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Formulation, characterization of functional crackers enriched with *Cardiospermum halicacabum* and *Drynaria quercifolia*

[1] S. Mohamed Ramlath Sabura, [2] R. Swarnalakshmi, [3] Yamuna Somaajjan
[4]Shafin Ammara and [5]M.I. Delighta Mano Joyce

[1,5]Assistant Professors of Zoology, Sadakathullah Appa College, Tirunelveli - 627 011.
[2]Assistant Professor of Food Science and Nutrition, Sarah Tucker College, Tirunelveli-627 002.
[3,4]Assistant Professors of Nutrition and Dietetics Programme, School of Allied Health Sciences, REVA University, Bangalore.
(Affiliated to Manonmaniam Sundaranar University, Tirunelveli - 627 007)
Corresponding author email ID: ramlathsabura@gmail.com
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Cardiospermum halicacabum; *Drynaria quercifolia*; plant-based crackers; functional food; bone health; calcium; sensory evaluation.

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Abstract

The present study aimed to develop and evaluate plant-based crackers incorporated with *Cardiospermum halicacabum andDrynaria quercifolia* as a value-added functional food with potential bone-health benefits. Three formulations (PC1, PC2 and PC3) were prepared by varying the levels of plant powders and evaluated for sensory, nutritional, physicochemical, functional and microbiological characteristics. PC1 showed the highest sensory acceptability, with an overall score of 24/30, and was selected as the optimized formulation. The developed product provided 1000 kcal, 150.9 g carbohydrate, 41.6 g protein, 32.7 g fat and 1914 mg calcium based on the reported formulation. Bulk density ranged from 0.42–0.48, pH from 5.3–5.4 and water activity from 0.387–0.398. Colour values showed only minor variation among formulations. PC1 exhibited the lowest microbial load, with a total plate count of 2.1×10^2 CFU/g and yeast and mould count of 1.0×10^1 CFU/g. The crackers retained acceptable sensory quality for at least 15 days under ambient storage. The production cost was approximately ₹33.3 per 100 g, indicating economic feasibility. Overall, incorporation of C. halicacabum and D. quercifolia produced an acceptable plant-based cracker with appreciable nutritional value and potential for development as a functional food.

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INTRODUCTION

Medicinal plants are important sources of bioactive compounds and have long contributed to traditional healthcare and modern drug discovery. Phytoconstituents such as flavonoids, phenolics, alkaloids, terpenoids, tannins, and glycosides exhibit diverse biological activities, particularly antioxidant and anti-inflammatory effects (1,2). Advances in chromatographic and spectroscopic techniques have further facilitated the identification and characterization of these plant-derived compounds, supporting the scientific validation of traditional medicinal practices.

Bone and musculoskeletal disorders, including osteoporosis, arthritis and impaired fracture healing, are major health concerns associated with aging, oxidative stress and chronic inflammation. Oxidative imbalance and inflammatory mediators can disrupt bone remodeling by impairing osteoblast activity and promoting osteoclast-mediated bone resorption. Consequently, medicinal plants possessing antioxidant, anti-inflammatory and osteoprotective properties are receiving increasing attention as potential complementary sources for bone-health interventions (3,4).

Cardiospermum halicacabum L. (Balloon Vine; Sapindaceae) and *Drynariaquercifolia* (L.) J. Sm. (Oak Leaf Fern; Polypodiaceae) are traditionally used for inflammatory and musculoskeletal ailments. *C. halicacabum* contains flavonoids, phenolics, alkaloids, tannins, saponins and triterpenoids and has demonstrated antioxidant and anti-inflammatory activities (4,5). Similarly, *D. quercifolia* is traditionally associated with bone strengthening and fracture recovery, and its rhizomes contain flavonoids, phenolic compounds, triterpenoids, and glycosides. However, despite promising preclinical evidence, standardized approaches for incorporating these medicinal plants into nutritionally acceptable functional foods remain limited.

Wheat flour provides a versatile nutritional matrix for developing value-added foods, while oregano (*Origanum vulgare*) contributes bioactive phenolics, flavonoids and essential oils with antioxidant and antimicrobial potential. Therefore, the present study explores the incorporation of selected medicinal plant materials into a wheat flour-based functional food formulation, with emphasis on their phytochemical potential and possible relevance to antioxidant, anti-inflammatory and bone-health-promoting applications.

MATERIALS AND METHODS

Selection and Procurement of Plant Materials

Fresh leaves of *Cardiospermum halicacabum* L. and the selected plant material of *Drynaria quercifolia* were procured from a

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local market in Tirunelveli, Tamil Nadu, India. Healthy, mature and undamaged plant materials free from visible fungal infection and physical contamination were selected. Wheat flour, sesame seeds, oregano seasoning, edible oil, salt and selected spices were procured from local commercial sources. All ingredients were stored under clean and dry conditions until further use.

Processing and Preparation of Plant Powders

The collected plant materials were manually sorted to remove damaged and extraneous materials and washed thoroughly with potable water. The cleaned materials were drained and dried under hygienic conditions until a constant weight was obtained. The dried materials were pulverized using a laboratory mixer-grinder and passed through a suitable sieve to obtain a relatively uniform powder. The prepared *C. halicacabum* and *D. quercifolia* powders were stored in clean, airtight containers until incorporation into the cracker formulations. The major ingredients used for cracker preparation were *C. halicacabum* leaf powder, *D. quercifolia* powder, wheat flour, sesame seeds, oregano seasoning, edible oil, salt, spices and water. An electronic weighing balance, mixer-grinder, stainless-steel utensils, rolling pin, cracker cutter, baking equipment, airtight packaging pouches and analytical instruments were used during product development and evaluation. All equipment and utensils were cleaned and dried before use.

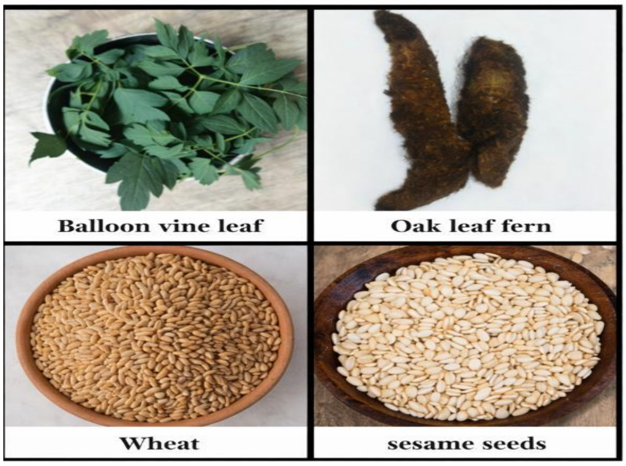

Figure1 showing the raw ingredients

Figure 2 showing the process of drying

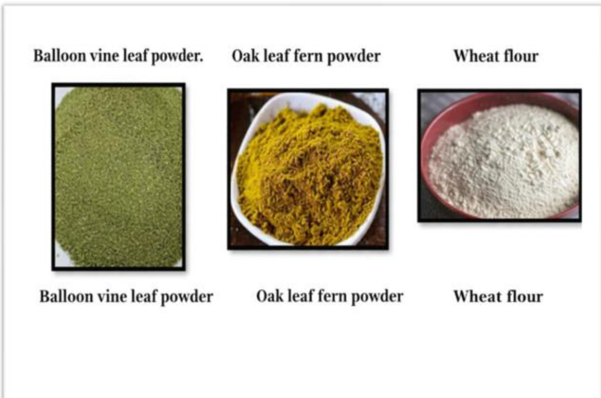

Figure 3 showing the grounded experimental samples

Figure 4 showing the dough preparation of the sample

Development of Plant-Based Crackers

Three experimental cracker formulations were developed by varying the levels of *C. halicacabum* and *D. quercifolia* powders while maintaining the basic formulation and dough consistency. A control formulation without plant powders was also prepared, wherever applicable. The ingredients were accurately weighed according to the formulation plan.

The wheat flour, plant powders, sesame seeds, oregano and spices were initially blended thoroughly. Edible oil was subsequently incorporated, followed by gradual addition of water to obtain a homogeneous dough. The dough was kneaded uniformly and allowed to rest briefly. It was then rolled into a thin sheet of approximately uniform thickness and cut into predetermined shapes. The pieces were transferred to baking trays and baked under controlled temperature and time conditions until a characteristic crisp texture and acceptable colour were obtained.

After baking, the crackers were cooled to room temperature and packed immediately in clean, airtight, food-grade pouches. The samples were coded and stored under ambient conditions until further evaluation.

Table 1 showing the formulation of plant-based crackers

S. No.	Ingredients	Quantity
1.	Balloon vine leaf powder	100 g
2.	Oak leaf fern powder	50 g
3.	Wheat flour	80 g
4.	Sesame seeds	20 g
5.	Spices	12 g
6.	Salt	5 g
7.	Olive oil	15 ml
8.	Oregano seasoning	20 g

Experimental Formulations

Three formulations were prepared to determine the effect of increasing incorporation of the selected plant powders on product quality. The proportion of *C. halicacabum* and *D. quercifolia* was varied systematically, while the quantities of the remaining ingredients were

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adjusted to obtain a workable dough and acceptable cracker structure. The formulations were coded as PC1, PC2, PC3. The formulation exhibiting the highest overall sensory acceptability was considered the optimized formulation and was subjected to detailed physicochemical and nutritional evaluation.

Table 2 shows the Formulation of Plant-Based Crackers (PC1, PC2, and PC3)

S. No.	Ingredients	PC1	PC2	PC3
1.	Balloon vine leaf powder	100 g	70 g	50 g
2.	Oak leaf fern powder	50 g	30 g	15 g
3.	Wheat flour	80 g	60 g	40 g
4.	Sesame seeds	20 g	10 g	5 g
5.	Herbs	15 g	10 g	5 g

Sensory Evaluation

Sensory quality of the developed crackers was evaluated using a semi-trained panel of 10–15 members. Samples were coded and presented in identical serving conditions to minimize bias. The panelists evaluated colour, appearance, aroma, taste, texture, crispness and overall acceptability using a nine-point hedonic scale, ranging from 1 = “dislike extremely” to 9 = “like extremely” (6,7).

The mean sensory scores were calculated for each attribute and formulation. The formulation receiving the highest overall acceptability score was selected as the optimized product for subsequent analysis.

Nutritional Analysis

Nutritional Analysis The proximate composition of the developed plant-based crackers was determined using standard analytical procedures (8). Moisture content was estimated by hot air oven drying method, crude protein by the Kjeldahl method, crude fat by Soxhlet extraction, ash content by muffle furnace incineration, and crude fibre by enzymatic–gravimetric method. Carbohydrate content was calculated by difference. The energy value was computed using Atwater factors (8,9). All analyses were carried out in triplicate to ensure accuracy and reproducibility.

Physical and Physicochemical Analysis

The physical characteristics of the crackers were evaluated by measuring weight, diameter and thickness using an electronic balance and digital vernier caliper. The spread ratio was calculated from the measured diameter and thickness, where available, hardness/crispness was determined using a texture analyzer.

Moisture content was determined by the hot-air oven method, ash by muffle-furnace incineration, crude protein by the Kjeldahl method, crude fat by Soxhlet extraction and crude fibre using an appropriate standard analytical method (8). Carbohydrate content was calculated by difference, and energy value was estimated using standard Atwater conversion factors (9). The pH and titratable acidity of the product were determined using standard analytical procedures. Peroxide value and free fatty acid content were measured to assess lipid stability where required (14).

Colour and Functional Properties

Colour Analysis Colour characteristics of the developed crackers were measured using a colorimeter based on the CIE Lab* colour system. The L* value indicates lightness, a* represents redness/greenness, and b* denotes yellowness/blueness (10,11). Measurements were taken at multiple points on the sample surface, and the mean values were recorded. Colour analysis is important as it significantly influences consumer perception and acceptability (10,11).

Functional properties of the composite flour, including water absorption capacity, oil absorption capacity and swelling capacity, were determined using standardized laboratory procedures. These measurements were used to assess the influence of plant powder incorporation on the functional characteristics of the formulation (12).

Microbiological Analysis

Microbiological quality was assessed using standard microbiological procedures (13). Total viable bacterial count, yeast and mould count and coliform count were determined where applicable. Samples were serially diluted, inoculated onto appropriate culture media and incubated under specified conditions. Results were expressed as colony-forming units per gram (CFU/g). The observed microbial counts were compared with applicable food-safety standards (13).

Shelf-Life Evaluation

The optimized cracker formulation was packed in airtight, food-grade packaging and stored under ambient conditions. Samples were evaluated at predetermined storage intervals, such as 0, 15, 30, 45 and 60 days. Changes in moisture content, sensory characteristics, peroxide value and microbiological quality were monitored during storage. Shelf stability was assessed based on changes in these parameters and the maintenance of acceptable sensory quality throughout the storage period (14,15).

Cost Analysis

The production cost of the crackers was estimated by considering the cost of raw materials, processing and packaging. The total cost was calculated for the quantity of product prepared and expressed as cost per 100 g or per unit package. The economic feasibility of the optimized formulation was subsequently assessed.

Packaging of Plant-Based Crackers

The prepared plant-based crackers were packed using clean, dry, food-grade packaging materials to ensure product safety and quality. The crackers were placed in airtight containers or packaging pouches to prevent exposure to air, moisture, and external contaminants. The product was packed in predetermined quantities and sealed properly to maintain freshness and extend shelf-life. Each package was appropriately labeled with essential product information, including product name, ingredients, date of preparation, and storage instructions. The packaged products were stored under suitable environmental conditions until further analysis and evaluation (15).

Popularization of Plant-Based Crackers

The developed plant-based crackers were popularized among adults and community members through product demonstration and sample distribution sessions. During these sessions, participants were informed about the nutritional significance of the ingredients used and the method of preparation of the product. The prepared cracker samples were distributed to the participants for tasting, enabling direct sensory evaluation. Feedback was collected from the participants regarding key sensory attributes such as taste, flavour, texture, and overall acceptability. The responses obtained from the participants were systematically recorded and analyzed to assess consumer preference and acceptance of the developed product. This activity also served to create awareness about nutraceutical plant-based foods and their potential health benefits.

Statistical Analysis

All analytical determinations were carried out in triplicate and the results were expressed as mean ± standard deviation (SD). Data obtained from the different formulations were statistically analyzed using one-way analysis of variance (ANOVA). Differences among treatment means were considered statistically significant at $p < 0.05$. Appropriate post-hoc comparisons were performed where applicable (16).

RESULT AND DISCUSSION

Standardization and Preparation of Plant-Based Crackers

Three cracker formulations (PC1, PC2 and PC3) were developed by varying the proportions of *Cardiospermumhalicacabum* and *Drynariaquercifolia*. Sensory evaluation using a 5-point hedonic scale showed that PC1 was the most acceptable formulation. PC1 recorded the highest scores for appearance (5), colour (5), taste (5), aroma (5) and overall acceptability (24/30), compared with PC2 (21/30) and PC3 (20/30). The lower scores observed for PC3, particularly texture suggest that higher plant-powder incorporation may negatively influence sensory quality (17,18).

Nutritional Composition

The developed formulation contained 1000 kcal, 150.9 g carbohydrate, 41.6 g protein, 32.7 g fat and 1914 mg calcium based on the reported ingredient composition. The relatively high calcium contribution was mainly associated with the plant materials and sesame

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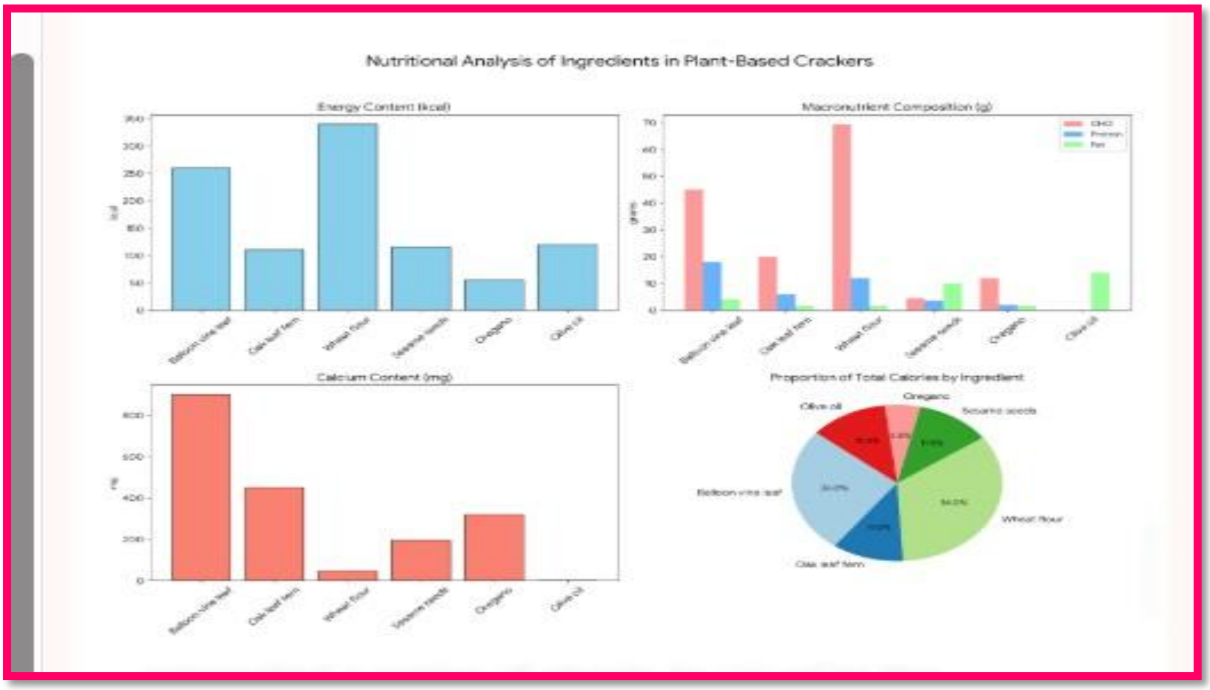
seeds, indicating the nutritional potential of the formulation as a value-added snack (1-5,17).

Figure 5 showing the nutritional



composition

Physical and Chemical Characteristics

Bulk density values were 0.48, 0.46 and 0.42 for PC1, PC2 and PC3, respectively, showing a gradual decrease across the formulations. The pH ranged from 5.3 to 5.4, while water activity remained low (0.387–0.398). These results indicate that the developed crackers had relatively low water activity, a desirable characteristic for dry baked products (14,15).

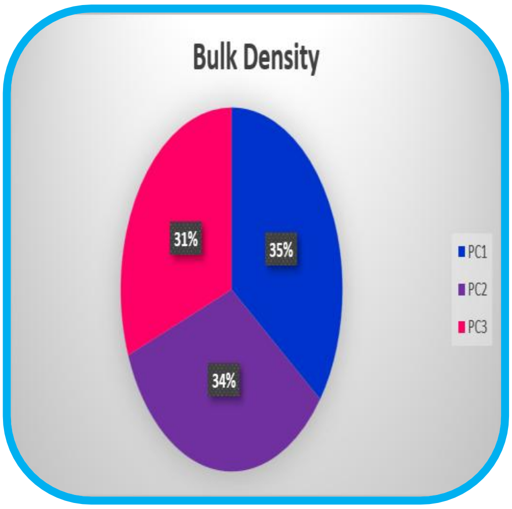


Figure 6 shows the bulk density

Colour Characteristics

The colour values showed only minor differences among formulations. L* values ranged from 44.18 to 44.43, a* from 6.01 to 6.30 and b* from 19.24 to 19.94. PC1 showed the highest L* value (44.43), indicating slightly greater lightness, whereas PC3 showed the highest a* and b* values. Overall, the formulations exhibited a relatively consistent brownish-yellow colour profile (10,11).

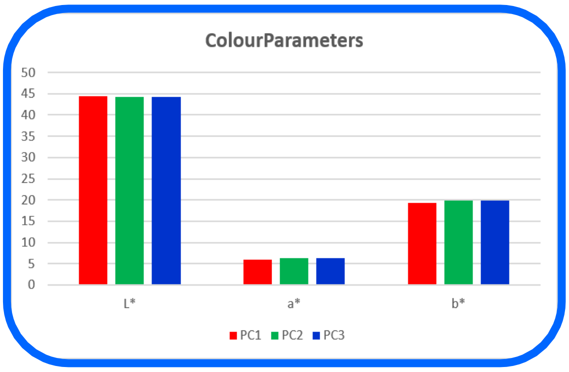


Figure 7 showing the colour parameters

Functional Properties

Water absorption capacity ranged from 181.08 to 184.35, with PC2 showing the highest value. Oil absorption ranged from 140.21 to 144.00, while swelling capacity varied from 31.45 to 33.11. The results demonstrate measurable differences in functional properties among the formulations, with PC2 exhibiting the highest water absorption and swelling capacity (12).

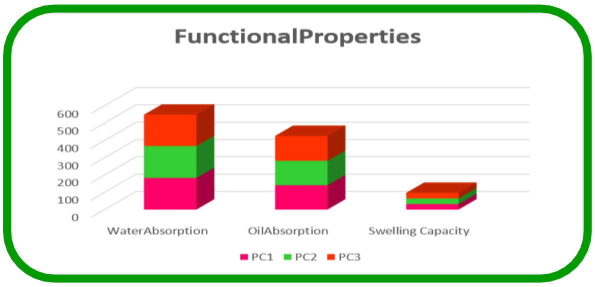


Figure 8 showing the functional properties

Microbiological Quality

The total plate count ranged from 2.1×10^2 to 2.4×10^2 CFU/g, while yeast and mould counts ranged from 1.0×10^1 to 1.2×10^1 CFU/g. PC1 recorded the lowest microbial counts among the formulations. The relatively low microbial load is consistent with the low-water-activity nature of the product and indicates satisfactory microbiological quality under the tested conditions (13,15).

Table 3 showing the Microbial Load

Sample	Total Plate Count (CFU/g)	Yeast/Mould(CFU/g)
PC 1	2.1×10^2	1.0×10^1
PC 2	2.4×10^2	1.2×10^1
PC 3	2.2×10^2	

Shelf-Life

During storage, no noticeable changes in colour or aroma were observed up to 15 days. Texture and overall quality remained unchanged up to Day 7, followed by a slight change on Day 15. Thus, the product retained acceptable sensory quality for at least 15 days under the tested ambient storage conditions (14,15).

Table 4 showing the Shelf-Life Study

Parameter	Day 0	Day 7	Day 15
Colour	No change	No change	No change
Texture	No change	No change	Slightchange
Aroma	No change	No change	No change
Overall Quality	No change	No change	Slightchange

Cost Analysis

The total cost of preparing 270 g of crackers was ₹90, corresponding to approximately ₹33.3 per 100 g. The major contributors to the ingredient cost were *C. halicacabum* (₹30), oregano (₹20) and *D. quercifolia* (₹20). The formulation therefore demonstrated reasonable economic feasibility based on the reported production cost.

Table 5 showing the Cost Calculation

Ingredient	Quantity	Cost (Rs)
Balloonvin eleaf	100 g	30
Oakleaffer n	50 g	20
Wheat flour	80 g	4
Sesameseed s	20 g	4
Olive oil	15 ml	12
Oregano	20 g	20
Total	270 g	₹90

Statistical Analysis

ANOVA indicated significant differences ($p < 0.05$) among the formulations for the evaluated sensory and functional characteristics. PC1 consistently demonstrated the highest overall sensory acceptability and was therefore selected as the optimized formulation (16).

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