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# Formulation and Characterization of High Protein Bar Incorporated with Enzymatic Modified Whey Protein Concentrate

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## ABSTRACT

*To enhance the applicability of whey proteins in the food industry, it is essential to improve their functional properties to match with the specific intended applications. This can be achieved by enzymatic modification method. The objective of this research is to develop enzymatic modified whey protein concentrate (WPC) incorporated high protein bar with the ingredients such as, millet flakes (sorghum, pearl millet, finger millet, little millet, kodo millet), traditional rice landrace (chithiraikar) flakes, sesame seeds, almonds, ghee with natural sweeteners like dates, raisins, honey, brown sugar and choco chips. Modification of WPC by enzymatic method resulted in enhanced functional properties which included increased protein solubility (from 83.5 to 85.7%), higher emulsifying capacity (from 151 to 430 g oil $g^{-1}$ protein), and foaming capacity (from 1.70 to 1.75 mL $mL^{-1}$). The textural and sensory properties were evaluated for protein bars developed using WPC and modified WPC. The modified WPC-incorporated high protein bar demonstrated superior outcomes in terms of both textural and sensory properties. A comprehensive evaluation of the physicochemical characteristics of the modified WPC incorporated high protein bar and WPC incorporated high protein bar was carried out. The findings revealed that the developed protein bars contain high protein and energy content and a significant amount of essential micronutrients. The modified WPC-incorporated high protein bar has been formulated as a nutritious dietary option for a broad demographic of health-conscious individuals.*

***Keywords:*** *Whey protein concentrate, Enzymatic modification, Functional properties, High protein bar, Protein solubility, Emulsion capacity, Foaming capacity*

## Introduction

In today's fast-paced society, people are looking for convenient and nutritious ready-to-eat options due to the challenges of time constraints involved in the preparation of traditional meals. Common snacks like extruded products, potato chips, and chocolate bars found in the market often lack the nutritional balance needed for a healthy diet (1). In response to the growing consumer preference for nutrient-rich snacks, food producers are driven to develop nutritious food bars that offer both convenience and essential nutrition (2).

Numerous delectable food bars with excellent nutritional and sensory characteristics would find immense demand among sportspersons, vulnerable population groups, the malnourished, in emergencies, and health food outlets. These bars come in various types, including, energy power, protein, breakfast/cereal, brain-boosting, and meal replacement bars. Notably, high protein bars are experiencing rapid market growth keeping in view the growth of a health-conscious generation. These bars contain over 20 grams of protein per serving, are low in carbohydrates, replete with the recommended levels of vitamins and minerals (3). The manufacturers of high protein bars face multiple challenges in the context of texture and sensorial changes during the shelf-life period. Despite multiple attempts being made until now, achieving acceptable taste and texture for some of the granola bars in the market remains elusive (4).

Whey protein concentrate (WPC 80%) is the most potent protein supplement, which is a calorie-dense, concentrated source of protein with all the essential macro and micronutrients obtained during its production. The WPC is receiving increasing interest in the food industry due to its significant advantages attributed to various functional characteristics such as solubility, emulsification, foaming, and gelation properties (5).

The nature of WPC is unstable and can lead to swift alterations in its structural integrity during processing and production, affecting its physical, chemical, and biological functions, which restricts its potential applications. Therefore, modifying WPC becomes crucial to alter its hydrophobic group distribution, spatial arrangement conformation, and amino acid composition. These modifications aim to enhance or introduce new functional properties (6). These functional characteristics contribute to improving the textural, sensory, and nutritional

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properties of the food product.

Therefore, the present study aims to develop enzymatic modified WPC incorporated high protein bars with improved taste, texture, and nutritional content. The high protein bar contains a variety of healthy ingredients, which holds great appeal to people of different age groups and fulfills to a great extent, their nutritional requirements. The high protein bar is mainly composed of nutri-cereals *i.e.,* multi millet flakes and traditional landrace chithiraikar rice flakes, modified WPC with other minor ingredients including sesame seeds, almonds, choco-chips, raisins, dates, honey, ghee, brown sugar, salt and cardamom which were added to improve the taste, flavor and nutritional properties. The physicochemical, textural, and sensory quality analysis of the high protein multigrain bar was studied. The outcomes of this study are expected to cater to the increasing demands of consumers for convenient grain bars with high nutrient content which can serve as meal replacement options.

## Materials and Methods

### Procurement of raw materials

Commercially available whey protein concentrate (WPC 80%), millets (sorghum, finger millet, pearl millet, kodo millet, and little millet), sesame seeds, dates, raisins, almonds, honey, choco chips, common salt, cardamom, ghee, brown sugar were purchased from Madurai local market.

Traditional landrace Chithiraikar rice was obtained from the Central Farm of Tamil Nadu Agricultural University, Madurai. Chemicals (Analytical grade) were obtained from the Food Science and Nutrition department, Community Science College and Research Institute, Madurai.

### Pre-treatments of raw materials:

Whey protein concentrate was modified by enzymatic method process as given in Fig.1. The modified WPC was freeze-dried, ground, and sieved. Millets and traditional landrace Chithiraikar rice were flaked and the process flow chart is given in Fig.2. The pitted dates, raisins, and almonds were chopped into fine pieces.

1. **Whey protein concentrate**
2. **Modified whey protein concentrate**

***Figure 2. Process of flaking millets and traditional rice landrace Chithiraikar (Reference.8)***

Dehulled the Chithiraikar grains

↓

Tempering the grains at 10-15%

↓

Gelatinized at 180°C @ 20 lbs. /psi pressure for 25 min

↓

Cooling the grains for surface dryness

↓

Grains were rolled into flakes in the flaking machine (aperture size of 0.25mm)

↓

Drying flake grains for 4-6 hours (moisture content, 10.5%)

↓

Stored for further analysis

1. **Sorghum flakes**
2. **Pearl millet flakes**
3. **Finger millet flakes**
4. **Little millet flakes**
5. **Kodo millet flakes**


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***Figure 1. Enzymatic modification of whey protein concentrate (Reference.7)***

Whey protein concentrate (80%)
↓
Mixed into Millipore water
↓
Agitated in magnetic stirrer
↓
Mixing till whey protein was hydrated
↓
Protein dispersion stored overnight at 4ºC
↓
Equilibrated to room temperature
↓
Adjusted pH to 7.8-8.0 using HCL/ NaOH
↓
Temperature equilibrated to 37ºC-40ºC
↓
Prepared trypsin solution and added to protein dispersions (1:100)
↓
Agitated in an incubator at 37-40ºC for 10 min
↓
Placing protein dispersions at 90ºC in a water bath (10 min) to deactivate the enzyme
↓
Freeze-drying the protein dispersions
↓
Ground the samples and sieved through a 250µm sieve

**Development of modified whey protein concentrate incorporated high protein bar:**
After the preparation of raw materials, the sugar syrup was prepared using ghee, and brown sugar, to which were added the other ingredients like modified WPC, millet flakes, traditional landrace Chithiraikar rice flakes, chopped dates, raisins, almonds, sesame seeds, choco chips, Cardamom, honey and salt, mixed thoroughly mix to ensure even distribution and to create a uniform mixture. The formulation of the high protein bar is depicted in Table 1. Following the mixing process, the grain formulation was rolled out into sheets and cut into bars of size measuring 5 cm width, 2 cm height, and 7 cm length. Each bar weighs around 50 grams and is kept in the refrigerator to set. The process flow chart of the high protein bar is given in (Fig.3).

***Table 1. Formulation of modified WPC incorporated high protein bar***

| Ingredients (g) | WPC incorporated high protein bar | Modified WPC incorporated high protein bar |
|---|---|---|
| **WPC** | - | 25 |
| **Modified WPC** | 25 | - |
| **Millet Flakes** | 7.5 | 7.5 |
| **Chithiraikar flakes** | 7.5 | 7.5 |
| **Brown sugar** | 12.5 | 12.5 |
| **Dates** | 8 | 8 |
| **Raisins** | 5 | 5 |
| **Almonds** | 5 | 5 |
| **Sesame seeds** | 5 | 5 |
| **Honey** | 15 | 15 |
| **Choco chips** | 5 | 5 |
| **Ghee** | 8 | 8 |
| **Vanilla extract (ml)** | 2 | 2 |
| **Salt** | 1 | 1 |

***Figure 3. Process flow chart of modified whey protein concentrate incorporated high protein bar***

Roast millet flakes, rice flakes, sesame seeds, almonds
↓
Made syrup using ghee and brown sugar
↓
Mix the roasted grains and other ingredients into the syrup
↓
Sheeted the syrup and added roasted grains
↓
Cutting into bars
↓
Packaging

**Modified whey protein concentrate incorporated high protein bar**


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**Assessment of functional properties**

**Protein solubility:** The solubility of whey protein concentrate was estimated according to the reference (7).

**Foaming capacity:** The foaming capacity of whey protein concentrate was analyzed by following reference (7).

**Emulsifying capacity:** The capacity of an emulsifier to emulsify a specific amount of oil which is known as emulsion capacity (EC) was measured according to the reference (9).

**Assessment of proximate composition**

**Moisture content:** The hot oven method was utilized to determine the moisture content by subjecting the sample to 105˚C until it reached a constant weight (10).

**pH:** The pH measurement was made using a digital pH meter.

**Water activity:** Water activity was determined using the Aqua Lab Series 4TE water activity meter (Decagon Devices, Pullman, Washington, USA) by the dew point detection method which utilizes a photoelectric sensor. Approximately 5 grams of the sample was placed in the testing container, which was introduced into the measurement chamber of the device. The resulting water activity value was recorded.

**Ash content:** Ash was produced through incineration in a muffle furnace at 550˚C (11).

**Protein content:** The protein was quantified through the micro Kjeldahl method, with the final result multiplied by a conversion factor of 6.38 (10).

**Fat content:** The fat content was determined using the Soxhlet extraction method, in which petroleum ether was used as the extracting solvent (10).

**Crude fiber content:** The crude fiber content was determined using the automated Fibra-Plus apparatus (11).

**Carbohydrate content:** The carbohydrate content was assessed using the anthrone method (10).

**Energy:** Energy was calculated by the factorial method, as per the following equation:

Energy (Kcal) = 4.0 x protein (g) + 4.0 x carbohydrate (g) + 9.0 x fat (g)

**Mineral content:** Minerals like Calcium, Phosphorus, magnesium, sodium, iron, and potassium were analyzed by using ICP.

**Texture profile analysis:** Texture measurements of the multigrain bars were evaluated using the texture analyzer (12).

**Sensory analysis:** The sensory attributes of the high protein bars were evaluated in a sensory laboratory at room temperature (30±5°C) by a panel of 20 semi-trained judges using a 9-point Hedonic Rating Scale to assess the sensory attributes like color/appearance, flavor, texture, taste, and overall acceptability

**Statistical analysis:** All analysis was conducted in triplicate. Mean±SD was calculated to verify the statistical significance

## Results and Discussion

**Proximate composition of whey protein concentrate:**

The results of the proximate analysis of whey protein concentrate (WPC) are summarized in Table 2. All the findings are reported per 100 grams of the sample on a dry matter basis. The WPC was determined to have a moisture content of 5.32±0.06%. According to literature, the moisture content of WPC was found to be 5.64±0.03 % (13).

The composition of whey protein concentrate, including its protein, carbohydrate, and fat content was determined to be 76.4±2.44%, 11.90±0.27%, and 3.92±0.10%, respectively. Additionally, it was found to provide an energy content of 388.48 K.cal. These results were in conformation with the findings in reference (14), the carbohydrate, protein, and fat content of WPC the results were found to be 11.80±0.87 %, 4.34±0.44 %, and 72.89±0.75 %

The ash content of WPC was found to be 2.45±0.015 % which was in agreement with the results in reference (15), showed the ash content of WPC was 2.85±0.02 %. The mineral composition including calcium, magnesium, sodium, potassium, phosphorus, and iron was found to be 522±8.16 mg/100g, 70.1±2.05 mg/100g, 175±5.47 mg/100g, 441±12.90 mg/100g, 358±6.33 mg/100g, 0.878±0.013 mg/100g respectively. According to literature, the mineral composition of WPC, the results were found to be Calcium - 5252±386 µg/g, iron - 8.77±0.75 µg/g, Magnesium - 703 ±59 µg/g, sodium - 1748±169 µg/g, potassium - 4456±363 µg/g, phosphorus - 3597±268 µg/g (14).

***Table 2. Proximate Composition of Whey Protein Concentrate***

| Parameters | Whey protein concentrate |
|---|---|
| **Moisture (%)** | 5.32±0.06 |
| **Protein (%)** | 76.4±2.44 |
| **Carbohydrate (%)** | 11.90±0.27 |
| **Fat (%)** | 3.92±0.10 |
| **Ash (%)** | 2.45±0.015 |
| **Energy (K.cal)** | 388.48±10.30 |
| **Calcium (mg/100g)** | 522±8.16 |
| **Magnesium (mg/100g)** | 70.1±2.05 |
| **Sodium (mg/100g)** | 175±5.47 |
| **Potassium (mg/100g)** | 441±12.90 |
| **Phosphorus (mg/100g)** | 358±6.33 |
| **Iron (mg/100g)** | 0.878±0.013 |


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**Functional properties of whey protein concentrate**

The functional properties of WPC and modified WPC were analyzed and the results are presented in Table 3. The results revealed that the protein solubility, emulsifying capacity, and foaming capacity of modified WPC showed an increase in functional properties. The protein solubility was 85.7±0.30 %, the emulsifying capacity was 430±9.06 g oil $g^{-1}$ protein and the foaming capacity was 1.75±0.013 mL $mL^{-1}$. According to literature, the emulsion capacity, protein solubility, and foaming capacity of milk protein concentrate (MPC) and modified milk protein concentrate (MMPC) the results were found to be 161±6 (g oil $g^{-1}$ protein) and 460±26 (g oil $g^{-1}$ protein) of emulsion capacity, 89.2±2.9 % and 80.3±3.4 % of protein solubility, 1.71±0.01 mL $mL^{-1}$ and 1.77±0.06 mL mL−1 of foaming capacity (7).

*Table 3. Functional Properties of whey protein concentrate*

| Parameters | WPC | Modified WPC |
|---|---|---|
| **Protein solubility (%)** | 83.5±0.98 | 85.7±0.30 |
| **Emulsion capacity (g oil $g^{-1}$ protein)** | 151±0.82 | 430±9.06 |
| **Foaming capacity (mL $mL^{-1}$)** | 1.70±0.02 | 1.75±0.013 |

**Nutrient composition of millet flakes and traditional landrace chithiraikar rice flakes**

The nutrient composition of millet flakes and traditional rice landrace Chithiraikar flakes were analyzed and the results are presented in Table 4. The millet flakes were found to have lower fat content (0.95-1.95 g/100g) than the native grain (0.85-4.39 g/100g). This could have resulted from dehulling and decortication operations that were performed during millet processing (16). The fat content of millet flakes was found to be low i.e., little millet flakes contain 0.40±0.19 g/100g and ragi millet flakes contain 0.67±0.05 g/100g respectively (17).

The carbohydrate content in millet flakes was notably reduced when compared to the original grains with values ranging from 62.31±0.59-67.24±0.91 g/100g for millet flakes and 67.0-78.2 g/100g for native grains (16).

Dietary fiber is an important factor for evaluating the quality of food products. It is a crucial nutraceutical component known for its diverse health benefits. The total dietary fiber (TDF) content in millet flakes was higher than that of the original grain. The increase in TDF might be attributed to the development of enzyme-resistant macromolecules, which consist of starch, protein, lipid, and non-starch polysaccharides (18).

The increased dietary fiber content in millet flakes could be attributed to the generation of resistant starch during the moist steaming and subsequent cooling phases during the process of flaking (19). High TDF content was recorded in finger millet flakes (11.37±0.37 g/100g). The protein content of pearl millet flakes was higher (10.87±0.34 g/100g) compared to other millet flakes. Similar findings of high protein content of millet flakes were reported in reference (16).

The nutritional composition of traditional rice landrace Chithiraikar flakes was analyzed and found to contain 12.04±0.29 % moisture, 1.74±0.05 % total fat, 7.23±0.09 % crude protein, 1.23±0.03 % TDF, 1.03±0.014 % total ash, 72.23±0.19 % total carbohydrates and 333.50±9.75 Kcals energy. According to literature, the chithiraikar native grain nutritional composition, and the results were found to contain 74.60 % carbohydrates, 6.90 % protein, 0.9 % of fiber, and 1.5 % fat respectively (20).

*Table 4. Nutritional composition of millet and traditional landrace chithiraikar flakes*

| Parameters | Sorghum | Pearl millet | Finger millet | Little millet | Kodo millet | Chithiraikar |
|---|---|---|---|---|---|---|
| **Moisture (%)** | 9.04±0.09 | 8.91±0.01 | 10.81±0.15 | 13.97±0.23 | 13.95±0.19 | 12.04±0.29 |
| **Fat (%)** | 0.95±0.007 | 1.34±0.01 | 1.04±0.002 | 1.21±0.04 | 1.95±0.04 | 1.74±0.05 |
| **Protein (%)** | 9.87±0.188 | 10.87±0.34 | 7.28±0.10 | 8.84±0.08 | 8.97±0.10 | 7.23±0.09 |
| **Dietary fibre (%)** | 10.34±0.14 | 11.28±0.09 | 11.37±0.37 | 6.76±0.18 | 6.46±0.14 | 1.23±0.03 |
| **Ash (%)** | 1.31±0.007 | 1.39±0.03 | 2.15±0.07 | 1.69±0.001 | 1.75±0.05 | 1.03±0.014 |
| **Carbohydrates (%)** | 67.24±0.91 | 62.31±0.59 | 66.54±1.04 | 65.12±1.50 | 66.14±1.08 | 72.23±0.19 |
| **Energy (Kcal)** | 316.99±8.19 | 304.78±9.95 | 30.64±0.16 | 306.73±1.25 | 317.99±1.51 | 333.50±9.75 |

**Physicochemical properties of WPC incorporated high protein bar and modified WPC incorporated high protein bar**

The shelf stability of food is significantly influenced by the moisture content and water activity (Aw). The water activity strongly influences both the texture of food products and the proliferation of microorganisms (21). The results for proximate composition analysis of WPC incorporated high protein bar and modified WPC incorporated high protein bar are presented in Table 5.

The WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to possess 12.20±0.10 and 12.44±0.03 % moisture and 0.64±0.01 and 0.69±0.005 water activity (Aw). The grain flakes that were utilized in the high protein bar formulations had notably low moisture content.

Dry roasting of the ingredients increases the product's shelf stability without altering the sensory profile (22). Food products with water activity less than 0.7 Aw were stable for about 6 months and had a good shelf life (23). Low water activity indicates a low risk of microbial growth, and pathogenic spoilage, and ensures that the product maintains good shelf stability.

For the development of the high protein bar, whey protein concentrate was used as the main protein source, while the other ingredients did not provide significant protein content. The results showed that the WPC incorporated high protein bar and modified WPC incorporated high protein bar contains 26.94±0.23 and 26.334±0.08 g/100g of protein. The high-protein diet bars by incorporating both whey protein concentrate and soy protein isolate had identical results with


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the protein content ranging from 20 to 23% in the final product (24).

Carbohydrates in the protein bars were mostly contributed by liquid glucose and jaggery. In this study, brown sugar, honey, dates, and raisins were added to improve the consistency and as natural sweeteners. The total carbohydrate content of the WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to be 44.12±0.48 and 44.049±1.04 g/100g. The high protein nutrition bar for undernourished children which provides 57.67-71.78 g/100g of carbohydrate content (25).

The fiber content of the incorporated WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to be 2.77±0.08 and 2.74±0.06 g/100g. The fibre content in the high protein bar was mainly contributed by the addition of millet flakes and traditional landrace Chithiraikar rice flakes. The composition of date bars which were prepared by using local ingredients like date paste, roasted chickpea, roasted white oats, skim milk powder, and dark chocolate to formulate 15 products that contributed to crude fiber ranging from 2.20 to 4.24% (26).

Fat is regarded as an essential part of everyday diet planning. Moderate dietary intake of fat has a positive influence on metabolism, athletic exercise, and body composition, as well as on body recovery (27). The results showed that the WPC incorporated high protein bar and modified WPC incorporated high protein bar contains 14.31±0.07 and 14. 52±0.40 g/100g of fat due to the addition of ghee. The ghee contains fat-soluble vitamins A, D, E, and K, in which A and E are important fat-soluble antioxidants that contribute to improving food stability by preventing rancidity (28). The calorie content of the WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to be 413.03±9.83 and 412.212±2.52 Kcal/100g. Similar findings of calorie content (425.12 g/100g) of nutribar enriched with zinc for sports athletes (29).

The mineral composition of WPC incorporated high protein bar and modified WPC incorporated high protein bar was analyzed and results showed that the nutribar provided 239.58±3.09 and 239.61±4.89 mg/100g calcium, 2.28±0.06 and 2.309±0.02 mg/100g iron, 192.34±2.35 and 192.35±5.36 mg/100g phosphorus, 183.06±0.75 and 183.05±3.11 mg/100g potassium, 58.91±1.12 and 58.92±1.24 mg/100g sodium, 60.34±1.92 and 60.337±0.73 mg/100g magnesium. The developed nutribars specifically targeted for women at risk of osteoporosis. The nutribar furnished 248-269mg calcium, 343-363mg phosphorus, and 188-211mg magnesium/bar (50g) (30). The pH of WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to be 6.94±0.10 and 6.98±0.03. Similar findings of pH (6.343-7.013) content of high-protein organic bars were reported (4). The production yield of WPC incorporated high protein bar and modified WPC incorporated high protein bar was found to be 98.73±1.94 and 98.74±1.27 %. Similar results were observed in high-protein organic muesli bars (96-99 %) (4).

***Table 5. Physicochemical properties of WPC incorporated high protein bar and modified WPC incorporated high protein bar***

| Parameters | WPC incorporated high protein bar | Modified WPC incorporated high protein bar |
|---|---|---|
| **Moisture (%)** | 12.20±0.10 | 12.44±0.03 |
| **Water activity (aw)** | 0.64±0.01 | 0.69±0.005 |
| **Protein (g/100g)** | 26.94±0.23 | 26.334±0.08 |
| **Carbohydrates (g/100g)** | 44.12±0.48 | 44.049±1.04 |
| **Fiber (g/100g)** | 2.77±0.08 | 2.74±0.06 |
| **Fat (g/100g)** | 14.31±0.07 | 14.52±0.40 |
| **Energy (Kcal/100g)** | 413.03±9.83 | 412.212±2.52 |
| **Calcium (mg/100g)** | 239.58±3.09 | 239.61±4.89 |
| **Iron (mg/100g)** | 2.28±0.06 | 2.309±0.02 |
| **Phosphorus (mg/100g)** | 192.34±2.35 | 192.35±5.36 |
| **Potassium (mg/100g)** | 183.06±0.75 | 183.05±3.11 |
| **Sodium (mg/100g)** | 58.91±1.12 | 58.92±1.24 |
| **Magnesium** | 60.34±1.92 | 60.337±0.73 |
| **Ph** | 6.94±0.10 | 6.98±0.03 |
| **Production Yield (%)** | 98.73±1.94 | 98.74±1.27 |

**Textural properties of whey protein concentrate incorporated high protein bar**

The textural properties of high protein bars were analyzed and the results are presented in Table 6. The hardness of the WPC and modified WPC incorporated high protein bars was found to be 18.40 and 16.32 respectively. Cohesiveness, springiness, chewiness, and gumminess were increased in the modified WPC-incorporated high protein bar. The textural property results for the WPC and modified WPC incorporated high protein bars were found to be 0.247 and 0.291 for cohesiveness, 0.414 and 0.422 for springiness, 1.88 and 2.0 for chewiness, 4.544 and 4.74 for gumminess respectively.

***Table 6. Textural properties of modified whey protein concentrate incorporated high protein bar***

| Parameters | Whey protein concentrate incorporated high protein bar | Modified whey protein concentrate incorporated high protein bar |
|---|---|---|
| **Hardness (N)** | 18.4±0.11 | 16.32±0.25 |
| **Cohesiveness** | 0.247±0.001 | 0.291±0.003 |
| **Springiness (mm)** | 0.414±0.01 | 0.422±0.003 |
| **Chewiness (N/mm)** | 1.88±0.06 | 2.0±0.05 |
| **Gumminess (N)** | 4.544±0.12 | 4.74±0.12 |


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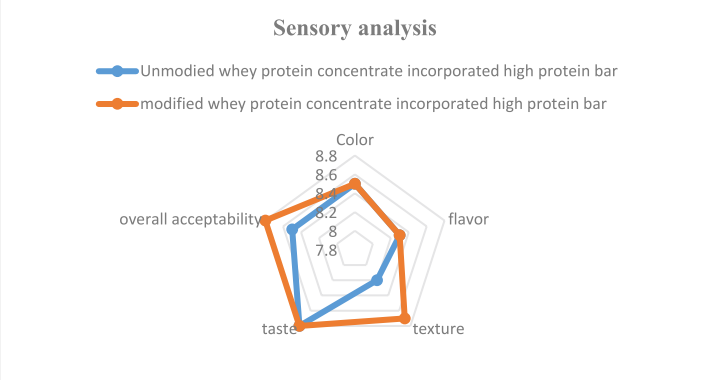
**Sensory analysis**

Sensory analysis of the high protein Nutri-bars was analyzed and the results are presented in Fig 4. The sensory profile of the modified whey protein concentrate incorporated high protein bar was compared with the control unmodified whey protein concentrate incorporated high protein bar. Results indicated that modified whey protein concentrate incorporated high protein bar had better textural properties such as chewiness and a more soft texture.

***Figure 4. Sensory analysis of developed high protein bars***




## Conclusion

The developed WPC incorporated high protein bar and modified WPC incorporated high protein bar had almost similar nutritional properties which lends its application as healthy meal replacement nutri-bars. The modified WPC incorporated high protein bar resulted in improved functional and textural properties of the high protein bar. The consumption of two bars per day containing whey protein concentrate would contribute 40% proteins and 15% calories in terms of the daily recommended dietary allowance for adults. The modified WPC incorporated high protein bar contains millet flakes, traditional landrace Chithiraikar rice flakes, dates, raisins, almonds, and sesame seeds which provide essential micronutrients. The modified WPC-incorporated high protein bar was highly acceptable as it is chewy and more palatable compared with WPC incorporated high protein bar.

**Future scope of the study:** The whey proteins will undergo modification through alternative methods like texturization, freeze modification and ultrasonic modification methods, and a comparison will be conducted to assess enhancements in functional properties. Subsequently, the modified whey proteins will be incorporated into various food products to improve their protein content and sensory acceptability.

**Conflict of interest:** The authors declare no conflict of interest

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