods offers a practical way to produce functional foods that combine traditional whole grains with the nutritional needs of modern consumers. Based on this rationale, the objective of this research was to develop oat- and barley-based snack foods fortified with pea and soy protein and to assess their nutritional content, texture, functionality and consumer acceptability to identify the most effective formulation for producing a nutritious and appealing snack food product.

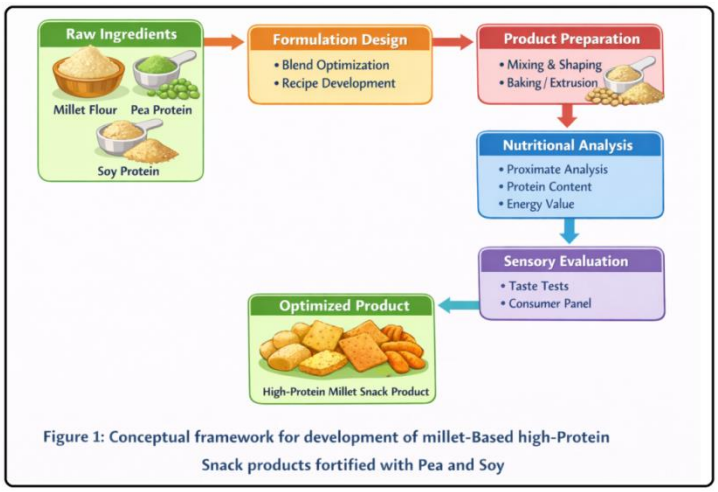

Figure 1: Conceptual framework for development of millet-Based high-Protein Snack products fortified with Pea and Soy

The data from Table 1 indicates that millet flour is the primary base ingredient of this product; it contains carbohydrates, dietary fiber, minerals, and other bioactives, whereas pea and soy proteins are added as main fortifiers to improve both the quality and quantity of protein content. The remaining ingredients (starches, oils, salts, spice blends, and water) contribute to the product's texture, stability during processing, palatability and acceptability to consumers. As a whole, the combination of all the ingredients provide a high-protein, nutritionally enhanced, sensory acceptable and process-stable millet-based snack food product.

In a comprehensive study of how to develop nutritious cereal-based snack foods, **Patil and Kaur (2016)** investigated the use of legume-proteins in combination with cereals and processed by means of extrusion. Results of their investigation revealed that incorporation of legume-protein increased the nutritional quality of the snack food products, especially by increasing the amount of protein present and the proportion of essential amino acids present in those protein fractions. **Naqash *et al.* (2017)** examined the preparation of extruded snack foods developed from blends of millet flour and legume flour. Results of the study demonstrated that the addition of legume components resulted in increased amounts of protein being present in the snack food products and that the nutritional value of the snack food products was generally improved relative to unfortified versions of the same product. **Sahu and Patel (2018)** evaluated the nutritional quality of extruded snack foods made from cereal/millet flour blends and fortified with soy-based ingredients. Their results indicated that the addition of soy-based ingredients resulted in increased protein content and that the nutritional quality of the snack food products was generally improved compared to unfortified versions of the same product.

Millet is a nutritious grain that has been extensively studied by **Saleh *et al.* (2019)**. Millet contains complex carbohydrates, fiber, vitamins, and minerals; it is also a source of bioactive compounds. The authors of this study stated that millet may provide an excellent opportunity to develop new functional foods because they have both nutritional value and do not contain gluten. In addition, the authors of this study proposed that millet could serve as a base for developing nutrient-enhanced proteins by combining it with other complementary protein sources like legumes. Additionally, **Devi and Khatkar (2020)** explored the use of a combination of millet and legume flours to produce protein-enriched snack products. This research demonstrated that when legume proteins are incorporated into millet flour-based formulations, they increase the protein content while providing acceptable physical and sensory characteristics. Furthermore, moderate amounts of fortification improve the textural characteristics and contribute to a better nutritional profile of the snack products

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Table 1: Nutritional significance and functional role of major ingredients used in product development

S. No.	Ingredient	Nutritional significance	Functional role in product development	Expected benefit in final snack product
1	**Millet flour**	Rich in complex carbohydrates, dietary fiber, minerals such as iron, calcium, magnesium, and phosphorus, and contains bioactive compounds with antioxidant potential	Acts as the **base cereal ingredient** and provides bulk, structure, texture, and characteristic millet flavor	Improves nutritional quality, enhances fiber content, supports gluten-free formulation, and increases overall health value
2	**Pea protein**	Good source of plant protein, rich in lysine, contributes to improved amino acid balance, and supports muscle-building nutrition	Serves as a **protein fortificant**, improves protein density, and contributes to water-binding and emulsification properties	Enhances protein content, improves satiety value, and supports development of plant-based high-protein snacks
3	**Soy protein**	High-quality plant protein with a relatively balanced amino acid profile, contains essential amino acids, and may contribute to improved protein digestibility	Functions as a **protein enrichment ingredient**, improves binding, water absorption, and texture formation	Increases total protein content, improves nutritional value, and contributes to better structural stability of snack products
4	**Starch / binding agent**	Provides digestible carbohydrate and contributes to energy value	Helps in **binding ingredients**, dough formation, shape retention, and uniform texture during processing	Improves product integrity, reduces breakage, and enhances crispness or expansion depending on processing method
5	**Edible oil / fat**	Source of energy and essential fatty acids; improves palatability	Contributes to mouthfeel, flavor release, lubrication, and desirable texture during baking, roasting, or frying	Enhances crispness, taste, and overall acceptability of the snack product
6	**Salt**	Provides sodium in small quantity and improves taste perception	Functions as a **seasoning agent** and flavor enhancer	Improves palatability and consumer acceptability
7	**Spices / seasonings**	May provide antioxidants, phytochemicals, and minor micronutrients depending on type used	Used for flavor development, aroma enhancement, and product differentiation	Increases sensory appeal and market acceptability
8	**Water**	Essential for hydration of ingredients though not a nutrient contributor in final dry product	Required for dough or batter preparation, mixing, hydration of proteins and starch, and proper processing	Ensures proper consistency, machinability, and uniform product formation
9	**Leavening agent** *(if used)*	Minimal direct nutritional contribution	Helps in aeration, puffing, porosity, and light texture development	Improves expansion, crispness, and eating quality
10	**Natural flavoring / herbs** *(if used)*	May contribute small amounts of antioxidants and phytochemicals	Enhances aroma, taste, and product uniqueness	Improves sensory score and consumer preference

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Finally, **Kumar and Sharma (2020),** evaluated the nutritional and sensory attributes of pearl millet-based snack products that had been fortified with soy protein. The data from this study indicated that the incorporation of soy protein into pearl millet products increases the protein density and enhances the nutritional profile of the products. Ultimately, **Singh *et al.* (2021)** created high protein-extruded snack products made from a composite flour blend of millet and legume components. The results of this study demonstrate that extrusion processing can be used to produce high protein-snacks that have improved functional and sensory properties. The authors of this study determined that the ratio of the composite flours contributes to better expansion, texture, and consumer acceptance while producing a substantial increase in the protein content of the final product. **Sharma and Kapoor (2022)** discussed the possibility of using plant protein ingredients to increase the nutritional value of cereal-based snack food formulations. Their work demonstrated that there is a growing trend toward the development of high protein snack formulations through the utilization of plant proteins including those derived from pea, soybeans and other legume sources. **Azam and Kumar (2023)** studied the effects of extrusion processing on the nutritional and functional properties of millet-based snack product formulations. Extrusion was shown by the authors to increase the digestibility of the proteins, alter the structure of starches, and affect the physical characteristics of the products (such as expansion and texture). **Sharma and Kumar (2023)** studied trends related to the use of millet and pseudomillet proteins for the development of functional food products. Their study demonstrated a growing interest in plant based proteins derived from millets and legumes due to their nutritional and environmental attributes. **Kaur *et al.* (2024)** researched innovative processes to extract and utilize millet proteins in sustainable food systems. In their research, the authors indicated that the application of advanced process technologies could enhance the functional and nutritional attributes of millet proteins. **Sharma *et al.* (2025)** showed how these are used in food products today. Based on their analysis, the authors concluded that plant proteins like soy and pea offer a number of nutritional advantages, including better protein quality and a better amino acid profile**. Simeunovic *et al.* (2025)** studied the nutritional and sensory properties of millet-based, gluten-free snack foods that were fortified with plant proteins. According to their data, the addition of proteins to gluten-free snack foods significantly improved the nutritional properties of those products and maintained desirable sensory properties. **Kumar *et al.* (2026)** conducted a study on the formulation of protein-rich extruded snack foods from blends of millet flour and plant-based proteins. Based on the findings of their study, when cereal and legume proteins are blended together, nutritionally improved snack foods can be produced with higher levels of protein and more acceptable texture. **Madiwal *et al.* (2026)** focused their study on the extraction and functional use of proteins extracted from millet in sustainable food systems. The authors of the study reported that millet proteins demonstrate favorable functional properties, including water absorption, emulsification and gelation; as a result, millet proteins are useful for use in the preparation of many types of food products.

II. MATERIALS AND METHODS

This section will describe how the study was conducted.

2.1 Materials: Raw materials for the production of fortified millet-based snack foods were made up of several varieties of millets, in addition to plant-based protein sources and a variety of additional functional ingredients that would assist in the formulation of the snack food. Millet flour was primarily the main ingredient in each formulation, although depending upon the availability and nutritional preferences of the various millets, one type of millet could be utilized alone or multiple types of millets can be blended together to increase the nutritional value and functional characteristics of the formulated millet flour blend. Millet is well recognized for its high content of dietary fiber and minerals, in addition to its numerous health promoting bioactive compounds. Yellow pea (Pisum sativum) protein is the primary plant-based protein source used as a fortifying agent because of its relatively high protein content, ease of digestion and functional properties such as water absorption and emulsion capability. Soy protein, which is derived from defatted soybean meal (Glycine max), is an alternative high quality plant-based protein source that has a balanced amino acid profile and can also serve to further enhance the protein content of the snack foods. Other than the primary ingredients, edible oils, common salt, specific spices or seasonings, starches or other binding agents, and leavening agents were also used to improve the dough formation, flavor, texture, expansion and overall sensory appeal of the final snack foods. Prior to the use of all raw materials in product formulations and analyses, they were obtained from reputable local markets and/or from certified food ingredient suppliers and were appropriately stored.

2.2 Experimental Design: The experimental procedure for this research study was implemented to investigate how plant-protein enrichment influences the nutrient and sensory attributes of millet-based snack foods. Control samples (C) of millet-based snacks were created with millet flour as the base ingredient and no added protein enrichment. Various enriched millet-based snack formulations were produced to measure the effect of different levels of pea and soy proteins added to the millet flour; these included low enrichment (F1); medium enrichment (F2); high enrichment (F3); and an optimized blend (F4) that would result in an optimal combination of protein content and acceptability of the product. Trials were performed utilizing a complete randomized experimental design with replication of each

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formulation, to allow for the collection of accurate and dependable data for nutritional analysis, physical properties, and sensory evaluations of the developed millet-based snack foods. Utilizing the described experimental method allowed for a comparative examination of the control and protein-enriched formulations to identify the best formulated product for creating nutritionally enhanced millet-based snack foods.

Table 2: Formulation of control and fortified millet-based snack products

Treatment code	Description	Millet flour (%)	Pea protein (%)	Soy protein (%)	Other ingredients (%)	Total (%)
C	Control	70	0	0	30	100
F1	Low fortification	60	5	5	30	100
F2	Medium fortification	50	10	10	30	100
F3	High fortification	40	15	15	30	100
F4	Optimized blend	45	12.5	12.5	30	100

The formulations used in developing the control (un-fortified) and fortified millet-based snack products are outlined in table 2. Only millet flour was present in the control treatment, which contained no protein additions as a result of its use as the primary base ingredient. Millet flour in the fortified treatments were substituted using increasingly higher amounts of pea protein and soy protein to develop samples that corresponded to low, moderate and high levels of fortification (F1-F3). An optimized protein addition was developed to enhance protein content relative to the physical and sensory attributes (acceptable texture and taste) of the final product (F4).

2.3 Product Preparation Method: The preparation of fortified milletbased snack products, involved a series of sequential processing to develop the quality, uniformity, and acceptable sensory attributes of the products. First, the millet grains that had been chosen were thoroughly cleaned to remove dust, stones, and other foreign material. Next, the cleaned millet grains were milled to produce millet flour, which could be used to formulate the various components of the products. Following milling of the millet grains, all of the dry ingredients (millet flour, pea protein, soy protein, starch or binding agent, salt, etc.) were accurately measured by weight in accordance with the formulation of each product and blended together until they formed a uniform blend. After blending of the dry ingredients, fat or edible oil and a sufficient amount of water were slowly added to the dry ingredient mix to hydrate and bind the ingredients together. Hydration and binding facilitated the formation of a consistent dough or batter that would have a suitable texture to allow it to be processed into its final form. The dough was then molded into the desired shape by utilizing techniques such as extrusion, shearing, or manual molding, depending on the type of snack product being produced. Once the products were shaped, they were then cooked using a variety of thermal processing methods, including baking, frying, or roasting, to create the desired level of crispiness, color, and flavor. After cooking, the products were cooled at room temperature to stabilize the texture of the product and to evaporate any excess moisture that may have been present on the surface of the product. Finally, after cooling of the products, the products were packaged in suitable airtight packaging materials to prevent moisture absorption and spoilage prior to nutritional, physical, and sensory testing.

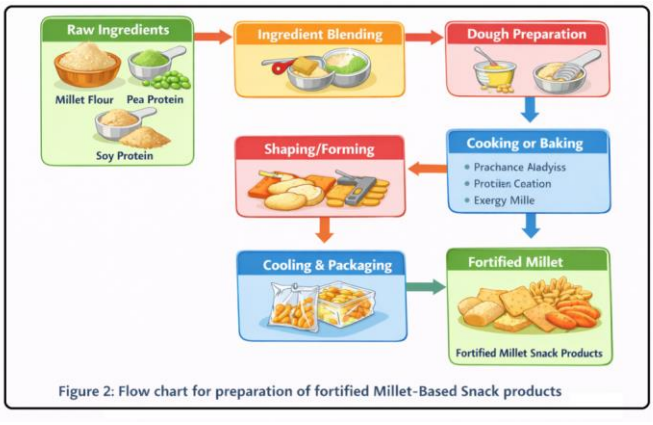

Figure 2: Flow chart for preparation of fortified Millet-Based Snack products

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2.4 Nutritional Analysis: The nutritional content of the millet-based snacks were determined via proximate analysis to assess the overall nutritional quality of the final product. Moisture content was evaluated to provide information about the water content of the sample to assess how long the samples would last on the shelf and how good the product will be when purchased. The protein content was assessed utilizing the Kjeldahl procedure, a conventional laboratory technique for estimating the total nitrogen content and converting it into crude protein by applying an appropriate conversion factor. The fat content was quantified through use of a Soxhlet apparatus as part of a solvent extraction method used to measure the total amount of lipids present within the various snack formulations. The ash content was assessed by burning the samples in a muffle furnace at elevated temperatures to determine the total amount of minerals remaining after combustion. The crude fiber content was estimated using acid and alkaline digestion techniques to break down the edible portion and leave behind the fibrous portion of each sample. The carbohydrate content was calculated by determining the difference of the total weight of each sample minus the sum of the moisture, protein, fat, ash, and fiber contents of each sample. Once the analytical results were obtained, the energy values of the developed snack products were calculated using standard Atwater factors. Since proteins and carbohydrates contain approximately 4 kcal/g and fats contain approximately 9 kcal/g, these analytical results provided an accurate representation of the enhanced nutritional profiles of the control and fortified millet-based snack products compared to the pea protein and soy protein fortified millet-based snack products.

2.5 Sensory Evaluation: Sensory evaluation of the millet-based snack products were conducted in order to assess the quality and acceptability of the new formulations as perceived by consumers. A group of semi-trained or trained panel members were recruited to participate in the evaluation. Panelists are generally individuals who have knowledge of how to conduct sensory evaluations of foods and can perceive and distinguish the different aspects of a food product. Snack samples formulated were evaluated under standard sensory evaluation conditions and coded so that there would be no influence (bias) of knowing which sample is being evaluated. The panelists were instructed to rate the appearance, color, flavor/aroma, taste, texture, crunch, and overall acceptance of the products using a nine-point hedonic scale. The ratings used for each sensory parameter were as follows; "Like Extremely" = 9, "Like Very Much" = 8, "Like Moderately" = 7, "Like Slightly" = 6, "Neither Like Nor Dislike" = 5, "Dislike Slightly" = 4, "Dislike Moderately" = 3, "Dislike Very Much" = 2, and "Dislike Extremely" = 1. The ratings were collected and averaged to provide an indication of the overall sensory quality of each formulation. Based upon this evaluation, it was possible to identify the formulation that most effectively balanced the enhancement of the nutritional quality of the products with the highest level of consumer acceptance.

2.6 Physical and Functional Properties: Physical and functional properties of the millet-based snack products made from different combinations of millet flour with pea protein and soy protein were investigated to evaluate the impact of protein fortification on the production process, structure and texture of the final product. Bulk density was used to measure the relative mass and volume of the samples to give a representation of compactness and porosity of each product. The expansion ratio (or hardness) of the snack was assessed to evaluate the textural characteristics of the snack; this is where expansion ratio provides a measure of how much the product has puffed or been deformed during processing, and where hardness measures the energy needed to break the product and therefore its crispness/firmness. The water absorption capacity (WAC) was used to determine the ability of the different formulations of the snack to absorb and hold water, which are important functional properties that can affect dough development, the structure of the product and the sensory aspects of the mouthfeel. Similarly, oil absorption capacity (OAC) was evaluated since OAC will provide information of the ability of the product to absorb oil during processing and therefore the flavor retention and texture of the product. Therefore, these physical and functional parameters have provided useful insights into the structural characteristics of the control and fortified snack formulations, and therefore the effects of incorporating pea and soy proteins into the millet-based snack formulations on the quality and processing behavior of the final product.

2.7 Statistical Analysis: The information collected through the testing of the nutritional, physical, and sensory aspects of the millet-based snack products was evaluated using statistical methods to determine if there was a difference in treatment effects. Each of the experimental measurement processes were conducted in triplicate and the resultant data is presented in terms of mean values along with the corresponding standard deviation (mean ± S.D.) to represent both the central tendencies and variabilities of the data. Using an analysis of variance (ANOVA), the study determined if there were statistically significant differences between the control group and the fortified groups based on their proximal chemical composition, physical properties, and sensory characteristics. The application of the ANOVA method also assisted in determining the effect of various levels of pea protein and soy protein fortification to the measured parameters. Upon observing significant differences among the treatments, post-hoc comparisons were conducted to identify which specific treatments had significantly different means than one another. This process further clarified the results of the study and identified the optimal formulation that resulted in enhanced nutritional value with the

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appropriate physical and sensory characteristics. The application of statistical methods in this research study was used to validate the reliability and science of the experimental findings.

ANOVA calculation (one-way ANOVA) assuming three replications for overall acceptability scores of the snack products.

Table 3: Sensory data (Overall Acceptability)

Treatment	Rep 1	Rep 2	Rep 3	Mean
C	7.9	8	8.1	8
F1	8.1	8.2	8.25	8.18
F2	8.3	8.35	8.3	8.32
F3	7.4	7.5	7.48	7.46
F4	8.45	8.5	8.48	8.48

Grand Mean = **8.087**

Table 4: ANOVA Table for Overall Acceptability

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F value	p value
Between treatments	1.844	4	0.461	114.7	<0.05
Within treatments (Error)	0.04	10	0.004		
Total	1.884	14			

The calculated F value (114.7) was higher than the critical F value at the 5% significance level, indicating that there were statistically significant differences among the snack formulations in terms of sensory acceptability.

Table 5: Mean comparison of overall acceptability scores

Treatment	Mean score	Significance group
F4 (Optimized blend)	8.48	a
F2 (Medium fortification)	8.32	ab
F1 (Low fortification)	8.18	b
C (Control)	8	b
F3 (High fortification)	7.46	c

The statistical analysis indicated a significant influence of the addition of protein to millet-based snack product on their sensory acceptability. Overall acceptability for F4 was the highest and significantly different than all other treatments. The medium fortified (F2) had higher acceptability than the majority of treatments and were similar to the optimized blend in terms of overall acceptability. However, the high fortified (F3) treatments had significantly lower scores; these results suggest that the addition of too much pea and soy protein can have negative effects on the flavor and texture attributes of the millet based snack product. Therefore, it is evident that the addition of moderate levels of protein will provide the best combination of enhanced nutritional value and desirable sensory quality.

III. RESULTS AND DISCUSSION

This section presents and interprets the findings.

3.1 Product Standardization: To select a suitable formulation for developing fortified millet-based snack products, the millet flour was compared with different levels of pea protein and soy protein fortification to standardize the product. Different formulations were prepared using millet flour and plant proteins as a substitute for other ingredients.

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When making the dough preparations, it was noticed that the properties related to dough handling (e.g., how well it could be shaped), shape retention (how well it kept its shape) and final product appearance varied among the treatments. The control sample had a consistent smooth dough and expanded evenly when cooked. Once the millet flour was replaced with pea and soy proteins, the dough became slightly firmer and more cohesive; this greatly impacted the dough's ability to be formed into desired shapes. While moderate levels of fortification improved the dough's cohesion and allowed it to retain an acceptable amount of shape during baking or frying, higher levels of protein resulted in a denser product and less expansion during cooking. The samples that were moderately fortified also appeared to have the best cooking quality and visual appeal based on color, crispness and evenness of surface. High levels of protein did result in some slight changes in the color and surface texture of the products but they were still acceptable. The overall combination of processing properties, structural stability and product quality led to the identification of the optimal formulation to be at a moderate level of protein fortification. This provided a product with improved nutritional value that still had desirable properties for hand-ling and sensory evaluation.

Table 6: Proximate composition of control and fortified millet-based snack products

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fiber (%)	Carbohydrate (%)	Energy (kcal/100 g)
C (Control)	4.8	10.2	14.5	1.8	2.9	65.8	432.1
F1 (Low fortification)	4.95	13.4	14.8	2.05	3.1	61.7	436.4
F2 (Medium fortification)	5.1	16.8	15.1	2.25	3.35	57.4	441.3
F3 (High fortification)	5.25	19.6	15.3	2.45	3.6	53.8	445.1
F4 (Optimized blend)	5.15	18.4	15	2.3	3.45	55.7	443.2

Protein content in fortified snack food products demonstrated an upward trend in comparison to the unfortified control product (Table 6). Protein in the control product was the least among all four treatments; in contrast, the most fortified treatment had the greatest amount of protein. Simultaneously, there was a downward trend in carbohydrate content since a portion of the millet flour was replaced by protein-rich ingredients. Although only slight changes occurred for moisture and fat content among the treatments, energy content in the products increased slightly with each increase in protein content. These results indicate that the addition of pea protein and soy protein to provide additional protein was successful. In general, it would have been anticipated that carbohydrate content would decrease in the fortified formulations since a portion of the cereal base was replaced with protein-rich ingredients. Additionally, there was a slight increase in ash content in the fortified samples which suggests there could be a positive effect on the mineral content of the products. Similarly, the amounts of fiber found in the fortified samples were slightly higher than those of the control, dependent upon the types of millet used and plant-based protein ingredients. When considering both the nutritional improvements in the formulated products and the potential consumer acceptance, the formulation with the optimal blend of protein ingredients (F4) appears to be the best option for use in the production of this product.

3.2 Physical and Functional Characteristics: The addition of either pea or soy protein significantly affected both the physical and functional attributes of the formulated millet-based snack products. Overall, the addition of proteins resulted in a number of observable differences in terms of texture, density, crispiness and puffing (or expansion) properties of the products. With an increase in protein fortification, there was an apparent increase in bulk density of the products, which would indicate a relatively greater density within the product structure. Additionally, the texture of the products demonstrated an observable trend toward harder textures as the amount of protein within each formulation increased; this was likely due to interactions between the millet starch and the plant-based proteins added. The overall crispness of the products remained reasonably consistent at moderate levels of protein fortification; however, as the concentration of proteins was elevated to higher amounts, the crispness of the products was observed to decrease. Likewise, as the amount of added pea and soy proteins continued to increase, the expansion ratio (also referred to as the spread ratio), which is a primary factor affecting the final product characteristics of puffed snacks, demonstrated an

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overall reduction in value, indicating that excessive protein fortification may contribute to reduced puffing and/or expansion of the cooked product. Ultimately, the changes exhibited by these physical and functional product attributes can impact how the snack products are processed and ultimately affect the quality of the final product. However, in general, formulations with reasonable levels of fortification were found to have a balance of structural characteristics that allowed them to provide desirable levels of crispness and texture, along with their enhanced nutritional value.

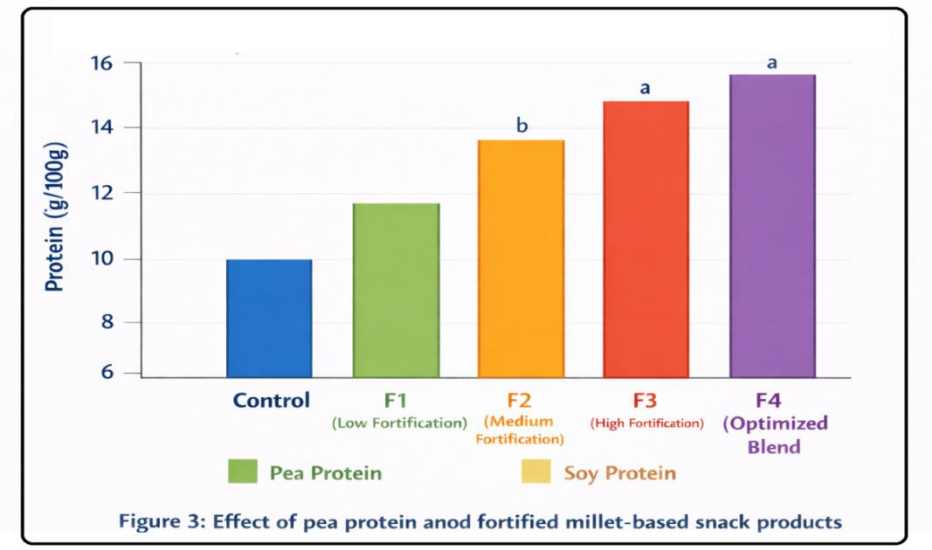

Figure 3: Effect of pea protein anod fortified millet-based snack products

Table 7: Physical and functional properties of developed snack formulations

Treatment	Bulk density (g/cm³)	Hardness (N)	Water absorption capacity (g/g)	Oil absorption capacity (g/g)	Expansion ratio / Spread ratio
C (Control)	0.42	18.6	1.82	1.48	2.85
F1 (Low fortification)	0.44	20.1	1.95	1.56	2.71
F2 (Medium fortification)	0.46	21.85	2.08	1.63	2.58
F3 (High fortification)	0.49	23.7	2.2	1.71	2.42
F4 (Optimized blend)	0.47	22.3	2.12	1.66	2.63

As shown by data presented in Table 7, the physical and functional characteristics of the snack items changed with an increase in the amount of pea protein and soy protein used as fortifications. There was a gradual increase in the bulk density from the unfortified sample to those that had high amounts of fortifications; therefore, it can be concluded that the formulation of the product is relatively dense when the plant proteins are incorporated into the millet flour. The increase in hardness observed in the fortified samples could be attributed to the strong interaction between the millet flour and the added plant proteins which form a stronger matrix. The water and oil absorption capacity of the fortified samples were significantly greater than that of the unfortified samples; this demonstrates the enhanced ability of the plant proteins to hydrate and bind fats. In contrast, the expansion ratio or spread ratio of the fortified samples was lower than that of the unfortified samples; therefore, it appears that adding large amounts of plant proteins may reduce the extent of puffing or spreading of the control sample. The F4 formulation (which is the optimized blend) exhibited intermediate values, thus demonstrating a good balance between having a stable product structure and obtaining a desired texture.

The increases in bulk density and hardness suggest that increasing the amount of fortifications will result in a more firm and compact snack product. Increasing the water and oil absorption capacities would be beneficial to enhance dough processing, texture perception by consumers and retention of flavors. However, reducing the expansion ratio at higher levels of fortification indicate that excessively high levels of protein may have a negative effect on the lightness and

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crispiness of the snack product. Therefore, the optimized formulation may be best suited to provide the desirable physical qualities of the product while providing the nutritional advantages.

3.3 Sensory Evaluation: The sensory evaluation was conducted to assess the acceptability of the control and fortified millet based snack formulations, and also to evaluate the comparative sensory performance of the two types of formulations. Using a nine point hedonic scale, the products were evaluated by a group of semi-trained panellists, for several product related descriptors including colour, appearance, aroma, flavour, texture, crispness and overall acceptability. Results from this evaluation, provided evidence that there were marked differences in the sensory characteristics among the various formulations tested. In terms of the sensory characteristics of the formulated snacks, the control sample received very favourable ratings due to it being a recognised flavour and texture. Conversely, the fortified samples, varied according to the degree of protein added. Low and medium degrees of fortification resulted in the formulated snack products having a highly desirable colour, pleasant aroma and an acceptable taste and texture that produced high sensory ratings. Conversely, with high levels of fortification, slightly less desirable flavours and textures were noted. These changes were thought to be a result of the strong beany flavour of pea and soy proteins and a resultant increased density of the product. Nonetheless, the optimised formulation achieved the highest overall acceptance rating, demonstrating that a moderate degree of fortification may provide significant increases to the nutritional value of the product without detracting significantly from its sensory quality. Therefore, the sensory evaluation data clearly demonstrated the importance of achieving a balance between increasing the protein content and the retention of desirable sensory properties for successful development of fortified millet based snack products.

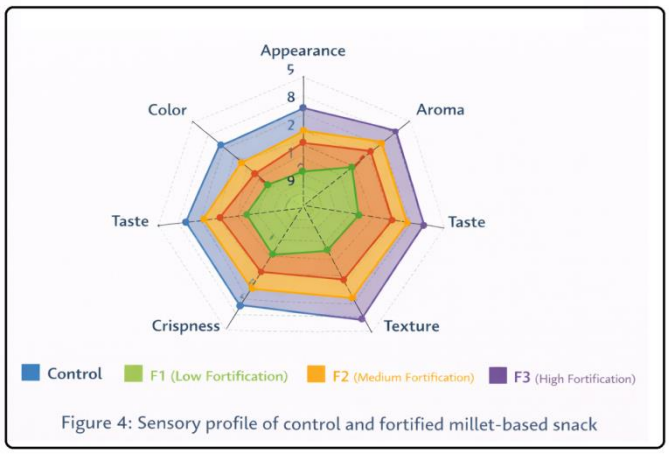

Figure 4: Sensory profile of control and fortified millet-based snack

Table 8: Sensory scores of control and fortified millet-based snack products

Treatment	Color	Appearance	Aroma	Taste	Texture	Crispness	Overall acceptability
C (Control)	8.1	8	7.85	7.9	8.05	8.1	8
F1 (Low fortification)	8.2	8.15	8	8.1	8.15	8.2	8.18
F2 (Medium fortification)	8.35	8.3	8.2	8.35	8.25	8.3	8.32
F3 (High fortification)	7.6	7.55	7.4	7.3	7.45	7.5	7.46
F4 (Optimized blend)	8.45	8.4	8.3	8.5	8.35	8.4	8.48

Results from Table 8 show that there was significant variation in sensory evaluations of both control and fortified millet-based snack items. The optimized blend (F4), demonstrated the highest scores for nearly all sensory evaluations such as; color, appearance, aroma, taste, texture, crispness and overall acceptability indicating that F4 had an optimal balance of nutritional value and consumer preference. Acceptability of the control samples were acceptable; however, they were lower than those of the optimized and medium-fortified blends. The high-fortification treatment (F3) had the lowest scores for sensory evaluations, likely because the amount of pea and soy protein used affected the flavors, textures and overall palatability of the product.

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Results from the sensory evaluations indicate that moderate to optimal levels of fortification resulted in higher levels of acceptability while excessive fortification resulted in decreased sensory quality. Higher levels of pea and soy protein may introduce a strong "beany" flavor, darkening of color, firming of texture and ultimately reducing consumer preference. Therefore, the optimized formulation (F4) is the most desirable for standardizing the product as it offers the greatest increase in protein content along with the highest level of sensory acceptance.

3.4 Discussion of Nutritional Improvement: Millet-based snack products that had been fortified with pea protein and soy protein resulted in much better nutritional profiles when compared to the formulation prior to the addition of the plant-based protein sources, especially in relation to the protein density. The inclusion of pea protein and soy protein resulted in a significantly higher total protein percentage relative to the control sample based on the proximate composition data. Millets have an inherent high carbohydrate content and an essential mineral content; however, they generally have a lower content of the essential amino acids that include lysine. The inclusion of legume-based proteins (pea protein and soy protein) in this study helped to complement the amino acid content of millets by providing a more complete amino acid profile. This combination illustrates the nutritional synergism that exists between legumes and cereals, and it has been well documented that this synergy will result in improved protein quality and biological value in food products. Similar improvements in protein content and nutritional quality have been demonstrated in other cereal-based snack studies where legume flours or protein isolates were added to cereal formulations. These fortification strategies can improve both the macronutrient composition and the functional properties of foods, and they are contributing to the production of foods with greater health benefits. The developed high-protein millet snack products therefore offer significant potential for utilization in a variety of specialized dietary applications, specifically for athletes who require higher protein intakes to maintain and recover from their muscles, and for children participating in school feeding programs and/or adults interested in consuming plant-based, high-protein, and nutrient-dense snack options.

3.5 Best Formulation: A formulation (the optimized blend) was found to be the best of all those created in terms of both its nutritional benefits and its appeal to consumers. While proximate analysis revealed the optimized blend had higher than normal amounts of protein, it also maintained desirable values for the other nutrients including moisture, fat, fibre, carbohydrates and so on. Furthermore, the results from sensory testing were positive, and the optimized blend was rated the highest across all parameters examined (colour, appearance, aroma, flavour, texture, crispiness). However, the formulation with the highest level of protein supplementation received lower ratings for some sensory characteristics, mainly due to increased flavour intensity and product texture. Therefore, the optimized formulation is the best one studied as it increases the protein concentration of the product without diminishing the texture or quality of the product. Consequently, the selected formulation has been shown to have an optimal combination of nutritional advantages and consumer acceptance making it ideal for further development and/or commercialization. Additionally, the use of millets, in conjunction with the use of plant-based protein sources, will provide a new type of product that meets the growing demand by consumers for healthy, sustainable and plant-based snack products; this provides additional support for the perceived market value of the optimized product.

IV. CONCLUSION

In this way, we were able to show the practicality of creating a new generation of high-protein snack products made from millet using pea protein and soy protein as additives. Plant protein additive ingredients allowed the developed formulations to have much higher amounts of protein than those formulated without them while still having acceptable nutritional values in terms of other nutrient categories. In addition to the nutritional enhancements created by the plant protein additive ingredients, physical and sensory assessments showed that the addition of plant proteins had an effect on the product's structure (density), appearance (texture) and water absorbing properties. However, when the level of fortification was at moderate levels, the structural integrity and processability of the products remained good. Results of sensory evaluations also confirmed that the formulation levels determined for optimization of the formulated products were highly acceptable to consumers and therefore the addition of nutrients does not have to compromise the taste or flavor of the products. These results indicate that it is possible to create a combination of millet flour with legumes to develop plant based snack food products that are nutritionally balanced to meet today's consumer demands for functional and plant based products. Such products could be very beneficial for health conscious consumers; school nutrition programs and athletes who require high energy, quick and easy to consume snacks. Future research may include additional studies regarding shelf life, amino acid composition, digestibility and large scale consumer acceptance to help establish the commercial viability and further widespread use of fortified millet-based snack products.

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