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Development and Sensory Evaluation of Calcium- and Vitamin D-Enriched Functional Foods for Bone Health Promotion

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Abstract

Pakistan faces significant nutritional challenges due to economic instability, limited access to healthy diets, and low nutrition awareness, resulting in widespread calcium and vitamin D deficiencies. These deficiencies contribute to bone-related disorders such as osteopenia and osteoporosis, particularly among vulnerable populations. This study aimed to develop cost-effective, calcium- and vitamin D-enriched functional foods using locally available traditional ingredients (sesame seeds, flaxseed, spinach) and food waste (eggshell powder). Four functional products, Green Crackers, Nutri Snack, Osteomax, and Sementes Wrap, were formulated through appropriate processing techniques. Nutritional analysis revealed Nutri Snack as the richest source of calcium (≈5100 mg/serving), followed by Green Crackers, Osteomax, and Sementes Wrap, with all products providing balanced macronutrient and energy contributions. Consumer acceptability was evaluated using a nine-point Hedonic Scale, and statistical analysis (one-way ANOVA, $p < 0.05$) showed significant differences among formulations. Nutri Snack and 70 g Green Crackers demonstrated the highest overall acceptability scores. The synergistic use of spinach, sesame, flaxseed, and eggshell powder enhanced nutritional density without compromising sensory quality. The findings highlight the potential of utilizing low-cost, locally sourced, and waste-derived ingredients to develop sustainable functional foods that may help alleviate calcium and vitamin D deficiencies. However, further shelf-life studies and clinical trials are recommended prior to commercialization.

Keywords: Functional Food, Calcium, Vitamin D, Egg Shell, Flaxseed, Bone Health, Osteoporosis

1. Introduction

The advancement in food and nutrition sciences has shifted the global trends towards developing novel approaches to managing prevailing health issues. Introducing nutraceuticals and functional foods has mesmerized the healthcare system and pharmaceutics. In

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recent decades, their demand has increased immensely due to their natural origin, minimal health hazards, and efficiency in promoting health. The global functional foods and nutraceuticals market was 712.97 billion USD in 2023 and is expected to grow at a compound annual growth rate of 8.4% from 2024 to 2030 (Chopra et al., 2022). Despite this scientific and industrial progress, the disease burden has been increasing every day, affecting millions of people worldwide. Developing and underdeveloped countries face several anomalies due to low income, poor dietary choices, inactive lifestyles, unhygienic foods, environmental hazards, and, most importantly, stress. All these factors contribute significantly to the occurrence of chronic metabolic disorders like diabetes mellitus (DM), hypertension (HTN), cardiovascular disorders (CVDs), hepato-renal syndrome (HRS), gastrointestinal problems, neurovegetative diseases, and pulmonary ailments (Lemieux and Després, 2020). Furthermore, micronutrient deficiency due to low affordability leads to malnutrition and malnutrition-associated complications. Children, older adults, and pregnant females are more prone to micronutrient/micronutrient deficiencies due to vulnerability and high caloric-nutrient demand (Ahmad et al., 2020).

The dynamic duo of Vitamin D and calcium is essential for strengthening bones and teeth and developing and maintaining skeletal health. These two nutrients build and maintain bone mass throughout life, which prevents osteoporosis and fractures in old age. Vitamin D3 (cholecalciferol) is produced in the skin by converting the inactive precursor vitamin D3 (7-dehydrocholesterol) to ultraviolet radiation of the band B kind. The skin can produce vitamin D3 at a rate greater than 90%, whereas only 10% comes from diet. The human body cannot produce calcium independently, so it must be obtained through diet or supplements (Capozzi et al., 2020). There are several ways in which vitamin D is crucial to human health. It plays a vital role in the absorption of dietary calcium in the gastrointestinal tract, the regulation of blood calcium levels, and the deposition of calcium in the bones (Melguizo-Rodríguez et al., 2021). The deficiency of both calcium and Vitamin D can result in various health problems; however, mainly, their deficiency leads to low bone mass and weak bones, eventually to rickets in children and osteoporosis in adults (Shlisky et al., 2022).

Rickets is caused by severe vitamin D deficiency in young people, leading to osteopenia. Osteopenia is a condition in which a loss of bone mineral density (BMD) weakens bones, further leading to osteoporosis. Osteoporosis is a health condition that weakens bones, making them fragile and prone to fractures. Severe cases may lead to osteoarthritis. It can cause joint pain and stiffness (Chanchlani et al., 2020). Osteoporosis is a prevailing global health concern, affecting a substantial number of adults, with ~200 million individuals diagnosed with the condition. Osteopenia and osteoporosis are diagnosed in approximately 22.2% and 59.9% of women, respectively, among women in their 50s. Recent studies suggest that by 2050, approximately 44 million individuals will experience osteopenia, while approximately 5 million will be affected by osteoporosis (Salari et al., 201).

Despite growing global and domestic awareness of micronutrient deficiency, limited studies are available on developing affordable, locally made functional foods fortified with calcium and vitamin D using local materials and food processing waste such as eggshells. Most existing research is centered on supplementation rather than food intervention. The current study, therefore, aimed to formulate and evaluate

Table 1 Nutritional labelling of green crackers per serving

Foods	Fat	Carbohydrates	Protein	Mag-nesium	Calci-um	Potassi-um	Sodium	Zinc	Total calories
Spinach	0.06 g	0.54 g	0.43 g	-	15 mg	84 mg	23.7 mg	-	25kcal
Flour	1.21 g	92.78 g	12.36 g	23.75 g	422.5 mg	155 mg	-	0.78 mg	233kcal
Whole wheat	1.12 g	43 g	8.22 g	82.2 mg	20 mg	21.8 mg	3 mg	2.5 mg	203kcal
Milk	2.62 g	3.64 g	2.59 g		91 mg	115 mg	32 mg	-	48kcal
Butter	23.04 g	0.02 g	0.24 g		7 mg	7 mg	164 mg	-	204kcal
Sesame seed	4.47 g	2.11 g	1.6 g	31.5 g	87 mg	42 mg	0.99 mg	0.7 mg	25 kcal
Total	32.52 g	142.09 g	25.44 g	55.25 g	635.5 mg	424.8	223.69 mg	3.98 mg	927kcal

four novel functional food products fortified with vitamin D and calcium from staple foods (spinach, sesame, flaxseed, and eggshell powder). Specific objectives were to formulate new products from local food ingredients. Evaluate their nutritional and sensory acceptability, and compare product characteristics with control samples for the identification of formulations for future pre-clinical or clinical evaluation

2. Materials and Methodology

Sensory evaluation is critical for evaluating consumer preferences and perceptions of various products. One often-used technique is the Hedonic Scale, which enables participants to score things depending on their level of liking or desire. This article describes the tools and procedures needed for a sensory assessment using the Hedonic Scale. The sensory evaluation Performa is provided in supplementary data.

The sensory panel consisted of 15 semi-trained participants (8 females, 7 males; aged 20–30 years) recruited from the Department of Food and Nutrition. Evaluation was performed using a 9-point hedonic scale ranging from 1 = “dislike extremely” to 9 = “like extremely.”

2.1. Functional Food 1 (Green Crackers)

2.1.1. Ingredients and Procedure:

The ingredients of the green crackers’ recipe include Dried spinach (1/3 cup 70g), Flour (1/2 cup 64 g), Whole wheat (1/2 cup 64 g), Butter (2 tbsp. 28.3 g), Milk (1/3 cup 43 g), Yeast (1 tsp. 4.2 g), Salt (1 tsp. 4.2 g), Baking powder (1/2 tsp. 2.84 g), and Sesame seed (1 tsp. 4.2 g).

First, lukewarm milk (1/3 cup) was added, and 1tsp yeast was mixed well and set aside for 2 to 3 minutes. Take 2 tbsp. of melted butter, pour melted butter into the milk. Add 1 tsp salt to it. Add flour and whole wheat to the milk mixture. Mix them with the help of a spatula. Make dough of it. Add 1/2 cup of spinach and mix the sesame seeds. Now, leave the dough for 30 minutes. Put dough on butter paper and roll out thinly with the help of a rolling pin. Bake at *170 °C* for 18 min until golden brown.

Table 2 Nutritional Labelling of Nutri Snack per serving

Foods	Fat	Carbs	Protein	Calcium	Vit D	Cholesterol	Fiber	Sodium	Total calories
egg	4 g	0.6 g	6 g	30 mg	0.9 mcg	165 mg	0 g	60 mg	60 kcal
butter	81 g	0.1 g	0.9	24 mg	0 mcg	215 mg	0 g	643 mg	717 kcal
white flour	1.25 g	97.68 g	13.2 g	19 mg	0 mcg	0 mg	3.5 g	3 mg	466 kcal
vanilla essence	0 g	0.5 g	0 g	0.5 mg	0 mcg	0 mg	0 g	0.4 mg	12 kcal
brown sugar	0 g	0 g	0 g	64 mg	0 mcg	0 mg	0 g	0 mg	285 kcal
baking powder	0 g	1.1 g	0 g	0 mg	0mcg	0 mg	0 g	363 mg	2.4 kcal
Egg shell powder	0 g	0 g	0.5 g	5.1 g	0 mcg	0 mg	0 g	0 mg	2.1kcal

Nutritional labeling of green crackers is mentioned in detail in Table 1. There are 927 kcal in a cracker.

2.1.2. Possible Interaction:

Regarding spinach cookies and their potential interaction with calcium and vitamin D when consumed with tea, here is what you should consider: Many food products contain oxalate, such as spinach. Foods that contain a high ratio of oxalate affect calcium absorption. The link between soluble and insoluble oxalate in the small intestine affects oxalate bioavailability, and taking calcium together with oxalate-rich food can lower the absorption of both (Akhtar et al., 2011). The interaction of spinach with drugs is minimal. Spinach contains vitamin K in large quantities. The primary function of vitamin K is blood clotting. Warfarin slows the clotting of blood. Spinach slows the effect of warfarin.

2.2. Functional Food 2 (Nutri Snack)

2.2.1. Ingredients and Procedure:

The ingredients of the nutri snack recipe with quantity are eggshell powder (15 grams/1 tbsp.), Vanilla essence (4 drops /half tsp.), Butter (100 grams/2/3 cup), Brown sugar (75 grams/1/2 cup), Egg (1), White flour (128 grams/1 cup), and Baking Powder (4.2 grams/1 tsp.).

The four eggshells were boiled for 20 minutes and then baked for 15 minutes at 150°C. After baking, the samples were ground to a fine powder. Sugar, egg, baking powder, eggshell powder, butter, and white flour were added to another pan and whisked. Mix it well. After that, add vanilla essence. Make the dough and give it the shape of cookies. Then, the oven was preheated and baked at 150°C for 30 to 35 minutes until light brown. After that, cookies are ready and served.

2.2.2. Nutritional value per serving per cookie (large)

In Table 2, the nutritional value of the nutri snack per serving is mentioned. Cookies contain 403 mg of calcium, 7.6 g of carbohydrates, 6.7 g of fat, 1.58 g of proteins, 9.2 mg of cholesterol, 82.2 mg of sodium, 0.26 g of fiber, and 118.80 calories total.

2.2.3. Possible Interaction

Calcium absorption can be influenced by many factors, including the presence of certain compounds in food. For example, oxalates are found in some foods, such as spinach, which can bind to calcium and inhibit its absorption. However, no specific compounds in milk or tea can interfere with calcium absorption. In contrast, tea, especially black tea, contains tannins that

Table 3 Nutritional labelling of Osteomax per serving

Ingredients	Fat	Carbs	Protein	Calcium	Cholesterol	Fiber	Sodium	Total kcal
lotus seeds	1.2 g	41.2 g	9.8 g	3.2 mg	0 mg	16 g	3.2 mg	212 kcal
sesame seeds	9 g	4.2 g	3.2 g	2 mg	0 mg	3.3 g	2 mg	104 kcal
2 tbsp. poppy seeds	7.4 g	5 g	3.2 g	3.2 mg	0 mg	3.7 g	3 mg	94 kcal
flax seeds	9.9 g	9.9 g	5.7 g	35.8 mg	0 mg	7.8 g	4.2 mg	142 kcal
seedless dry dates	0 g	31 g	1 g	34 mg	0 mg	2.6 g	1 mg	110 kcal
almonds	24 g	9.08 g	9.98 g	264 mg	01 mg	12 g	0 mg	579 kcal
Dry ginger	0.5 g	1.07 g	0.11 g	2 mg	0 mg	0 mg	0 mg	4.8 kcal
crystal sugar	0 g	0 g	0 g	0 mg	0 mg	0 g	1 mg	9.0 kcal

can inhibit calcium absorption, and its effect is considered moderate. On the other hand, studies have shown that the impact of tea consumption on calcium absorption is minimal, mainly when calcium intake is adequate. Milk is a good source of calcium, and it contains lactose, which aids in calcium absorption. Moreover, milk is fortified with vitamin D, which helps facilitate calcium absorption (Waheed et al., 2019). Vitamin D is a fat-soluble vitamin that is better absorbed when consumed with dietary fat. Since milk contains fat, consuming egg-shell cookies with milk may enhance vitamin D absorption in the milk. In summary, consuming eggshell cookies with tea or milk is unlikely to impact calcium or vitamin D absorption significantly (Fleet, 2022).

2.3. Functional Food 3 (OSTEOMAX)

2.3.1. Ingredients and Procedure:

Ingredients of the osteomax recipe with quantity are Lotus seeds (2 cups/280 grams), Sesame seeds (2 tbsp. /20 grams), Poppy seeds (2 tbsp/18 grams), Flax seeds 2 tbsp./20 grams, Seedless dry dates 4/40 grams, Almonds 1 cup/100-gram, Dry ginger (1 inch/5 gram).

Take a bowl and roast 2 cups of lotus seeds and 1 cup of almonds until adequately roasted. Allow them to cool completely. Next, roast the four seedless dry dates. In a separate pan, add the 2 tbsp. of sesame seeds, 2 tbsp. flax seeds, 2 tbsp. of poppy seeds and dry ginger (cut into 1-inch pieces). Roast them properly, then let them cool completely. All the roasted ingredients were combined in a grinder, along with the two pieces of crystal sugar. They were ground into fine powder. Transfer the powder to an airtight container. Your calcium booster powder is now ready. Roast ingredients at 120 °C for 10 min; grind to fine powder

2.3.2. Serving per tablespoon:

A nutritional serving of Osteomax is given in Table 3. Fat 1.3 g, Carbohydrate 2.6 g, Protein 0.86 g, Calcium 9.05 mg, Fiber 1.19 g, Sodium 0.37 mg, Total kcal 33 kcal.

2.3.3. Versatile uses of Osteomax:

Add this powder to milk for a nutritious drink, sprinkle it over yogurt for an added crunch and flavor, blend the powder into smoothies for a healthy boost, or use it as a topping for salads or roasted vegetables. The seed powder was mixed with honey or nut butter to make a delicious spread.

Table 4 Nutritional composition Sementes wrap

Food	Fat	Carbs	Protein	Cholesterol	Calcium	Potassium	Vit D	Fiber	Calories
Wholegrain flour	1 g	76 g	10 g	0	18.8 g	230 mg	0.01 ug	13 g	366 kcal
White flour	1 g	100 g	13.64 g	0	18.8 g	107 mg	0	3.4 g	233kcal
Sesame seed	14.4 g	5 g	6 g	0	49 g	173.2 mg	_	5.1 g	297 kcal
Flax seed	11 g	10 g	18 g	0	92 g	300.8 mg	17 µg	10 g	450 kcal
Total	27.4 g	191	170.64	0	178.6 g	811 mg	11.01 ug	31.5 g	1,420kcal

2.3.4. Possible Interaction:

When considering the interaction between food and nutrient absorption, almonds and sesame seeds stand out with notable interactions. Almonds are good calcium sources and contain phytic acid, which may slightly inhibit calcium absorption. Sesame seeds, also rich in calcium, contain oxalates that could hinder calcium absorption to a minor extent. However, the overall impact of these interactions is considered minimal. Additionally, when you consume the prepared calcium booster powder with milk, you benefit from the synergistic effect of calcium and vitamin D absorption. Milk is a good source of calcium and naturally contains small amounts of vitamin D, which enhances calcium absorption. Therefore, combining osteomax powder with milk can further support the absorption and utilization of calcium and vitamin D. The remaining ingredients in your recipe, including lotus seeds, poppy seeds, seedless dry dates, dry ginger, flaxseeds, and crystal sugar, do not exhibit significant interactions with any specific nutrients or drugs. Their consumption alongside milk does not pose any notable interference with nutrient absorption.

2.4. Functional Food 4 (SEMENTES WRAP)

2.4.1. Ingredients and Procedure:

Ingredients of the segments recipe with quantities are listed: Whole wheat flour (1 cup/128 grams), White flour (2 cups/256 grams), Sesame seed (3 tbsp. /37 grams), and Flax seed. (3 tbsp. /37gram), Salt 1 Pinch, Oil (2 tablespoons/28grams).

First, 37 g of flaxseed and 37 g of sesame seeds were ground well to make powder. Take 2 cups of white flour and 1 cup of whole-grain flour. Add a pinch of salt. And two tablespoons of oil. The solution is gradually mixed with water to make dough. In addition, leave it for half an hour. Flaxseed and sesame seed powder were added and mixed well. Roll a small portion of the dough with a rolling pin. Make a 6-inch wrap of it. The wrap was added to a hot pan until it was cooked. Cook each side on a pre-heated pan at 180 °C for 1–2 min. Filling of wrap includes Chicken, Yogurt, Cucumbers, Lettuce, and Cheese

2.4.2. Serving per wrap:

The nutrients available in the Sementes wrap are Calcium 22.35 mg, Carbs 38.2 g, Fat 5.8 g, Protein 9.5 g, and Fiber 6.3 g. The total calories are 1174 kcal, and the Calories from each wrap are 234 kcal. The nutritional serving of the Sementes wrap is listed in Table 4.

2.4.3. Possible Interaction:

Flax seeds contain phytic acid, an anti-nutrient, ranging from 23 to 33 g/kg of flaxseed meal. Phytic acid interferes with calcium, zinc, magnesium, copper, and iron absorption. It is a potent chelator, forming protein and mineral-phytic acid complexes and thus reducing their

Table 5 Processing conditions for the developed calcium- and vitamin D-enriched functional foods

Functional Food	Main Ingredients	Processing Steps	Processing Temperature (°C)	Processing Time (minutes)	Remarks
Green Crackers	Spinach, wheat flour, sesame seeds, butter, milk	Kneading dough → resting → rolling → baking in oven	170 ± 2 °C	15–20	Baked until crisp and light golden brown
Nutri-Snack Cookies	Eggshell powder, white flour, butter, brown sugar, egg	Eggshells boiled → baked → ground → dough preparation → baking	150 ± 2 °C	30–35	Baked until light brown and firm
Osteomax Powder	Lotus seeds, almonds, sesame, flax, poppy seeds, dry ginger	Dry roasting of ingredients → cooling → grinding → mixing with sugar → packaging	120 ± 2 °C (roasting)	10–15	Roasted to a light golden color; no moisture left
Sementes Wrap	Whole wheat flour, white flour, sesame, flaxseed	Dough kneading → resting → rolling → pan cooking	180 ± 5 °C (pan surface)	1–2 per side	Cooked until brown spots appear and the surface is dry

bioavailability. The consumption of flaxseed may decrease the absorption of medication, vitamins, and minerals. Therefore, oral drugs should be taken 1 hour before or 2 hours after flaxseed to prevent reduced absorption of anticoagulants, antiplatelet drugs, NSAIDs, and antihypertensive drugs (Chen and Xu, 2023).

3. Statistical Analysis:

Compile the sensory evaluation form data into a format that will be useful for analysis. Determine the overall preference or liking based on the Hedonic Scale ratings by calculating the average rating for each product. If needed, use statistical analysis to find significant differences between goods using t-tests or analysis of variance (ANOVA)

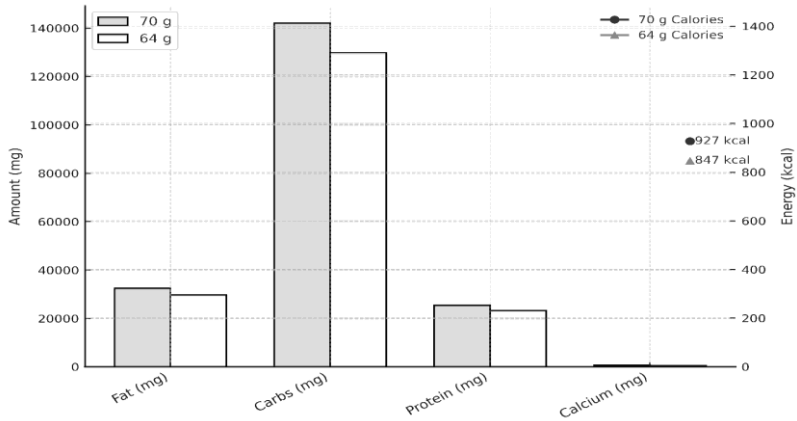

Figure 1 Nutritional comparison of 70g and 64g spinach-based crackers

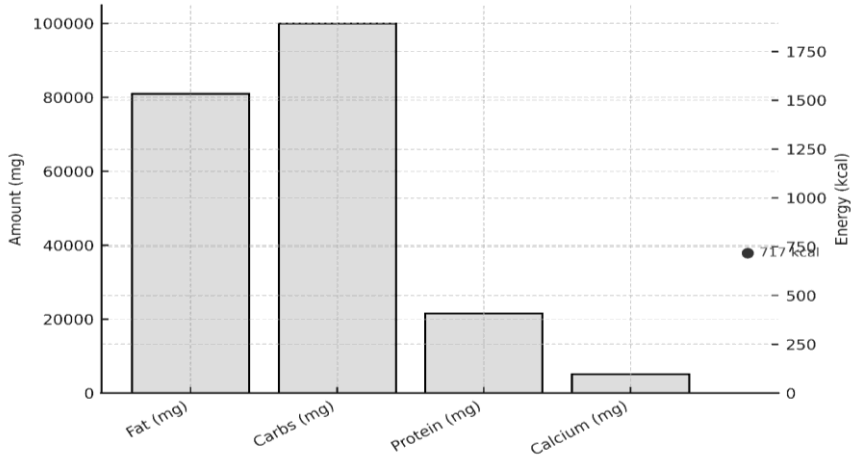

Figure 2 Nutritional Composition of Nutri Snack

Sensory data were analyzed using one-way analysis of variance (ANOVA) to compare mean scores among formulations, followed by Tukey's post-hoc test at $p < 0.05$ using SPSS v.26. Results are expressed as mean ± standard deviation (SD).

4. Results and Discussion:

These Functional foods were developed to enhance individuals' calcium and vitamin D levels. A hedonic scale was used for sensory evaluation, with the main aim of checking the acceptability of products.

4.1 Green Crackers (Spinach-Based)

Figure 1 illustrates the comparative nutritional and sensory evaluation of 70 g and 64 g spinach-based green crackers. The 70 g formulation demonstrated superior overall acceptability compared to the 64 g version. Sensory attributes, including texture, flavor, aroma, and appearance, were consistently rated higher for the 70 g crackers. The improved acceptability was primarily associated with better crispness and a less dense structure, whereas the 64 g crackers were comparatively harder and less palatable.

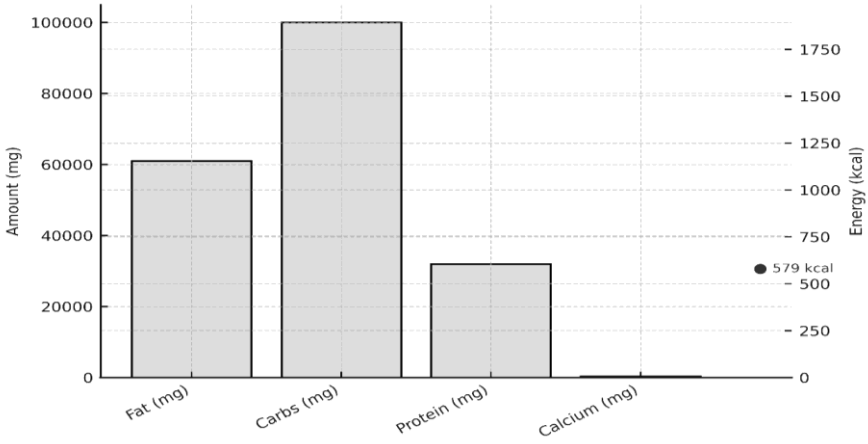

Figure 3 Nutritional composition of Osteomax

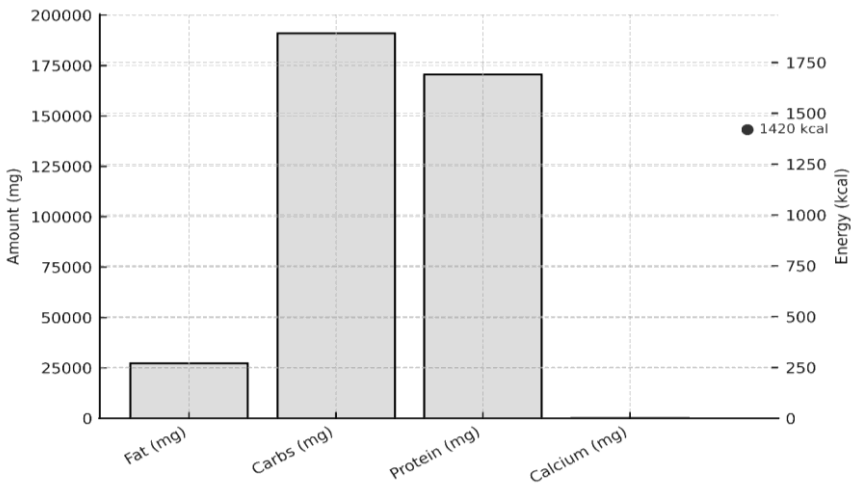

Figure 4 Nutritional Composition of Sementes Wrap

From a nutritional perspective, spinach contributes significantly to the mineral enrichment of the product, particularly calcium. It is well documented that one cup of raw spinach provides approximately 29.7 mg of calcium (Waseem et al., 2021). Calcium plays a vital role in bone mineralization, neuromuscular signaling, and muscle contraction. Previous studies have also shown that consuming spinach with vitamin C-rich foods enhances calcium absorption. Czarnowska-Kujawska et al. (2022) reported that fortifying bakery products with spinach (40 %) and kale (20 %) increased calcium, iron, and folate contents by up to twofold. In the present formulation, the incorporation of spinach powder substantially improved the calcium profile of the crackers while maintaining a desirable sensory texture. Consequently, the 70 g spinach-based green cracker can be considered the optimized formulation balancing nutritional value and consumer acceptability.

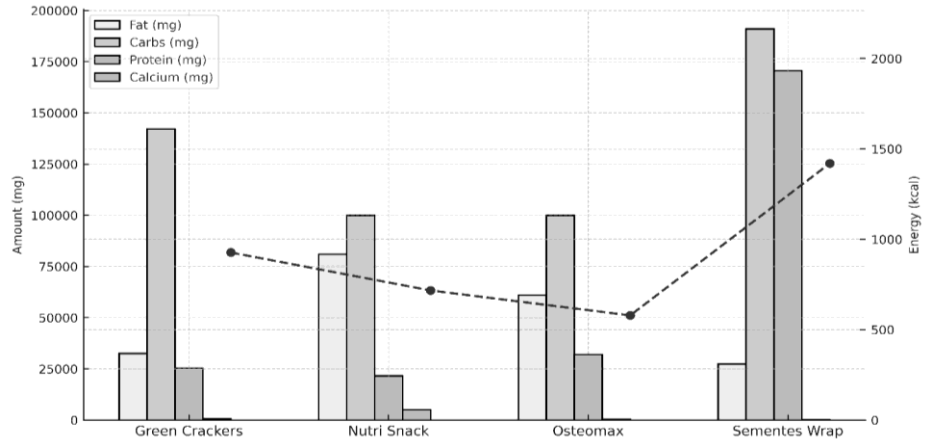

Figure 5 Comparative nutritional composition of functional foods

4.2 Nutri-Snack Cookies (Eggshell-Based)

Figure 2 presents the nutritional and sensory evaluation of Nutri-Snack cookies formulated using eggshell powder as a calcium fortification. The results revealed that Nutri-Snack cookies exhibited higher scores for appearance, aroma, sweetness, and overall acceptability compared with the control formulation. The enhanced sensory quality may be attributed to the optimized balance between texture and sweetness, contributing to consumer preference.

Eggshell powder (ESP), the principal ingredient in this formulation, represents a sustainable approach to valorizing food industry by-products. Eggshells are composed primarily of calcium carbonate (approximately 94%) and trace minerals such as magnesium and phosphorus, which are highly bioavailable. Aditya et al. (2021) demonstrated that eggshell-derived calcium is efficiently absorbed by the human body. Additionally, proper thermal or microbiological processing ensures safety by eliminating potential pathogens (Kulshreshtha et al., 2022).

Clinical investigations further confirm the functional value of ESP in improving bone mineral density, promoting tooth enamel re-mineralization, and supporting urinary stone clearance (Opris et al., 2020). Compared to other natural calcium sources, such as oyster shells, eggshell powder contains beneficial micro-minerals, offering a superior nutritional profile. Incorporating ESP into bakery and dairy products is thus an effective strategy to improve dietary calcium intake. Previous studies have validated eggshells as a low-cost, bioavailable, and safe calcium source suitable for functional food development (Arif et al., 2022). Consequently, the Nutri-Snack cookies developed in this study demonstrate both nutritional enhancement and consumer acceptance, supporting their potential as a fortified functional food.

4.3 Osteomax Powder (Seed Blend)

Figure 3 presents the sensory evaluation of Osteomax, a functional seed-based powder formulated from a blend of nutrient-rich seeds. The product achieved an exceptional overall acceptability score of 144 on the hedonic scale, reflecting high consumer preference for its appealing flavor, aroma, and smooth texture. Although all sensory attributes performed well, sweetness received slightly lower ratings, likely due to the inclusion of flaxseeds, which are naturally low in carbohydrates and high in dietary fiber.

Table 6 Mean Sensory Scores of Functional Food Formulations (9-Point Hedonic Scale*)

Product	Appearance	Aroma	Flavour	Texture	Overall Acceptability
Green Crackers (64 g spinach)	7.4 ± 0.3[b]	7.5 ± 0.2[b]	7.2 ± 0.4[b]	7.6 ± 0.3[b]	7.5 ± 0.3[b]
Green Crackers (70 g spinach)	8.2 ± 0.3[a]	8.0 ± 0.3[a]	8.1 ± 0.2[a]	8.4 ± 0.2[a]	8.1 ± 0.4[a]
Nutri Snack (eggshell fortified)	8.5 ± 0.2[a]	8.3 ± 0.3[a]	8.4 ± 0.3[a]	8.2 ± 0.3[a]	8.3 ± 0.2[a]
Osteomax (seed-based powder)	8.1 ± 0.3[a]	8.0 ± 0.2[a]	7.8 ± 0.2[b]	8.3 ± 0.3[a]	8.2 ± 0.3[a]
Sementes Wrap (sesame + flax)	7.8 ± 0.3[b]	8.0 ± 0.3[a]	7.2 ± 0.3[b]	7.9 ± 0.3[b]	7.6 ± 0.3[b]

Values represent mean ± SD (n = 25). Means within a column followed by different superscripts (a, b) differ significantly ($p < 0.05$).

This compositional characteristic contributes to glycemic regulation and supports the development of functional foods targeted at individuals with metabolic concerns (Rehman et al., 2021).

Nutritionally, flaxseeds are recognized for their rich profile of essential minerals, particularly calcium and potassium, and bioactive compounds that influence hormone regulation related to calcium deposition and bone health (Batool et al., 2024). Additionally, flaxseeds provide omega-3 fatty acids and lignans, which play significant roles in vitamin D and calcium metabolism. Chen et al. (2019) demonstrated that dietary supplementation with 10% flaxseed oil over 22 weeks improved bone formation biomarkers (ALP, P1NP, β-catenin, and osterix) while reducing bone resorption marker CTX-1 in experimental models.

Collectively, these findings support the nutritional potential of Osteomax powder as a plant-based functional supplement for promoting bone health and enhancing mineral absorption. The synergistic combination of seeds and flaxseed-derived bioactives establishes Osteomax as a valuable nutritional intervention for supporting skeletal integrity and overall wellness.

4.4 Sementes Wrap (Flaxseeds and Sesame)

Figure 4 illustrates the sensory evaluation of the Sementes Wrap, a functional formulation enriched with flaxseeds and sesame seeds. Interestingly, the control (simple wrap) exhibited higher scores in overall acceptability, flavor, and

sweetness compared to the Sementes Wrap. However, the Sementes Wrap achieved superior results for aroma and appearance, indicating that while its visual and aromatic appeal was enhanced by the inclusion of seeds, its taste profile was influenced by the inherent bitterness of sesame. The slightly lower sweetness and flavor perception can thus be attributed to the characteristic taste of sesame seeds.

Despite the minor sensory differences, sesame and flaxseeds provide substantial nutritional advantages, particularly in relation to bone health. Sesame seeds are rich in calcium (975 mg/100 g) and potassium (468 mg/100 g), both essential for maintaining bone mineral density (Arooj et al., 2023). Experimental studies have demonstrated that supplementation with sesame seed oil (0.25–0.5 mL/kg/day) or its extracts can enhance bone strength and mineral density in animal models. These effects are linked to the antioxidant and anti-inflammatory properties of sesame bioactives, which help mitigate bone loss and support skeletal health (Hsu et al., 2024).

Moreover, sesamolin, a natural lignan isolated from sesame oil, has been reported to protect against bone degradation by modulating NF-κB and MAPK signaling pathways (Yang et al., 2021). Therefore, while the Sementes Wrap exhibited moderate sensory acceptance, it possesses considerable nutritional value due to the synergistic effects of flaxseed and sesame-derived bioactives that contribute to bone health and overall well-being.

4.5 Nutritional Composition of Functional Foods

The developed calcium- and vitamin D-enriched products Green Crackers, Nutri Snack, Osteomax, and Sementes Wrap showed considerable variation in macronutrient and mineral profiles (Figure 5). Among them, Nutri Snack exhibited the highest calcium concentration (≈5100 mg per serving) due to the inclusion of eggshell powder, followed by Green Crackers (≈635 mg), Osteomax (≈344 mg), and Sementes Wrap (≈179 mg). The elevated calcium in Nutri Snack underscores the potential of eggshell waste as a bioavailable, low-cost calcium source. Energy values ranged from 579 kcal (Osteomax) to 1420 kcal (Sementes Wrap), primarily reflecting fat and carbohydrate content. Green Crackers provided a balanced nutritional profile (32.5 g fat, 25.4 g protein, 142 g carbohydrates), offering a moderate-energy, high-fiber alternative suitable for elderly populations at risk of osteopenia.

The high-energy Sementes Wrap, rich in flax and sesame seeds, contributed substantial unsaturated fats and lignans known to modulate bone metabolism. These compositional results confirm that the formulated foods collectively deliver synergistic sources of calcium, vitamin D, and essential fatty acids, key for maintaining bone mineralization and endocrine regulation of calcium homeostasis.

4.6 Sensory Evaluation and Product Acceptability

The sensory response pattern assessed through a nine-point Hedonic Scale revealed statistically significant ($p < 0.05$) differences among formulations (Table 6). Green Crackers containing 70 g spinach powder achieved the highest mean score (8.1 ± 0.4) for texture, crispness, and overall acceptability, outperforming the 64 g variant. Nutri Snack cookies were highly rated for appearance, aroma, and sweetness, consistent with their butter-rich matrix and eggshell calcium content. Osteomax, a powdered seed blend, achieved high acceptability due to its nutty aroma and smooth texture, while Sementes Wrap displayed moderate acceptability, largely limited by a bitter aftertaste from sesame oxalates.

The overall sensory pattern demonstrates that fortification with natural calcium sources can enhance nutritional

quality without compromising consumer appeal when ingredient ratios are optimized.

4.7 Sensory Evaluation and Product Acceptability

Sensory evaluation of the developed calcium- and vitamin D-enriched functional foods was conducted using a nine-point Hedonic Scale by a panel of 25 semi-trained assessors. Attributes including appearance, aroma, flavor, texture, and overall acceptability were recorded, and data were analyzed by one-way ANOVA followed by Tukey's post-hoc test ($p < 0.05$).

The sensory profiles (Table 5) revealed significant ($p < 0.05$) differences among formulations. **Green Crackers** fortified with 70 g spinach powder achieved the highest scores for texture (8.4 ± 0.2) and overall acceptability (8.1 ± 0.4), outperforming the 64 g variant, which scored lower for color and mouthfeel. The moderate green hue and crisp texture of the 70 g formulation improved visual and textural perception without introducing bitterness.

Nutri Snack cookies obtained the highest overall sensory scores (8.3 ± 0.2) for appearance, aroma, and flavor. Butter and eggshell-derived calcium contributed to a desirable creamy flavor and cohesive structure, enhancing palatability. **Osteomax**, a seed-based powder blend, received high texture and aroma scores (8.3 ± 0.3 and 8.0 ± 0.2, respectively) but a slightly lower flavor rating (7.8 ± 0.2), possibly due to mild flaxseed bitterness. Nevertheless, its balanced sensory performance supports its suitability as a functional supplement.

The **Sementes Wrap** achieved moderate acceptance (7.6 ± 0.3) because of a slight bitter aftertaste associated with sesame oxalates, though its aroma and appearance were rated favorably. Flavor masking strategies, such as the incorporation of herbs, yogurt-based dressings, or low-sodium condiments, may further enhance consumer perception.

Mean sensory scores are summarized in Table 6. Overall, Nutri Snack and Green Crackers (70 g spinach) exhibited the most balanced and desirable sensory profiles. The results confirm that fortification with natural calcium and vitamin D sources did not negatively influence consumer acceptance. On the contrary, the optimized ingredient ratios improved both texture and aroma, reinforcing the feasibility of producing nutritionally enhanced foods with high market appeal.

4.8 Functional and Mechanistic Insights

The integration of spinach, flaxseed, sesame, and eggshells yielded foods combining micronutrient density with functional bioactives. Spinach provides oxalate-bound calcium and magnesium, whose bioavailability can increase in the presence of vitamin C and lipid matrices. Eggshell powder contributed to highly soluble calcium carbonate and trace elements (Sr, Mg, F) that enhance bone remodeling. Seeds such as flax and sesame provide α-linolenic acid and lignans, which influence osteoblast differentiation via the Wnt/β-catenin pathway. Together, these interactions underline the multi-mechanistic potential of the developed foods: (i) direct calcium and vitamin D supply, (ii) enhanced intestinal absorption through lipid and phytochemical synergy, and (iii) modulation of bone-formation signaling.

4.9 Overall Evaluation

From both nutritional and sensory perspectives, all four formulations exhibited promising potential as cost-effective functional foods for calcium and vitamin D supplementation. Among them, the 70 g spinach Green Crackers and the Nutri Snack cookies emerged as the most acceptable and nutrient-dense prototypes. Minor formulation adjustments, such as flavor masking of sesame bitterness or partial fat substitution, could further

enhance consumer perception and commercial feasibility.

5. Conclusion

These cost-effective functional foods are rich in calcium and other bioactive compounds, and they can improve bone health and overall well-being in the elderly. However, caution is needed with calcium-rich foods for those on blood-thinning medications. The overall sensory evaluation showed that all products were good in taste, aroma, flavor, and other parameters, but concerning green crackers, the 70g spinach product showed better results.

5.1 Antioxidant Potential of Functional Ingredients

Although antioxidant assays were not performed in the present work, the ingredients used, spinach, flaxseed, and sesame seeds, are rich in phenolic compounds, lignans, and tocopherols that possess significant antioxidant activity (Arooj et al., 2023; Batool et al., 2024). These bioactives may indirectly contribute to bone protection by reducing oxidative stress induced bone resorption. Future studies should quantify the antioxidant capacity (e.g., DPPH, ABTS, FRAP) of the developed products to substantiate their therapeutic potential

5.2 Future Research

Future research must evaluate the stability and shelf-life of these fortified foods under a range of temperature and humidity conditions to ensure product safety and nutrient retention during storage. Future studies should determine the storage stability and shelf-life of such fortified foods under different temperatures and humidities to ensure product safety and nutrient retention upon storage. Furthermore, pilot-scale human trials assessing the bioavailability of calcium and vitamin D and their effect on bone markers are suggested to validate pre-clinical findings. Because nutrient quality and sensory response are not adequate to determine the bioavailability or physiological action of calcium and vitamin D, pilot human studies are needed to determine the absorption and bone metabolism activity of these functional foods in real consumers.

The present study focused on developing and evaluating calcium- and vitamin D-enriched functional foods using locally available ingredients and by-products. Although sensory evaluation and nutrient profiling confirmed their acceptability and nutritional potential, human bioavailability and physiological efficacy cannot be determined through compositional analysis alone. The absorption and utilization of calcium and vitamin D are influenced by several factors, including individual metabolic status, gut health, and interactions with other dietary components (Capozzi et al., 2020; Fleet, 2022).

Therefore, conducting pilot-scale human trials is essential to assess how effectively these nutrients are absorbed and contribute to bone health biomarkers such as serum calcium, 25(OH)D, alkaline phosphatase, and bone mineral density. Such translational research bridges the gap between food formulation and clinical application, validating the functional efficacy of developed products before large-scale commercialization or public health implementation.

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Conflict of interest

All authors declare that there is no conflict of interest.

Consent of publication

All authors gave their consent for publication.

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