***Original Research Article***

**VALORIZATION AND NUTRITIONAL ASSESMENT OF MILLET-BASED VEGAN MEATBALLS USING JACKFRUIT SEED POWDER AND COMPOSITE FLOUR**

**Abstract**

The increasing demand for plant-based foods has led to the innovation of nutritious meat analogues. Ethical and health concerns related to red meat have driven demand for meat analogues using sustainable crops like soy, amaranth, and jackfruit. Roasting jackfruit seeds enhances nutrient bioavailability by reducing anti-nutrients. Jackfruit seed powder can improve protein and starch levels in food items such as noodles, cakes, cookies, and biscuits. This study aimed to formulate and develop vegan meatballs using a blend of finger millet, amaranth, barnyard millet, and jackfruit seed powder. Jackfruit seeds, an underutilized agro-waste rich in starch and protein, were processed into flour and blended with millets and defatted soya chunks in varying proportions. The prepared meatballs were analyzed for their proximate composition, texture, and color. Proximate analysis showed that T4 had the highest protein content (20.61%), along with favorable fat, fiber, and energy values. Textural analysis revealed that T4 provided a firm yet cohesive texture, while color measurements confirmed its appealing visual quality. Sensory evaluation conducted using a 9-point hedonic scale rated T4 highest across all attributes colour (7.70), texture (7.83), flavour (8.13), taste (8.47), and overall acceptability (8.04) comparable to the commercial control. The study demonstrated that incorporating jackfruit seed powder and millets can result in a nutrient-dense, acceptable, and sustainable plant-based meat alternative, offering both health benefits and value addition to agro-waste products like jackfruit seeds.

**Keywords**: Vegan meatballs, jackfruit seed powder, millet flour, nutritional, proximate analysis, plant-based protein.

1. **INTRODUCTION**

The plant-based food industry is experiencing phenomenal growth as more and more people choose to live vegan, vegetarian, or flexitarian lifestyles. Products made from plants can be used as dairy alternatives or as meat substitutes. Although now somewhat tiny, the market for meat alternatives is expected to grow in the next years (Keerthana Priya et al., 2022). Jackfruit (*Artocarpus heterophyllus*) is a tropical fruit tree, an exotic species native from Southeast Asia, especially India and Bangladesh, also cultivated in several parts of the country and confused with *Artocarpus integer* (Saha et al. 2022). Jackfruit is one of the largest crops from the family of Moraceae (Annonymous1). Each fruit is divided into the rind (48%), seeds (18%), and bulbs (34%). Jackfruit seeds, comprising 8–15% of the fruit's total weight, are rich in carbohydrates (60–80% dry matter), proteins, vitamins, minerals, and dietary fiber. They also contain lignans, isoflavones, and saponins with antiviral, antibacterial, cardio-protective, and anti-mutagenic properties (Anudhar et al. 2024). Jackfruit seeds are less acknowledged and underutilized by people, even though they are considered as highly nutritious and constitute approximately 10-15% of the total Jackfruit weight. Jackfruit seeds contain phytonutrients such as isoflavones, lignans, and saponins. Jackfruit seeds have wide ranging health benefits from antihypertensive to anticancer, antiulcer, antiaging, antioxidant, etc. Jackfruit seeds contain phytonutrients that are good for human health, including saponins, isoflavones, lignans, and other substances. Jackfruit seed contains resistant starch which helps in controlling the blood sugar and also keeps the gut healthy. The consumption of resistance starch of jackfruit seed consequently leads to the slow release of glucose into the bloodstream (Karthik et al., 2024).

The seeds are typically light brown, 2–3 cm long, and 1–1.5 cm in diameter (Ranasinghe et al. 2019). A tree can yield 390 kg of seeds annually (Kalse and Swami, 2022), which can be stored for a month under cool, humid conditions (Khan et al., 2021). Jackfruit seeds are nutritionally valuable: carbohydrates (25.80–38.40 g), protein (0.40–0.43 g), fat (0.40–0.43 g), crude fibre (1.0–1.5 g), and minerals like calcium, potassium, and iron (Dhani et al. 2025). They offer numerous health benefits, support bone health, muscle function, and cardiovascular health, and reduce skin wrinkles (Chhotaray and Priyadarshini, 2022; Weyh et al. 2022; Reynolds et al. 2022).

Roasting jackfruit seeds enhances nutrient bioavailability by reducing anti-nutrients. Jackfruit seed powder can improve protein and starch levels in food items such as noodles, cakes, cookies, and biscuits (Mohammed Shafi et al. 2024).

Finger millet (*Eluesine coracana*), also known as ragi or mandua, offers health benefits like weight loss, cholesterol reduction, and improved bone health due to its high calcium and iron (Karki et al. 2020; Jaiswal et al. 2022). Amaranth (*Amaranthus spp.*), known as Rajgira, is rich in complete proteins and hypoallergenic compounds (Patro et al. 2025; Meza et al. 2022). Barnyard millet (*Echinochloa spp.*), or Japanese millet, is gluten-free and rich in essential fatty acids and minerals, offering benefits for diabetes, cholesterol, and metabolism (Bhatt et al. 2022).

The rising global population and environmental concerns have increased interest in plant-based protein sources. Ethical and health concerns related to red meat have driven demand for meat analogues using sustainable crops like soy, amaranth, and jackfruit (Yuliarti et al. 2021; Penchalaraju et al. 2022). Jackfruit seeds, often discarded, combined with nutritious millets like finger millet, barnyard, and amaranth, can enhance food value while minimizing waste. This study explores their use in formulating vegan meatballs with improved nutrition and texture.

1. **Material and Methods**

The materials required for the preparation of vegan meat balls such as jackfruit seed powder, finger millet flour, barnyard millet flour, amaranth flour, defatted soya chunks, salt, and baking powder were procured from local market Dapoli, (Dist. Ratnagiri). The experiment was conducted at the Bakery Unit of Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.). The experimental work and chemical analysis of prepared vegan meat balls were carried out in laboratory, Department of Processing and Food Engineering, CAET, and the Department of Agricultural Chemistry and Soil Science, College of Agriculture, Dapoli.

#### **Formulation, Evaluation, and Analysis of vegan meat balls**

The formulation of millet-based vegan meatballs was developed by varying the proportions of jackfruit seed powder, finger millet, amaranth, barnyard millet flours, and defatted soya chunks to achieve a nutritionally balanced and sensory acceptable product. five different treatments were prepared, each with 10% jackfruit seed powder and varying levels of millet flours and soy chunks, along with a control made using traditional vegetable and corn flour. Through experimental trials, the formulation designated as T4, comprising 10% jackfruit seed powder, 20% finger millet flour, 33% amaranth flour, 5% barnyard millet flour, and 30% defatted soya chunks, was identified as the most nutritionally rich and well-accepted in terms of texture and overall sensory quality. The evaluation process included maintaining consistent processing steps such as roasting, kneading, and frying methods to ensure product uniformity. Analysis of the formulated meatballs involved proximate composition (moisture, protein, fat, fiber, ash, carbohydrate, and energy), textural properties (maximum compressive force and hardness ratio), and color parameters (L, a*,* b\*).These evaluations confirmed that the optimized formulation not only enhanced protein and fiber content but also demonstrated favorable textural and sensory qualities, making it a suitable plant-based meat alternative.

* 1. **Vegan meat balls Formulation**

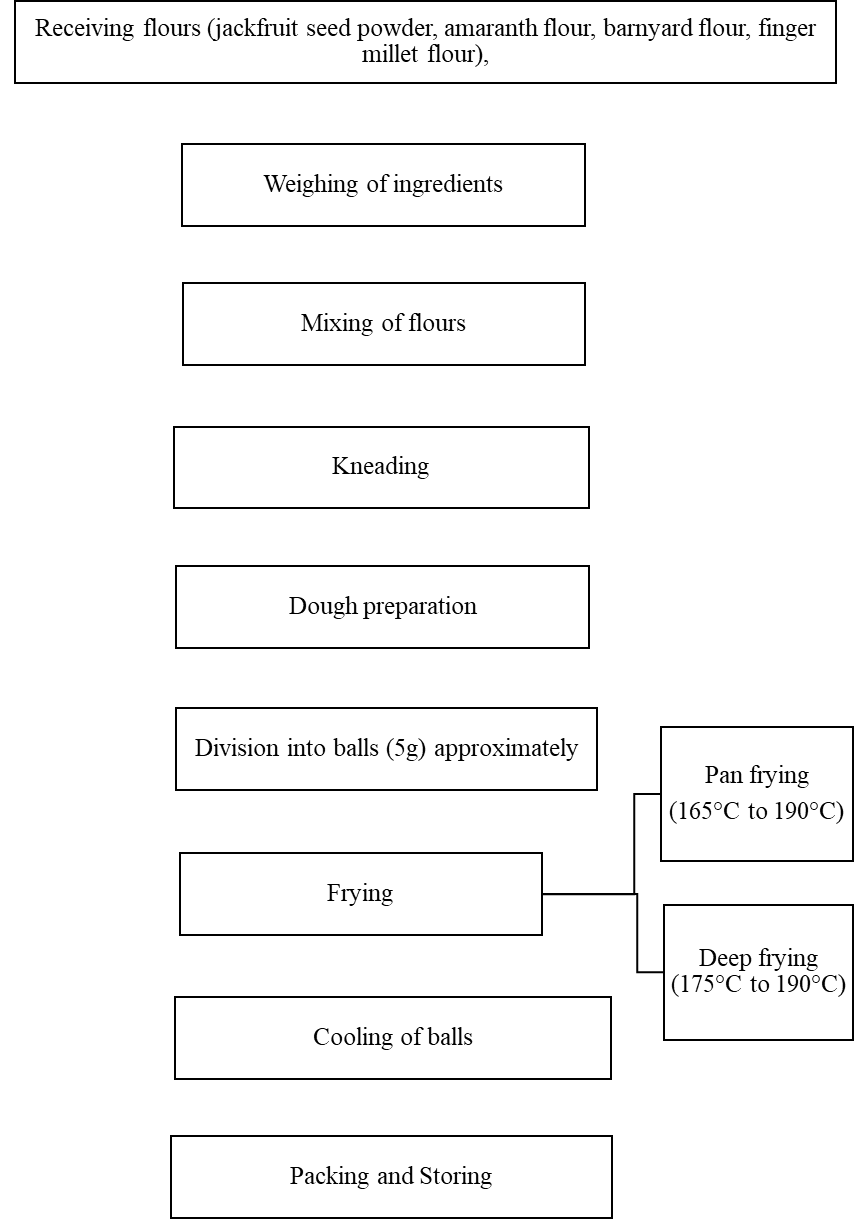
The ingredients used for the preparation of vegan meat balls -were shown in Table 1

**Table 1 Formulations of vegan meat balls**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr. No.** | **Ingredients (%)** | **T1** | **T2** | **T3** | **T4** | **T5** | **T6**  **(Control)** **Manchurian Balls** |
| **1.** | Jackfruit seed powder | 10 | 10 | 10 | 10 | 10 | - |
| **2.** | Finger millet flour | 50 | 40 | 30 | 20 | 10 | - |
| **3.** | Amaranth flour | 18 | 13 | 23 | 33 | 43 | - |
| **4.** | Barnyard millet flour | 20 | 15 | 10 | 05 | 00 | - |
| **5.** | Soya chunks | 0 | 20 | 25 | 30 | 35 | - |
| **6.** | salt | 1 | 1 | 1 | 1 | 1 | - |
| **7.** | Baking powder | 1 | 1 | 1 | 1 | 1 | - |
| **8.** | Manchurian mix | - | - | - | - | - | 100 |
| **Total** | | **100%** | | | | | |

**2.2.1 Process for the preparation of vegan meat balls**

To prepare the vegan meatballs, all ingredients like jackfruit seed powder, finger millet flour, barnyard millet flour, amaranth flour, soya chunks, salt, and baking powder were weighed as per the formulations. The flours were roasted at 150°C for 2 minutes and stored in a cool place. The soya chunks were soaked in hot water for 10–15 minutes, then drained and pulsed to a mince-like texture. All the ingredients were mixed well and kneaded into a smooth dough. Small balls of about 5 grams each were made from the dough. These balls were fried either in a pan or in a deep fryer. For pan-frying, they were cooked on both sides for 5–7 minutes at 165–190°C. For deep-frying, they were cooked for 4–6 minutes at 175–190°C. After frying, the meatballs were cooled and packed in airtight containers or freezer bags for storage.



**Fig 1 Process flow chart for preparation of vegan meat balls**

## **2.3 Proximate and Nutritional Composition of vegan meat balls**

### **2.3.1 Moisture Content**

Moisture content was estimated following the method described by AOAC (2000).  
Formula:

100   … (1)  
Where,

W1 = Weight of empty sample box, g

W2 = Weightofempty box + sample before drying, g

W3 = Weight of empty box + sample after drying, g

**2.3.2 Ash Content**

The ash content was determined by the method given in AOAC (2000).

Formula:

Ash content (%) = 100    … (2)

Where,

W = weight of crucible, g

W1 = weight of crucible and flour, g

W2 = weight of crucible with ash, g

### **2.3.3 Crude Fat**

The fat content of individual raw flour samples for all treatments will be determined by the Soxhlet fat extraction system (AOAC, 2000) by the Soxhlet apparatus (Elico, Hyderabad).  
Formula:

  … (3)  
Where,

W = weight of sample, g

W1 = Initial weight of sample with flask, g

W2 = Final weight of sample with flask, g

### **2.3.4 Crude Fibre**

The fiber content flour samples for all treatments will be determined by the fat-free sample available in filter paper from the fat extraction method (AOAC, 2000).

Formula:  
 … (4)  
Where,

W1 = Weight of the sample, g

W2 = Weight of insoluble matter, g

W3 = Weight of ash, g

### **2.3.5 Protein**

Protein content was determined by the Kjeldahl method (AOAC, 2000) applying a nitrogen-to-protein conversion factor of 6.25.  
Formula:  
  …(5)  
Where,

S = Volume of standard acid (0.1 N HCl) used for titration, ml

B = Volume of 0.1 N HCl used for blank, ml

W = Weight of the sample, g

N = Normality of acid used for titration (0.1 N HCl)

**2.3.6 Carbohydrates**

The carbohydrate content was calculated by using a standard method of analysis (AOAC, 2000). Formula:  
Carbohydrates (%) = 100 - (Moisture % + Protein % + Fat % + Fibre % + Ash %   … (6)

### **2.3.7 Energy**

Energy value (kcal) was calculated using the Atwater factors (AOAC, 2000).

Energy = (4 crude protein %) + (9 crude fat %) + (4 carbohydrates %)  …(7)

## **2.4 Sensory Evaluation**

Sensory evaluation of the developed vegan meatball samples was carried out at laboratory of the Processing and Food Engineering department by 30 panellists on a 9-point hedonic scale. All the vegan meat balls, including control were judged by 30 semi-trained panellists of age group 20-50 years consisting of staff, students and faculty members of the CAET, Dr. BSKKV, Dapoli (MS) using hedonic scale. The panellists were trained about the concepts and scoring systems of the various attributes such as, Colour, flavour, texture, taste and overall acceptability. Samples of all the treatments were served to each panellist to taste each sample one after another with due to interval in between. Panellists were provided with a glass of water and instructed to rinse and swallow water between samples and were served potato chips to break the monotony in taste of the vegan meat balls. To analyse results, numerical values were assigned to each point on the scale, 9 points for like extremely and 1 point for dislike extremely. Mean sensory scores for quality attributes (colour, flavour, taste, texture, appearance, and overall acceptability) were recorded on the given score sheet. (Sudha et.al 2019).

**2.5 Statistical analysis**

Statistical analysis was done to study the effect of different physicochemical properties, such as moisture content, protein, fat, crude fibres, ash content, energy, and carbohydrates on the quality of the developed vegan meat balls. Statistical analysis was done using Randomized Block Design (RBD).

**3. Results and Discussion**

**3.1 Physiochemical properties of vegan meat balls**

3.1.1 **Moisture Content**

**The moisture content of all vegan meatball samples was calculated and is presented in Figure 2.** Moisture ranged from **30.46% to 37.80% (wet basis),** with the lowest value observed in treatment **T1 (30.46%)** and the highest in the control treatment **(38.66%).** Among the treated samples, **T5 showed the highest moisture content (37.80%)**, which increased with the addition of softer,high-moisture ingredients. **ANOVA revealed significant differences (p < 0.05) among the treatments.** The **coefficient of variation (C.V.) was 2.48%**, and the **critical difference (C.D.) was 1.56%.**

**Fig. 2 Effect of treatment combinations on moisture content (%)**

**3.1.2 Protein Content**

**The protein content of all vegan meatball samples was calculated and is presented in Figure 3.** Protein ranged from **8.83% to 20.61%**, with the lowest value observed in **T1 (8.83%)** and the highest in **T4 (20.61%)**. The **control treatment showed the lowest protein content (4.95%)**.Among the formulated samples, **T4 recorded the highest protein content**,which corresponded with better sensory scores. This formulation included **10% jackfruit seed powder, 20% finger millet flour, 33% amaranth flour, 5% barnyard millet flour, and 30% soya chunks. ANOVA revealed significant differences (p < 0.05) among the treatments.** The **coefficient of variation (C.V.) was 1.78%**,and the **critical difference (C.D.) was 0.49%**.

**Fig. 3.Effect of treatment combinations on protein content (%)**

**3.1.3 Fat Content**

**The crude fat content of all vegan meatball samples was calculated and is presented in Figure 4.** Fat content ranged from **2.09% to 3.00%**, with the lowest value observed in **T4 (2.09%)** and the highest in **T2 (3.00%)**. These findings are in line with **Singh et al. (2023)**, who reported fat content between **2.8% and 3.2%** in vegan meatballs made from defatted soya, amaranth, and jackfruit flours. **ANOVA revealed significant differences (p < 0.05) among the treatments.** The **coefficient of variation (C.V.) was 5.13%**, and the **critical difference (C.D.) was 0.37%**, indicating statistically significant variation in fat content between treatments.

**Fig. 4 Effect of treatment combinations on fat content (%)**

**3.1.4 Ash content**

Ash content of all vegan meatball samples was calculated and is presented in Figure 5 Ash content ranged from 1.80% to 2.30%, with the lowest value observed in T1 (1.80%) and the highest in T5 (2.30%). Similar findings were reported by Singh et al. (2023), where ash content in vegan meatballs made from defatted soya, amaranth, and jackfruit flours ranged from 3.3% to 3.5%. ANOVA revealed significant differences (p < 0.05) among the treatments. The coefficient of variation (C.V.) was 11.40%, and the critical difference (C.D.) was 0.45%, indicating statistically significant differences in ash content across treatments.

**Fig. 5 Effect of treatment combinations on ash content (%)**

**3.1.5 Crude fiber**

Crude fiber content of all vegan meatball samples was calculated and is presented in Figure 6Fiber content ranged from 3.81% to 4.18%, with the lowest value observed in T1 (3.81%) and the highest in T5 (4.18%). The control sample showed a lower fiber content (3.06%) compared to all other treatments. ANOVA revealed significant differences (p < 0.05) among the treatments. The coefficient of variation (C.V.) was 4.83%, and the critical difference (C.D.) was 0.34%, indicating statistically significant differences in fiber content across treatments.

**Fig. 6 Effect of treatment combinations on fiber content (%)**

**3.1.6 Carbohydrates**

Carbohydrate content of all vegan meatball samples was calculated and is presented in Figure 7.

Carbohydrate content ranged from **31.02% to 52.31%**, with the highest value observed in **T1 (52.31%)** and the lowest carbohydrate value in **T5 (31.02%)**. The **control sample showed a carbohydrate content of 39.71%**. These findings align with **Singh et al. (2023),** who reported carbohydrate values between **51.1% and 53.6%** in vegan meatballs made with defatted soya, amaranth, and jackfruit flours. **ANOVA revealed significant differences (p < 0.05) among the treatments.** The **coefficient of variation (C.V.) was 1.97%,** and the **critical difference (C.D.) was 1.4358%**, indicating statistically significant differences in carbohydrate content across treatments.

**Fig. 7 Effect of treatment combinations on carbohydrates content (%)**

**3.1.7 Energy Content**

Energy content of all vegan meatball samples was calculated and is presented in Figure 8.

Energy values ranged from **229.51 kcal to 269.48 kcal**, with the highest observed in **T1 (269.48 kcal)** and the lowest in **T5 (229.51 kcal). Treatment T4** recorded the next highest energy content (**250.01 kcal**). The **control sample showed the highest energy value (277.66 kcal)** compared to all treatments. **ANOVA revealed significant differences (p < 0.05) among the treatments.** The **coefficient of variation (C.V.) was 1.35%**, and the **critical difference (C.D.) was 6.34%**, indicating statistically significant differences in energy content across treatments.

**Fig. 8 Effect of treatment combinations on energy content (%)**

**3.4 Sensory Evaluation of Vegan meat balls**

The sensory evaluation of the developed vegan meatballs, prepared with varying compositions of jackfruit seed powder and millet flours, was conducted using a 9-point Hedonic scale by 30 semi-trained panelists. Parameters evaluated included colour, texture, flavour, taste, and overall acceptability.

Among all treatments, Treatment T4 (10% jackfruit seed powder, 20% finger millet flour, 33% amaranth flour, 5% barnyard millet flour, and 30% soya chunks) achieved the highest overall acceptability score (8.04). It was highly rated for its appealing colour (7.70), firm and cohesive texture (7.83), well-balanced flavour (8.13), and satisfying taste (8.47), closely resembling traditional meatballs in sensory attributes.

The lowest scores were observed in Treatment T1, which lacked soya chunks and had a high proportion of finger millet, resulting in lower acceptability in terms of flavour and texture.

Statistical analysis revealed significant differences (p<0.05) among treatments for all sensory attributes. The overall findings confirmed that T4 was the most acceptable formulation, offering a nutritionally rich and sensorially appealing plant-based meatball.

Table 2 provides a summary of these findings and is presented in Figure 9.

**Table 2 Average sensory score values of developed vegan meat balls**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Colour** | **Texture** | **Flavour** | **Taste** | **Overall Acceptability** |
| T1 | 5.9 | 5.2 | 5.70 | 5.3 | **5.57** |
| T2 | 6.4 | 6.3 | 6.1 | 5.9 | **6.20** |
| T3 | 6.5 | 6.5 | 6.4 | 6.5 | **6.51** |
| T4 | 7.7 | 7.8 | 8.1 | 8.4 | **8.04** |
| T5 | 7.0 | 7.1 | 7.5 | 7.5 | **7.32** |
| T6 | 7.8 | 8.0 | 8.1 | 8.3 | **8.07** |
| **F Cal** | **28.94** | **41.12** | **51.24** | **70.56** | **59.83** |
| **F Tab (5%)** | **2.77** | **2.77** | **2.77** | **2.77** | **2.77** |
| **CD (≤0.05)** | **0.39** | **0.40** | **0.35** | **0.36** | **0.32** |
| **S. E** | **0.16** | **0.16** | **0.14** | **0.15** | **0.13** |
| **C.V** | **3.78** | **3.27** | **2.90** | **2.67** | **2.49** |
| **Results** | **S\*** | **S\*** | **S\*** | **S\*** | **S\*** |

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**Fig.9 Effect of different treatments on the sensory properties of developed vegan meat balls**

|  |  |
| --- | --- |
|  |  |

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**Developed vegan meat balls of treatment T2**

**Developed vegan meat balls of treatment T1**

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**Developed vegan meat balls of treatment T4**

**Developed vegan meat balls of treatment T3**

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**Developed vegan meat balls of treatment T6**

**Developed vegan meat balls of treatment T5**

**Plate 1 Developed vegan meatballs (T1-T6)**

**Conclusion:**

The present study successfully developed millet-based vegan meatballs utilizing jackfruit seed powder in combination with finger millet, amaranth, barnyard millet, and defatted soya chunks. Among the five formulations tested, Treatment T4 (10% jackfruit seed powder, 20% finger millet flour, 33% amaranth flour, 5% barnyard millet flour, and 30% soya chunks) was identified as the most nutritionally balanced and sensorily acceptable.

Proximate analysis showed that T4 had the highest protein content (20.61%), along with favorable fat, fiber, and energy values. Textural analysis revealed that T4 provided a firm yet cohesive texture, while color measurements confirmed its appealing visual quality. Sensory evaluation conducted using a 9-point hedonic scale rated T4 highest across all attributes colour (7.70), texture (7.83), flavour (8.13), taste (8.47), and overall acceptability (8.04), comparable to the commercial control.

Statistical analysis using Randomized Block Design (RBD) indicated that differences across treatments were significant at the 5% level for all sensory and nutritional parameters. The low coefficient of variation and high F-calculated values supported the reliability of findings.

In conclusion, the study demonstrated that incorporating jackfruit seed powder and millets can result in a nutrient-dense, acceptable, and sustainable plant-based meat alternative, offering both health benefits and value addition to agro-waste products like jackfruit seeds.

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