RESEARCH PAPER

Ranking of the Sensory Samples by Fuzzy Analysis for a Novel Nutraceutical Meal Replacer

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ABSTRACT

Background and Objectives: Diabesity represents the coexistence of obesity and type 2 diabetes. This study aimed to develop and standardize a nutritionally balanced functional beverage as a meal replacement.

Materials and Methods: The study was conducted in the Nutrition Laboratory of Amity University in the year 2025–2026. Five different samples were developed using roasted Bengal gram and barley as the main ingredients, containing 23.5 g and 10 g, along with other functional ingredients. The organoleptic evaluation was conducted using a 9-point hedonic test, and the most advanced ranking method, MAHP-TOPSIS, was used to select the best samples, and statistically significant differences were determined by One-way ANOVA. The rheological. Functional and proximate analyses were carried out in triplicate.

Results: Sample D exhibited the highest overall acceptability (7.67±2.91) and ranked first (Ci = 1). Apparent viscosity ranged from 0.0034 to 0.0042 Pa·s. Functional properties indicated good solubility (12.14–24.88%) and swelling capacity (16.58–28.66%). Nutritional analysis revealed energy (117.5–131.95 kcal), protein (5.29–5.99 g), and low fat (1.52–1.67 g).

Conclusion: Sample D demonstrated optimal sensory acceptability, desirable rheological properties, and balanced nutrition, indicating its potential as a functional meal replacement.

Keywords: Rheological properties, Sensory properties, Fuzzy analysis, Functional food, Meal Replacement

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INTRODUCTION

Diabesity, characterized by the coexistence of obesity and type 2 diabetes, is driven by insulin resistance, chronic inflammation, and sedentary lifestyles. The global prevalence is increasing rapidly, particularly in developing countries like India, due to urbanization and dietary transitions. Diabesity, the coexistence of obesity and type 2 diabetes, is characterized by insulin resistance, visceral adiposity, and chronic low-grade inflammation (Ortega et al., 2020). This pathophysiological condition arises from insulin resistance, visceral fat deposition, and chronic low-grade inflammation. It is linked to increased risk of long-term complications, including cardiovascular disease, stroke, and renal failure at its end-stage. Patients with diabesity tend to have poor physical functioning, lower life quality, and diminished life expectancy. There is also emerging evidence that indicates close associations between obesity and diabetes and psychological stress,

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depression, and sleep disturbances. (Pálsson & Patel, 2014; Tomic et al., 2022).

Meal Replacements (MRs) are widely recognized as effective dietary tools for weight management and glycemic control. (Astbury et al., 2019; Mardhiah Irfan et al., 2025). This indicates the need to come up with alternatives that are affordable, plant-based, and made with easily accessible and culturally acceptable products. To replace one or two regular meals, meal replacement products are created that can provide all the necessary nutrients to the body. Dietary and lifestyle interventions commonly include the use of meal replacement beverages by healthcare professionals for overweight and obese people. The meal replacements are available in different food forms, such as shakes, bars, and ready-to-drink beverages (Alves et al., 2013; Raza et al., 2025; Shao, 2017) (**Figure 1)**. Existing meal Replacements are predominantly dairy-based, expensive, and highly processed, limiting their accessibility. There is a need for affordable, plant-based alternatives aligned with traditional dietary patterns. Meal Replacement Foods, e.g., fortified powders, bars, beverages, and formulations ready-made, are scientifically formulated to deliver balanced micro and macro-nutrients in measured portions (Chen et al., 2020). Development of products is also important in ensuring that the products serve the needs of the consumer appropriately. The increasing demand for functional and plant-based foods has driven the development of nutritionally balanced meal replacements that are both sustainable and culturally acceptable.

……. Insert Figure 1 here……

In Asian populations, cereals and legumes form the dietary foundation and offer an opportunity for developing cost-effective, plant-based meal Replacements. Chana sattu (roasted Bengal gram flour), a traditional Indian ingredient, is rich in protein, fiber, and low glycemic index components, making it a suitable base for functional meal replacement development. It is used alongside phytonutrient-functional blends (mint, beetroot, moringa, lemon-jeera, mango), worked with bioactive extracts (curcumin + piperine) to form a nutritionally adept, anti-inflammatory, and edible meal replacement, which can be used in the context of diabesity. The present study integrates traditional ingredients with bioactive compounds such as curcumin and piperine to enhance functional and therapeutic potential, particularly for diabesity management. Single cereals and legumes will not give full nutrition of proteins, hence multi-grain beverages that contain a blend of cereals, legumes, millets, and nuts can be made to fulfill the nutritional needs. In addition, legumes and cereals will also complement the protein, which enhances the quality of the protein content. This paper concerns the design, nutritional description, and uniqueness of such a meal replacement as a basis to justify further clinical analysis.

This study evaluates the developed functional beverage using a multi-dimensional approach, including nutritional profiling, rheological characterization, sensory evaluation, and fuzzy decision-making techniques (MAHP-TOPSIS). This integrated methodology provides a comprehensive framework for optimizing food product quality and consumer acceptability replacement

NOVELTY:

- The current study focuses on the development of a plant-based, culturally relevant meal replacement formula using roasted Bengal gram and barley as main ingredients and the incorporation of bioactive compounds extracted from pepper and turmeric.
- This study integrates the advanced approaches in the selection of various samples of the products, such as MAHP-Topsis, a fuzzy analysis in a decision-making tool. It also includes the sensory evaluation assessment, physicochemical, and rheological properties of the product for better consumer acceptance.
- This novel functional meal replacement developed food product is cost-effective, nutritionally enriched, and culturally acceptable providing a balanced dietary solution for metabolic disorders.

AIM AND OBJECTIVES

1. To evaluate the feasibility and perform standardization of the raw materials to develop a meal replacement functional beverage.

2. To conduct the Organoleptic Evaluation of the developed Meal Replacement product and rank them by the MAHP and TOPSIS methods.

3. To assess the nutritional quality and rheological properties of a functional beverage as a potential meal replacement.

MATERIALS AND METHODS

Procurement of raw materials

The experimental work was carried out at the Nutrition Laboratory of Amity University, Haryana, Gurugram. The procurement of the raw material was done from the local market of the university campus and departmental stores. The ingredients were appropriately measured using an electronic weighing machine, and the rest of the materials were stored carefully.

Preparation Method

The meal-replacement formula was developed using roasted Bengal gram flour, roasted barley flour, and a flavoring agent. All five formulated samples (Sample A, Sample B, Sample C, Sample D, and Sample E) consist of 33.5-38.5g and are to be mixed in 250 mL of warm water (50 ^{0}C) for better solubility (the amount of the sample varies as per the formulation). The mixture was gently stirred to obtain a uniform, homogeneous solution. All the samples were marked as Sample A, Sample B, Sample C, Sample D, and Sample E, respectively. The formulation is discussed in **Table 1**.

The formulated functional meal replacement consists of controlled thermal processing, milling, and a combination of extracts to ensure the product's safety, bioavailability,

functional efficacy, and palatability. The steps are as follows and illustrated in **Figure 2**.

1. Raw Bengal gram was bought from the market and washed thoroughly to remove the husk, dust, and other impurities.
2. The cleaned and dried Bengal gram was roasted in hot sand at a controlled temperature (140-160 °C) for approximately 12-18 minutes) till it turned swollen and light brown. The same treatment was done for the barley.
3. The roasted Bengal quickly cooled down at room temperature to avoid the moisture condensation during milling. After that, it was ground into fine flour (high speed for approximately 1 to 2 minutes, with RPM around 22,000 to 24,000) with the help of a grinding machine (Sujata company) and sieved through a fine mesh (250 µm pore-sized) to get uniform-sized flour and smooth texture.
4. Mint leaves were cleaned and dehydrated using low-temperature drying to preserve the nutrients. The dried functional ingredients were pulverized into a fine powder and sieved for consistency.
5. Jeera spices are lightly roasted to enhance flavor and aroma, then ground and sieved.
6. The mango powder was prepared by peeling the mango and cutting it into thin slices. Then dried it in 150 ^{0}C for 60 minutes, until completely crispy. Grind the dried slices into fine powder using a grinder and store them in an airtight container.
7. A measured quantity of curcumin extract and piperine extract is taken according to the formulation requirement.
8. All dry ingredients, including chana sattu, flavor blend, and extract premix, are combined in a ribbon blender or suitable mixer.
9. The mixture is blended until a uniform color, aroma, and texture are achieved.
10. The final blended powder is packed in airtight, moisture-proof pouches under low-humidity conditions. The product is stored at room temperature away from sunlight and moisture to maintain stability and shelf life.

Steps Involved in the Development of Meal Replacement

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Sensory analysis and TOPSIS test

Quantitative Descriptive Analysis (QDA) was used for profiling the samples (Lawless et al., 1991). The formulated samples were passed with a 9-point hedonic test of organoleptic characteristics. An appropriate card with selective sensory attributes such as Appearance, Taste, Crispiness, Texture, Colour, and Overall acceptability was looked into. Initially, 25 panelists were recruited (including postgraduate students and faculty members from the Department of Nutrition and Dietetics) for the sensory evaluation. To assess the discrimination ability and reliability of the panel, a triangle test was conducted as a screening procedure. In this test, panelists were presented with three coded samples (two identical and one different) and were asked to identify the odd sample. Based on the statistical criteria for triangle testing ($p < 0.05$), only those panelists who correctly identified the different samples were retained for further evaluation. As a result, 20 panelists who demonstrated adequate sensory discrimination ability were selected as the final panel. The remaining panelists were excluded due to insufficient discrimination performance. This screening ensured that the sensory data were obtained from a reliable and responsive panel, thereby improving the accuracy and validity of the sensory evaluation results.

The Nutritionists are considered to be the semi trained panelists, so twenty semi-trained panellists (Faculties and Master's final year students) were selected from the Department of Dietetics & Applied Nutrition to rate the formulated samples on a 9-point scale, such as 9-like extremely and 1-dislike extremely, and so on. The panelists were asked to rate the sample based on the organoleptic characteristics of the product, such as Appearance, Taste, Crispiness, Texture, Colour, and Overall acceptability. After the panelist scores, the mean value was calculated for each attribute and expressed as mean ± standard deviation. All analyses were conducted in triplicate, and results are expressed as mean ± standard deviation. All analyses were conducted in triplicate, and results are expressed as mean ± standard deviation. One-way ANOVA was performed using SPSS software (version 30). Differences were considered statistically significant at $p < 0.05$.

The TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) test is a multi-criteria decision-making method that ranks alternatives by selecting the one closest to an ideal solution and farthest from the worst, allowing for effective, structured prioritization of choices based on multiple criteria. It is essential in food product development to objectively evaluate numerous prototypes against complex, often contradictory, factors like sensory attributes (D. et al. Sharma, 2025; L. Sharma et al., 2025).

The study was reviewed and approved by Amity University Haryana, under approval **Ref.No.IEC-AMS/AUH/81/2025-2026**.

FUNCTIONAL PROPERTIES

Swelling and solubility characteristics

The swelling and solubility characteristics of the developed formulated meal replacement formula were assessed at the various temperatures of 30, 50, 70, and 90 ^{0}C. Singh and Ali (2000), demonstrated a method that which about 500 mg dry weight of the sample was boiled in 20 mL water o this controlled temperature. They were measured and made equivalent to 25.5 mL by pouring the distilled water into

them. Then the sample was centrifuged for 15 minutes at 3000 RPM. The supernatant was taken, and the residue was measured to determine the swelling power. In a petri dish, 10 mL of the supernatant was kept for water bath evaporation. The Petri dish was dried at 105 ^{0}C for 3 hours, then cooled and measured it (V. Singh & Ali, 2000).

Water absorption and soluble index

Water absorption index (WAI) of the formulated mix and water solubility index (WSI) were evaluated by dried solids from the supernatant as per the method demonstrated by Anderson et al., 1969. The WAI and WSI methods are used to assess the functional characteristics of food and the behavior of the particle upon processing. These parameters are used to identify the physicochemical changes of the biopolymers in the form of extrusion processing. In a 50 mL pre-weighed centrifuge tube, 2.5g of the food sample was added to 30 mL of water, then stirred gently for 30 minutes at 30 ^{0}C and centrifuged for 10-15 minutes at 3000 RPM. The supernatant was poured carefully into the evaporating dish. The rest pellet material was weighed, and WAI was calculated. The dried solid obtained from the water absorption test was articulated as a dry solid percentage in a 2.5 g sample (Sci. & 1969, n.d.).

Particle size analysis

Samples sieved with a 250 µm pore-sized mesh were used for particle size analysis by the Microtrac Blue Wave Particle size analyzer. It uses Laser Diffraction (LD), a light scattering technique, to determine the size distribution of the sieved material, measuring how light scatters off particles to calculate sizes, complying with standards like ISO 13320. The method involves wetting or dispersing the powder and passing it through the analyzer's cell, which directs light from lasers (often multiple) through the sample, capturing scattered light to build a detailed size distribution curve, from fine to coarse particles.

Rheological analysis of sattu beverage

The viscosity and flow behavior of the formulated sample were used to analyze the rheological properties of the food. A rheometer MCR 102 (Anton Paar, GmbH, Germany) advanced with a 4-bladed impeller ST22-4V-40 was used to measure these properties, the temperature controlled at 20±2 ^{0}C. The impeller was introduced vertically into the specimen container containing the food sample, and the shear rate range from 1-100 s-1 was identified for the rheological analysis. The analysis was done in triplicate for each sample using rheological software (Meher et al., 2017). The observed shear-thickening behavior suggests increased resistance at higher shear rates, which may enhance satiety and mouthfeel.

Sedimentation Index (SI)

The sedimentation index was determined by the method explained by Cano-Ruiz and Richter (1998) (Cano-Ruiz & Richter, 1998). The formulated samples were mixed properly and transferred to 15 mL test tubes. The h_o is indicated as the initial height of the sample in the test tube. Then the sample was centrifuged for 20 minutes at 3000 RPM, and the sedimented height in the test tube is indicated as h_f. The SI was calculated using the following formula Sedimentation Index (SI) = h_o/h_f

Shelf-life analysis (Free fatty analysis)

Fat was extracted by soaking the sample in petroleum ether (boiling range 60-80 °C) for 5 hours or overnight at room temperature. The extract was filtered through Whatman No. 1 filter paper, and the filtrate was divided into two equal portions. One portion was transferred to a pre-weighed Petri dish, evaporated on a water bath, and then dried at 105 °C for 1 hour.

To the second portion of the filtrate, an equal volume of warm neutral alcohol was added, followed by titration with a standard alkali solution using phenolphthalein as the indicator. Free fatty acid (FFA) content was calculated and expressed as oleic acid percentage using Equation (3):

FFA (%) = (Volume of alkali × Normality of alkali × 28.2) / Weight of fat.

Proximate analysis

Determination of moisture

The moisture content of the dehydrated yam chips was determined using the standard method prescribed by the Association of Official Analytical Chemists (AOAC, 2005). For each determination, 2 g of the sample was accurately weighed using a chemical balance (Model UB-302 IFS, England) and placed in a clean, dry tray. The tray containing the sample was then dried in a hot-air oven (Gallenkamp, Model OV 880, London, England) maintained at 80 °C for 14-15 hours, or until a constant weight was achieved. After cooling the sample in a desiccator, its mass was measured. This process was repeated until a constant weight was obtained. The moisture content percentage was then calculated based on the weight loss, following the procedure outlined in A.O.A.C. No. 945.38 (AOAC, 2005).

Determination of ash

Two grams of oven-dried and milled samples were placed in pre-weighed, dry porcelain crucibles and measured using a balance (Model UB-302 IFS, England). Each sample was heated on a hot plate until the release of black fumes indicated the removal of water and other volatile substances. The samples were then incinerated in a muffle furnace (Gallenkamp, OV 880 Model, London, England) that had been preheated for six hours. After cooling in a desiccator, the crucibles containing the ash were weighed, and the ash content percentage was determined following the procedure described in A.O.A.C. No. 936.07 (AOAC, 2005).

Determination of crude fat

Each sample was placed directly into a solvent extraction thimble and then inserted into a 2 g extraction tube, which was sealed with glass wool. The tube was weighed before being placed in a 250 mL Soxhlet flask filled with 200 mL of petroleum ether (boiling point 40°-60°C). The extraction process was carried out by refluxing for 3 hours. Afterward,

the sample was removed, and the flask was emptied. The apparatus was reassembled to allow the ether to be recovered by siphoning while distillation continued. The flask was then heated on a steam bath to evaporate any remaining ether and dried overnight in an oven at 60°C. Once cooled in a desiccator, the flask was weighed. The crude fat content was calculated as a percentage of the original sample weight following the procedure described in A.O.A.C. No. 2003.05 (AOAC, 2005).

Determination of crude fiber

A 750 mL Erlenmeyer flask containing the extracted sample from the crude fat analysis and 0.5 g of asbestos was prepared. Then, 200 mL of boiling 1.25% sulfuric acid (H_2SO_4) was added, and the flask was immediately placed in a boiling water bath fitted with a condenser. The mixture was brought to a boil for 1 minute, followed by digestion for 30 minutes. After digestion, the liquid was poured through a funnel lined with a linen cloth and washed until the filtrate was no longer acidic. Next, 200 mL of boiling 1.25% sodium hydroxide (NaOH) solution was used to wash the residue, which was then returned to the flask. The condenser was reattached, and the mixture was boiled for another 30 minutes. The sample was then rinsed repeatedly with hot water until the washings no longer had an alkaline taste and filtered again through the linen cloth. The residue was transferred to a clean crucible with a spatula, and any remaining particles were rinsed into the crucible with 15 mL of ethanol. The crucible was dried in a kiln (Gallenkamp, Model OV 880, England) for 24 hours, cooled in a desiccator, and weighed. Finally, the crucible and contents were ashed in a muffle furnace (Size 2, England) at 600°C for 30 minutes, cooled, and weighed again. The crude fiber content was determined as a percentage of the original sample weight following the procedure described in A.O.A.C. method 920.86 (AOAC, 2005).

Determination of crude protein

Using a balance (Model UB-302 IFS, England), 2 g of the sample was weighed into a digestion flask, followed by the addition of 0.5 g of selenium reagent. Then, 25 mL of concentrated sulfuric acid (H_2SO_4) was added, and the flask was shaken thoroughly to mix the contents evenly. The flask was heated on a digestion burner for 8 hours until the solution turned green and clear. The digested solution was then transferred to a 100 mL volumetric flask and diluted to the mark with distilled water.

In a 250 mL conical flask, 25 mL of 2% boric acid, 2 drops of mixed indicator solution (prepared by combining 20 mL bromocresol green and 4 mL methyl red), and 15 mL of 40% sodium hydroxide (NaOH) were added. Next, 10 mL of the digested sample was placed in a Kjeldahl distillation flask. The condenser tip was positioned so that it dipped into the boric acid solution in the conical flask. Ammonia (NH_3) released from the sample was distilled into the boric acid, causing the solution to turn bluish-green. The distillate was then titrated with 0.1 M hydrochloric acid (HCl) until the color disappeared.

The total nitrogen and crude protein percentages were calculated following the method described in Appendix A of A.O.A.C. No. 2001.11 (AOAC, 2005). Protein content was determined by multiplying the nitrogen percentage by the conversion factor of 6.25.

Determination of total carbohydrates

A different approach was used to obtain the total proportion of carbohydrates. According to A.O.A.C. No. 986.25 (AOAC, 2005), the accessible carbohydrate content was estimated by subtracting 100 from A, where A equals moisture plus crude fat plus ash plus crude fiber plus crude protein.

RESULTS AND DISCUSSION

Sensory evaluation result

Sample D achieved the highest overall acceptability score (7.67±2.91), along with top ratings in appearance (7.7±1.52), taste (7.32±1.73), color (7.82±1.33), and texture (6.27±3.20), indicating it was the most preferred sample. Sample C followed with an overall acceptability of 6.85±3.19 and relatively high scores for appearance (7.27±1.51), taste (6.9±1.71), and color (7.65±1.18). Samples A and E showed moderate performance, with overall acceptability values of 6.2±1.64 and 6.12±3.41, respectively, while Sample B recorded the lowest overall acceptability (5.77±2.75). Crispiness scores were low across all samples, ranging from 1.57±3.04 (Sample E) to 2.15±3.42 (Sample A), indicating poor and inconsistent crispiness. The sensory result is summarized in **Table 2** and the radar chart is illustrated in **Figure 3**. The sensory results show a significant difference ($p<0.05$) among the various formulated samples against the various attributes such as color, texture, taste, appearance, and overall acceptability. Sample D shows the highest overall acceptability among the various formulated samples, indicating the superior organoleptic quality.

……. Insert Figure 3 here……

……... Insert Table 2 here……

MAHP & TOPSIS of Meal Replacement Beverage

Finding the weights by Means of the Analytical Hierarchy Process (AHP)

MAHP is used for selecting the best option from a list of available alternatives. A pair-wise comparison scale was used for the ranking procedure (D. et al. Sharma, 2025; L. Sharma et al., 2025).

Analytical Hierarchy Process technique

Let the set of evaluation criteria be denoted as A={Aj}, where j = 1, 2, 3… n. A pairwise comparison matrix Z is then constructed for the "n" criteria, resulting in an n×n matrix. Each element of this matrix is represented as Z_{ij}, where i,j = 1,2,3,……., n, and indicates the relative importance of criterion "i" over criterion "j". Step-by-step protocols of the MAHP and TOPSIS methods are presented in **Table 3**.

AHP calculation

Step 1: The first step is to draw a '5*5' matrix for five different samples, and calculations were done

Step 2: After drawing the matrix, the calculation of 4th root was done. 4th root for A= (1* 0.33* 0.20* 0.11*0.14)1/4; B= (3* 1* 0.33* 0.11*0.20)1/4; C= (5* 3* 1*1*0.33)1/4; D= (9* 9*1*1*9)1/4 ; E= (7*5*3*0.11*1)

Step 3: After 4th root calculation, the summation of all 4th roots was calculated, which shows 9.0151.

Step 4: After that, the PV value for each group was calculated. The PV value was calculated by dividing the 4th root for each sample by the summation of 4th roots (eg, 0.1004/9.0151=0.0111), following the same procedure for the calculation of all variables

Step 5: The summation PV for each variable was calculated as, Sum PV for A= 25*0.0111 = 0.27; For B= 18.33*0.0426= 0.78; For C= 5.53*0.1652 = 0.88; For D= 2.33*5.196 = 1.34; For E = 10.67*0.2045=2.18;

Step 6: Then the calculation of Total for Sum PV= λ(max) {Lambda- max} was done. λ(max)= Σ(PV (A,B,C,D,E) = 5.45

Step 7: Then the next step is to calculate CI value (Consistency Index). It is calculated using formula given below:

CI= (λ(max) – n)/ (n-1), Where n= number of systems/ variables being compared CI (Consistency Index) = 5.45-5/ 4= 0.112

Step 7: Then finally, the CR (Consistency Ratio) value was calculated by dividing CI (Consistency Index) by RI value, Where, RI is Random Index. The Values of RI are 5=1.12, 6=1.24, 7= 1.32, 8=1.41, and 9=1.45.

- In this study, 6 criteria were compared; RI for this is 1.24. The process of CR calculation is 0.112/1.24 = 0.090
- The CR value is used to calculate the consistency of different samples taken, and its value should be less than 0.1.
- The CR for this study found 0.090, which shows less than 0.1; hence, this CR value is accepted.

TOPSIS for Ranking the Samples of

The only mean value of the sensory results of all 6 attributes was used to calculate the TOPSIS result, along with the calculated weightage of AHP.

Test results of the 9-scale Hedonic rating were then analyzed, and mean and standard deviation were calculated. All five samples were ranked using TOPSIS.

m= varieties of sample= 5; n= number of attributes= 6

Calculation of (Σx2 ij)1/2 for each row

The results present the values of S_i^+, S_i^-, and the closeness coefficient $C_i$for the five samples along with their final ranks. Sample-A has $S_i^+ = 0.6847$, $S_i^- = 0$, and $C_i = 0$, giving it the lowest rank (5). Sample-B shows $S_i^+ = 0.6541$, $S_i^- = 0.0307$, and $C_i = 0.0448$, placing it in rank 4. Sample-C has $S_i^+ = 0.5090$, $S_i^- = 0.1758$, and $C_i = 0.2567$, ranking third. Sample-E records $S_i^+ = 0.4840$, $S_i^- = 0.2010$, and $C_i = 0.2935$, giving rank 2. Sample-D has $S_i^+ = 0$, $S_i^- = 0.6847$, and $C_i = 1$, achieving the first rank.

…….. Insert Table 3……

Ranking

Sample D indicates the highest overall ranking, followed by Sample E, C, and B, while Sample A received the lowest rank. This reflects that Sample D was the most accepted among all the samples, whereas Sample A showed the lowest level of acceptance.

Rheological analysis

The rheological properties of the formulated samples showed measurable variation among formulations. The apparent viscosity of the formulated sample showed the values between 0.0034-0.0042 Pa·s. Among the samples, D showed the maximum viscosity of 0.0042 Pa·s followed by Sample E, 0.0040 Pa·s, whereas Sample B showed a lower viscosity of 0.0034 Pa·S. The consistency index (k) of 1.6354×10^{-5} to 1.1136×10^{-4} indicates noticeable differences in sample thickness. Sample E showed the highest consistency index, while Sample B had the minimum value, as illustrated in **Table 4**. The flow behavior of all formulated samples was calculated, and the values ranged from 1.6513 to 1.9482. These values indicate the shear-thickening flow behavior. Among the samples, Sample E showed the highest value (1.9482) while Sample D showed the lowest (1.6513). The sedimentation index values ranged from 24.55-49.57, indicating the significant association in the physical stability of formulated samples. The highest sedimentation index values were found in Sample E 49.57, Sample A 35.47, and Sample D 33.41, whereas the lowest values were found in Sample B (24.55), indicating comparatively better suspension stability. The high values of SI in the formulated samples indicate the decreased stability and nutritional quality of the samples. The aggregation of degraded protein present in the formulated samples might be the reason for the sedimentation as described by (Baccouche et al., 2013) (**Table 4**). So, the rheological analysis revealed significant differences ($p < 0.05$) among the formulated beverage samples in apparent viscosity, consistency index, flow behaviour index, and sedimentation index. Due to the complex nature of the ingredients used in the formulations, their interaction with pectin contributed to an increase in beverage viscosity at 5% enrichment. This observation was supported by sensory evaluation results, as confirmed by the panelists during assessment of sensory characteristics. The concentration of both pectin and beetroot juice showed a significant effect on the shear stress-related stability and degradability of the sattu beverage. Similar trends have been reported in earlier studies on fruit yogurt and lactic beverages (Penna et al., 2001; G. Singh & Muthukumarappan, 2008). As an increase in viscosity was observed, rheological analysis was carried out using the

Herschel-Bulkley fluid model by determining the consistency index and flow behavior index. The consistency index values further indicated an increase in viscosity among the beverage samples. Moreover, the flow behavior index for all samples exceeded unity, demonstrating that the beverages exhibited shear-thickening (dilatant) flow behavior.

The rheogram (**Figure 4**) illustrates the relationship between shear stress and shear rate for the blank sample and formulated beverage samples A to E. In all cases, shear stress increases non-linearly with increasing shear rate, indicating non-Newtonian flow behavior. The upward curvature of the plots shows that the samples exhibit shear-thickening (dilatant) behavior, where resistance to flow increases as the applied shear rate increases. This observation is consistent with flow behavior index (n) values greater than 1 obtained from the rheological analysis. Among the samples, differences in the magnitude of shear stress at a given shear rate reflect variations in viscosity and structural interactions within the formulations. Samples having the more curve show a greater resistance to flow, indicating stronger particle-particle or particle-liquid interaction, while the sample having the down curve flows more easily under shear. The blank sample normally shows comparatively lower shear stress than the formulated or mixed samples, which highlights the integration of added ingredients into viscosity development. The solid line represents the model-fitted data, which closely follows the experimental points, and confirms the good fit of the rheological properties to observe the flow behavior of the meal replacement samples.

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Functional properties of the meal replacement drink

Swelling power and solubility

The swelling power of the formulated mix was increased as the temperature increased from 30 ^{0}C to 90 ^{0}C. The Swelling power of the formulated mix at 30 ^{0}C was indicating 17.69 (Sample A), 17.47 (Sample B), 16.58 (Sample C), Sample D (16.71), and 17.42 (Sample E), this implies its water holding capacity (Liang & King, 2003) and was depend on the amylose content in the formulated mix. When the heating temperature rises the crystalline structure of starch changes due to the disappearance of the moisture/water content of the mix. An increase in granule swelling and solubility is caused when the water molecule gets linked, by hydrogen bonding, to the exposed hydroxyl group of amylose and amylopectin of the starch (Liang & King, 2003). Significant difference was observed in swelling power in the formulated samples at 30 ^{0}C, 50 ^{0}C, 70 ^{0}C, and 90 ^{0}C. Significant difference was also observed for solubility between the formulated samples (Sample A, Sample B, Sample C, Sample D & Sample E) at 30 ^{0}C, 50 ^{0}C, 70 ^{0}C, and 90 ^{0}C, respectively. The swelling power ranged 16-28% for samples A, B, C, D, and E. The solubility for Sample A, Sample B, Sample C, Sample D & Sample E ranged from 12 to 24%. The high swelling power and solubility of samples indicate the higher susceptibility of its starch granules to disintegrate and the linear molecules get leached out. A shorter average amylopectin chain length could be one of the reasons for the excessive leaching of starch in the control sample (Mizukami et al., 1999). The low swelling power and solubility of the samples propose the presence of more amylose-lipid complexes and a stronger bonding force within the interior of the starch granules (Tester et al., 1990). Ong and Blanshard (1995), observed that a double helix structure of amylose occurred due to the interaction of amylopectin, and upon heating it lowers the swelling and leaching materials. This may also be the reason for low solubility and swelling power in the samples (Ong et al., n.d.) (**Table 5**).

WAI and WSI

The WAI is generally used as an indicator of gelatinization, and it indicates the water content absorbed by the starch molecules, whereas the WSI is an indicator of dried solids obtained by removing the evaporated water molecules from the supernatant. So, increased WAI was found in 3.66 (Sample A), 2.74 (Sample B), 2.53 (Sample C), 3.02 (Sample D), and 3.11 (Sample E) for formulated samples. Significant difference was observed in WAI formulated samples when treated at the 0 day; however, no significant difference was observed at 30 and 60 days. The WAI increased when the samples were stored for longer. The increased WAI indicates the higher amylose content, whereas the lower WAI indicates high water binding capacity and thus decreases the water availability for gelatinization of starch molecules (**Table 5**). A significant difference was found in the formulated sample at 0, 30, and 60 days of WSI value. The WSI value reduced during the storage period when compared to WAI. This phenomenon resulted the reduced viscosity and increased protein content, which made it less soluble and affected the reconstitution ability. Because of this, raw material, which consists of starch molecules, can expand and absorb water well (Ding et al., 2005). Hence, the samples that have low WSI were highly soluble in water but had less protein (**Table 5**).

Particle size analysis

The particle size distribution values of formulated samples revealed that Sample C, Sample D, and Sample E had a larger diameter, followed by Sample A, and then Sample B (**Table 5**). Generally, the viscosity of solutions of the products is significantly affected by differences in particle size distribution among products. Dispersion containing coarse fractions exhibited more viscous behavior than dispersions made up of ‘‘medium fine’’ or ‘‘very fine’’ particles (Ihekoronye, 1988). Width of the Sample A, Sample B, Sample C, Sample D, and Sample E, respectively. The samples' particle size characteristics showed clear differences in diameter, volume percentage, and width. The average particle diameter was found in between 47.51-78.45 μm, the Sample B showing the smallest (47.51 μm) and Sample C showing the highest (78.45 μm), as explained in **Table 5**.

…….. Insert Table 5 here……

Shelf-life analysis of meal replacement drink (Free fatty acid analysis)

The free fatty acid (FFA) levels of Bengal gram and barley across the samples were expressed as percentages and showed clear variation among formulations. In the case of Bengal gram, FFA values ranged between 0.18% and 0.22%. Samples A and C recorded the highest values (0.22%), followed by Sample B (0.21%), while Samples D and E exhibited the lowest FFA content at 0.18%. Barley samples showed relatively higher free fatty acid levels, with values ranging from 0.34% to 0.38%. The highest FFA content was observed in Samples C and D (0.38%), followed by Sample B (0.37%) and Sample A (0.35%), whereas Sample E had the lowest value (0.34%).

Nutritional value

The developed formulated meal replacement shows the balanced macronutrients in 100 g of all the Samples (A to E). The product shows the minimum moisture and fat content, rendering the appropriate shelf-life of the product and the low fat as a healthier option. The nutritional value and graph have been demonstrated in **Table 6** and **Figure 5**. The moisture content ranged from 3.085 to 4.155g, which is very significant for storing the sample for longer use. The ash content of the sample ranged from 0.59 to 0.89, which shows the total amount of mineral content in the sample. The energy content of this health drink varies from 117.5 to 131.95 Kcal, which could be a better meal replacement. Sample A shows the least energy, while samples C, D, and E had more energy content because of the higher carbohydrate, protein, and fat content. The sample C contains the most carbohydrates of 20.83 to 23.58g across the sample; this higher carbohydrate content shows a continuous source of energy for a longer period of time. The developed product also shows a significant amount of protein content, 5.29 to 5.99 g, which indicates good muscle growth and makes us feel full.

…….. Insert Table 6 here……

The product also shows the least content of fat across the samples, 1.52-1.67 g, which shows that the product is the healthier option for health-conscious people and for heart and liver patients. It also shows a significant amount of dietary fiber content, 2.78-3.73, which could be a healthier option for many people, such as those with constipation problems, and also be good for prescribing to people with diabesity. Overall, the sample shows good nutritional qualities for the healthy meal replacement drink. Moreover, Sample D had the most balanced and nutritionally significant profile and was a healthy meal replacement formula.

……. Insert Figure 5 here…….

Strengthen linkage to the food/dairy sector

The developed formulated plant-based meal replacement offers various advantages compared to existing dairy-based meal replacements. As these dairy-based foods contain lactose, which may cause the lactose intolerance problem to many people, specially of Asian countries. However, the present study focused on the development of the lactose-free product, which can be acceptable by any age group without any problem, and focused on its wider applicability. The developed product containing the locally grown food ingredients, such as roasted Bengal gram, barley with significantly available at minimum cost and improved affordability and accessibility for the middle- and low-income group people.

The product also shows improved shear-thickening properties (n>1), indicating greater resistance under shear, which in turn improves satiety and mouthfeel. The efficient hydration and reconstitution are just because of enhanced wettability and solubility, which are an essential part of consumer satisfaction.

From the marketing point of view, the product is in accordance with the functional beverage market, especially the nutraceutical and plant-based segments. The increasing consumer demand for sustainable, healthy, and clean-labeled products provides a suitable space for the commercialization of such developed products. Moreover, the incorporation of bioactive molecules such as piperine and curcumin enhances the bioavailability of the products and shows many therapeutic health benefits, especially in managing metabolic disorders such as diabesity.

It also demonstrates the promising applicability with advanced and instant expansion in the plant-based nutrition sector. With the increased demand and movement of consumers towards healthy products, this product is a key player in the current global trends in functional and nutraceutical products. This product is a complete and balanced mixture of macronutrients, good functional products, and significant rheological properties, and the highest sensory acceptability, which makes it more convenient and suitable for meal replacement.

Overall, this novel developed food product is aligned with the current trends in plant-based nutrition, functional nutraceutical foods, a cost-effective option for the dietary management of lifestyle-related disorders, and also it holds the potential for commercialization in the beverage sector.

CONCLUSION

The present investigation demonstrates that the formulated functional meal replacement drink mix is the key requirement of an effective meal replacement. It shows the significant nutritional adequacy, sensory attributes, appropriate rheological characteristics, and storage stability. The ingredients used in the meal replacement formulation are roasted Bengal gram and barley flour, resulting in a nutrient-rich formulation that would provide adequate energy, protein, and appropriate dietary fiber with low fat content. This formulation makes a suitable meal replacement supplement product for health-conscious people. These would be suitable for those suffering from diabesity, as they have low glycemic index ingredients. The rheological properties of the sample revealed the appropriate flow behavior, viscosity, solubility, and hydration capacity, which provide easy preparation, improved satiety, and user convenience. The shelf life indicates the safety of the products throughout the storage

periods. The study concludes that the developed formulated functional meal replacement mix, particularly Sampel D, shows the highest potential and affordable and nutritionally balanced meal replacement.

ABBREVIATIONS

MRs: Meal Replacements

LD: Laser Diffraction

WAI: Water absorption capacity

WSI: Water solubility Index

ISO: International Organization for Standardization

SI: Sedimentation Index

FFA: Free Fatty Acids

A.O.A.C.: Association of Official Analytical Chemists International

HCl: Hydrochloric acid

NaOH: Sodium hydroxide

mL: Milliliter

MAHP: Means of Analytical Hierarchy Process

TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

Si+: Positive Ideal Solution

Si-: Negative Ideal Solution

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Table 1: Raw Ingredients Variants for the meal replacement

Ingredient	Amount (g)

	Sample A (Turmeric & Piperine)	Sample B (Lemon)	Sample C (Beetroot)	Sample D (Mint)	Sample E (Mango Sweet)
Roasted gram flour	23.5 g	23.5 g	23.5 g	23.5 g	23.5 g
Barley roasted flour	10 g	10 g	10 g	10 g	10 g
Spices & natural flavoring agents	Curcumin extract (1 g) Piperine (500 mg)	Lemon juice (10 ml)	Beetroot powder (5 g)	Mint powder (5 g)	Ripe mango powder (5 g)

Table 2: Sensory evaluation result

Sample	Appearance	Taste	Color	Crispiness	Texture	Overall
A	6.15 ± 0.98^{a}	6.15 ± 1.08^{a}	6.5 ± 0.88^{a}	2.15 ± 3.42^{a}	5.7 ± 2.29^{a}	6.2 ± 1.64^{a}
B	6.15 ± 1.13^{a}	6.12 ± 1.19^{a}	6.25 ± 1.51^{a}	1.65 ± 2.87^{a}	5.55 ± 2.28^{a}	5.77 ± 2.75^{a}
C	7.27 ± 1.51^{b}	6.9 ± 1.71^{b}	7.65 ± 1.18^{b}	1.7 ± 3.13^{a}	5.95 ± 2.98^{b}	6.85 ± 3.19^{b}
D	7.7 ± 1.52^{c}	7.32 ± 1.73^{c}	7.82 ± 1.33^{c}	1.82 ± 3.39^{a}	6.27 ± 3.20^{c}	7.67 ± 2.91^{c}
E	6.77 ± 1.36^{b}	6.47 ± 1.39^{b}	6.57 ± 1.51^{a}	1.57 ± 3.04^{a}	5.7 ± 2.97^{a}	6.12 ± 3.41^{a}
***p*-value**	< 0.05	< 0.05	< 0.05	> 0.05	< 0.05	< 0.05

Different superscripts (a, b, c) within a column indicate significant differences ($p < 0.05$).

Table 3: (Σx2 ij)1/2, rij for each attribute, and Positive (V+) and Negative Ideal (V-) Situation

Calculation of (Σx2 ij)1/2 for each row of five sample						
	Appearance	Taste	Colour	Texture	Crispiness	Overall
Sample A	0.402364	0.416215	0.41599	0.537294	0.436531	0.422897
Sample B	0.402364	0.414185	0.39999	0.412342	0.425044	0.393567
Sample C	0.47564	0.466973	0.489588	0.424837	0.455677	0.467233
Sample D	0.503773	0.495398	0.500468	0.454825	0.480184	0.523164
Sample E	0.442928	0.437872	0.42047	0.392349	0.436531	0.41744

rij for each attribute of the five samples						
	Appearance	Taste	Colour	Texture	Crispiness	Overall
Sample A	0.0044662404	0.0046199865	0.004617489	0.0059639634	0.0048454941	0.0046941567
Sample B	0.0171407064	0.017644281	0.017039574	0.0175657692	0.0181068744	0.0167659542
Sample C	0.078575728	0.0771439396	0.0808799376	0.0701830724	0.0752778404	0.0771868916
Sample D	0.2903243799	0.2854978674	0.2884197084	0.2621156475	0.2767300392	0.3014994132
Sample E	0.090578776	0.089544824	0.085986115	0.0802353705	0.0892705895	0.08536648

Positive (V+) and Negative Ideal (V-) Situation						
	Appearance	Taste	Colour	Texture	Crispiness	Overall
V+	0.2903243799	0.2854978674	0.2884197084	0.2621156475	0.2767300392	0.3014994132
V-	0.0044662404	0.0046199865	0.004617489	0.0059639634	0.0048454941	0.0046941567

Table 4: Apparent viscosity, consistency index, flow behaviour index, and sedimentation index of beverage samples

Samples	Apparent Viscosity (Pa·s)	Consistency Index (k)	Flow Behaviour Index (n)	Sedimentation Index
Sample A	0.0038 ± 0.0001^{b}	7.65×10^{-5b}	1.81 ± 0.03^{b}	35.47 ± 1.12^{b}

Sample B	0.0034 ± 0.0001^{a}	1.63×10^{-5a}	1.74 ± 0.02^{a}	24.55 ± 0.95^{a}
Sample C	0.0037 ± 0.0001^{b}	8.97×10^{-5c}	1.88 ± 0.04^{c}	26.38 ± 1.05^{a}
Sample D	0.0042 ± 0.0002^{c}	6.34×10^{-5b}	1.65 ± 0.02^{a}	33.41 ± 1.20^{b}
Sample E	0.0040 ± 0.0001^{c}	1.11×10^{-4d}	1.95 ± 0.05^{c}	49.57 ± 1.45^{c}

Values are expressed as mean ± standard deviation (n = 3). Different superscripts (a–d) within a column indicate significant differences at $p < 0.05$.

Swelling Power (%)	**Samples**	**30^0 C**	**50^0 C**	**70^0 C**	**90^0 C**
	Sample A	17.69 ± 0.32^{b}	26.78 ± 0.45^{c}	20.46 ± 0.38^{b}	27.65 ± 0.41^{b}
	Sample B	17.47 ± 0.29^{b}	24.54 ± 0.39^{a}	21.33 ± 0.42^{c}	28.29 ± 0.44^{c}
	Sample C	16.58 ± 0.25^{a}	24.39 ± 0.36^{a}	20.75 ± 0.37^{b}	28.32 ± 0.46^{c}
	Sample D	16.71 ± 0.27^{a}	26.55 ± 0.43^{c}	20.23 ± 0.35^{b}	28.66 ± 0.47^{c}
	Sample E	17.42 ± 0.30^{b}	25.74 ± 0.41^{b}	22.45 ± 0.48^{d}	28.57 ± 0.45^{c}
Solubility (%)	**Samples**	**30^0 C**	**50^0 C**	**70^0 C**	**90^0 C**
	Sample A	12.14 ± 0.21^{a}	13.42 ± 0.25^{a}	15.12 ± 0.31^{a}	23.08 ± 0.40^{a}
	Sample B	12.23 ± 0.22^{a}	14.19 ± 0.28^{b}	15.22 ± 0.32^{a}	23.47 ± 0.42^{b}
	Sample C	12.31 ± 0.23^{a}	13.44 ± 0.24^{a}	16.34 ± 0.35^{c}	24.88 ± 0.48^{c}
	Sample D	12.15 ± 0.21^{a}	13.25 ± 0.23^{a}	16.28 ± 0.34^{c}	24.33 ± 0.45^{c}
	Sample E	12.26 ± 0.22^{a}	13.39 ± 0.24^{a}	16.17 ± 0.33^{c}	24.17 ± 0.44^{c}

WAI (g/g)	**Samples**	**0 Day**	**30 Day**	**60 Day**
	Sample A	3.36 ± 0.08^{c}	2.21 ± 0.05^{a}	3.47 ± 0.09^{c}
	Sample B	2.74 ± 0.06^{b}	3.17 ± 0.07^{b}	3.27 ± 0.08^{b}
	Sample C	2.53 ± 0.05^{a}	3.43 ± 0.09^{c}	3.22 ± 0.07^{b}
	Sample D	3.02 ± 0.07^{b}	3.51 ± 0.10^{c}	2.19 ± 0.05^{a}
	Sample E	3.11 ± 0.07^{b}	2.69 ± 0.06^{a}	2.15 ± 0.05^{a}
WSI (%)	**Samples**	**0 Day**	**30 Day**	**60 Day**
	Sample A	14.45 ± 0.35^{a}	13.29 ± 0.31^{b}	11.69 ± 0.28^{c}
	Sample B	15.22 ± 0.36^{b}	13.33 ± 0.32^{b}	11.52 ± 0.27^{c}
	Sample C	15.17 ± 0.34^{b}	10.13 ± 0.25^{a}	9.37 ± 0.22^{a}
	Sample D	15.38 ± 0.35^{b}	10.11 ± 0.24^{a}	9.75 ± 0.23^{a}
	Sample E	16.09 ± 0.38^{c}	12.14 ± 0.29^{b}	8.64 ± 0.21^{a}

Particle size	**Diameter (μm)**	**Volume (%)**	**Width**
Sample A	49.33 ± 1.12^{b}	23.21 ± 0.88^{a}	59.64 ± 1.05^{c}
Sample B	47.51 ± 1.05^{a}	34.35 ± 1.12^{c}	58.69 ± 1.02^{b}
Sample C	78.45 ± 1.85^{c}	34.39 ± 1.15^{c}	58.25 ± 0.98^{b}
Sample D	69.66 ± 1.62^{c}	33.23 ± 1.10^{b}	57.45 ± 0.95^{a}
Sample E	51.22 ± 1.20^{b}	27.29 ± 0.95^{b}	57.23 ± 0.94^{a}

Values are expressed as mean ± standard deviation (n = 3). One-way ANOVA was performed, and differences were considered significant at $p < 0.05$. Different superscripts (a–d) within a column indicate significant differences among samples. Hence, ssignificant differences ($p < 0.05$) were observed in: Swelling power (temperature dependent), Solubility at higher temperatures, WAI and WSI during storage, Particle size distribution, and this confirms formulation significantly influences functional properties

Table 6: Nutritional value of the formulated meal replacement drink

Nutrients	**Sample A**	**Sample B**	**Sample C**	**Sample D**	**Sample E**
Moisture (g)	3.09 ± 0.08^{a}	4.16 ± 0.10^{c}	3.24 ± 0.07^{a}	3.21 ± 0.07^{a}	3.19 ± 0.06^{a}
Ash (g)	0.59 ± 0.02^{a}	0.62 ± 0.02^{a}	0.87 ± 0.03^{b}	0.89 ± 0.03^{b}	0.64 ± 0.02^{a}
Energy (kcal)	117.5 ± 2.1^{a}	120.0 ± 2.3^{a}	130.2 ± 2.8^{b}	131.8 ± 2.9^{b}	132.0 ± 3.0^{b}
Carbohydrate (g)	20.83 ± 0.45^{a}	21.52 ± 0.48^{b}	23.58 ± 0.52^{c}	21.93 ± 0.47^{b}	22.43 ± 0.49^{b}
Protein (g)	5.29 ± 0.12^{a}	5.33 ± 0.11^{a}	5.89 ± 0.15^{b}	5.99 ± 0.16^{b}	5.37 ± 0.13^{a}
Fat (g)	1.52 ± 0.05^{a}	1.52 ± 0.05^{a}	1.53 ± 0.05^{a}	1.67 ± 0.06^{b}	1.56 ± 0.05^{a}
Dietary Fiber (g)	2.79 ± 0.09^{a}	2.82 ± 0.09^{a}	3.74 ± 0.12^{c}	3.69 ± 0.11^{c}	3.04 ± 0.10^{b}

Values are expressed as mean ± standard deviation (n = 3). One-way ANOVA was performed, and differences were considered significant at $p < 0.05$. Different superscripts (a–c) within a row indicate significant differences among samples.

Figure 1

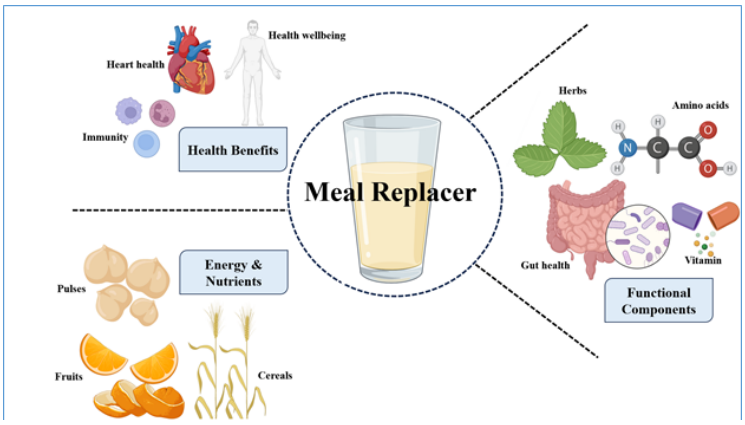

Figure 1: Health benefits and functional components of meal replacement as Nutraceutical (Diagram has **been created by biorender.com)**

Figure 2

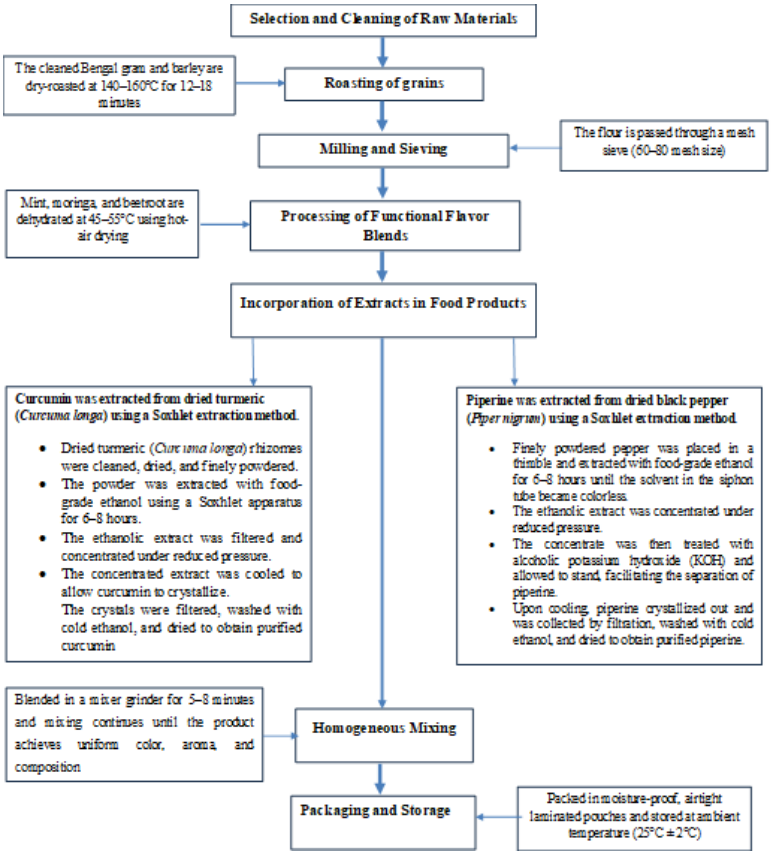

Figure 2: Steps Involved in the Development of Meal Replacement Beverage

Figure 3

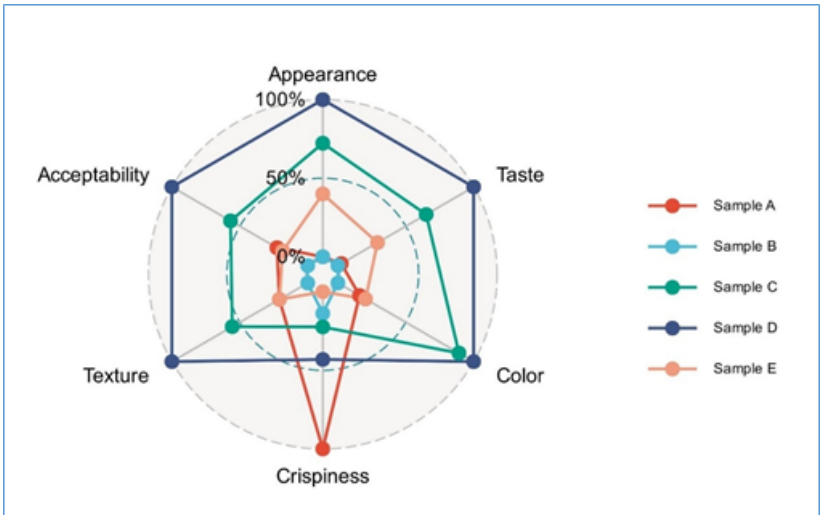

Figure 3: The illustration of the sensory result by the radar chart

Figure 4

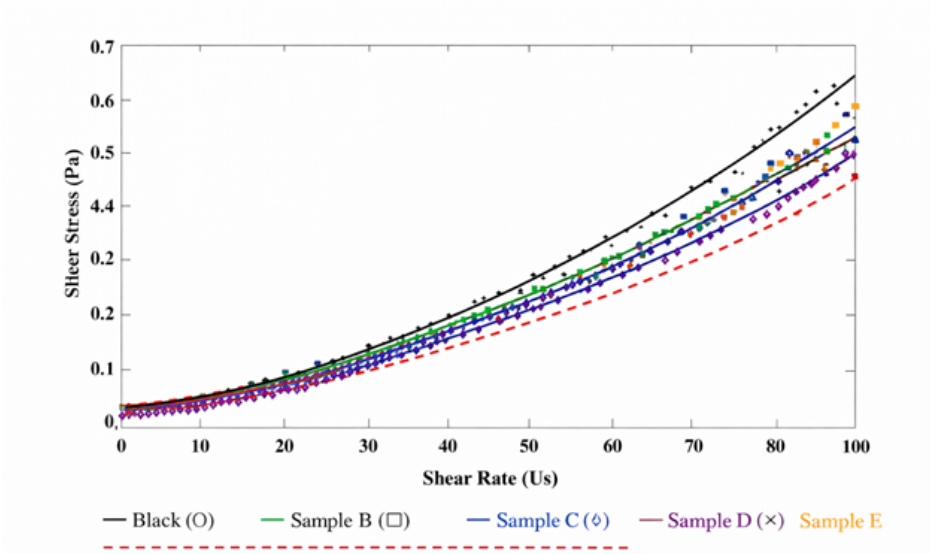

Figure 4: Rheogram of formulated sattu beverage: Sample A (○), Sample B (□), Sample C (◊), Sample D (×), Sample E (+). Lines represent fitted model data

Figure 5

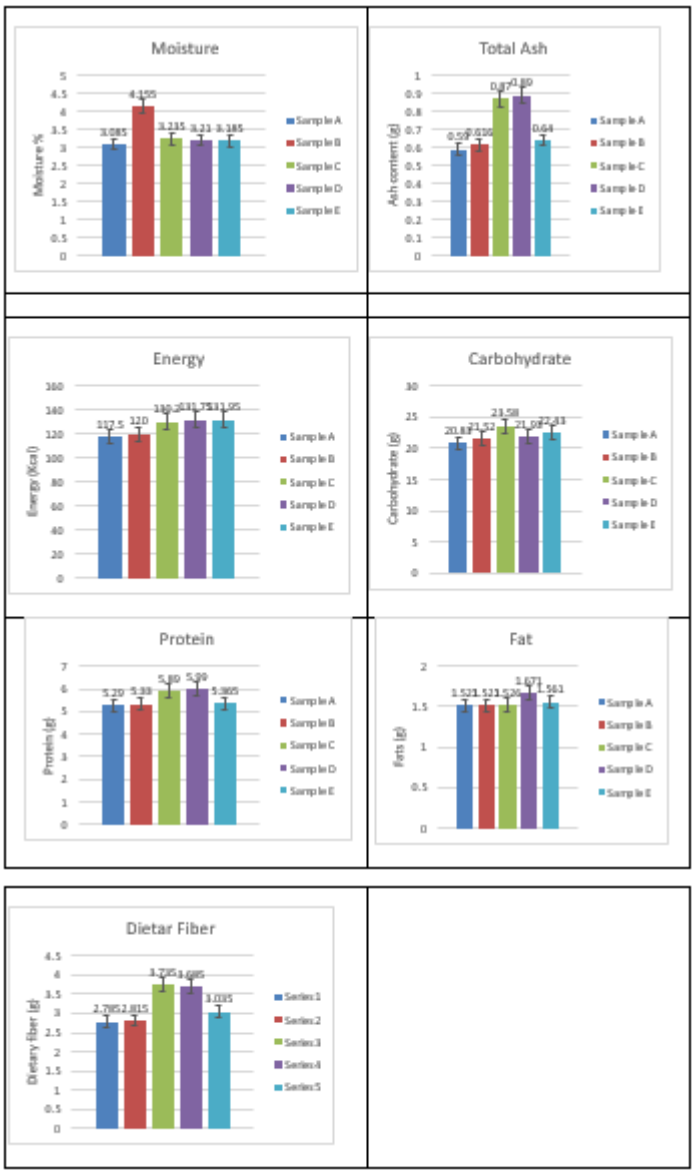

Figure 5: Bar graph with standard error of Nutritional value of the formulated meal replacement drink