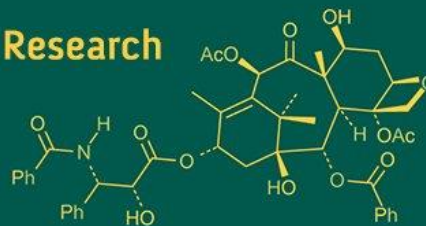


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Development and evaluation of plant based meat analogue

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Abstract

A plant-based meat analogue was developed using tender jackfruit flour blended with soy protein isolate (SPI) and pea protein isolate (PPI) along with potato starch, gum arabic, calcium chloride, sunflower oil, salt, baking soda and seasonings. Six formulations were prepared, a jackfruit-dominant control and five treatments (T₁-T₅), with SPI increasing from 12% to 20% and PPI decreasing from 16% to 8%. The samples were processed by low-moisture extrusion at barrel temperatures of 40-105 °C and evaluated for cooking quality, proximate composition, colour, water activity, texture profile, sensory acceptability and microbial quality. The cooking yield was highest in T₄ (87.46%), while diameter and thickness reductions were lowest in T₄, indicating better water-holding and dimensional stability with increasing SPI content. The protein content increased progressively from 13.76% in the control to 29.00% in T₅, while the carbohydrate and crude fibre content decreased. T₄ showed the firmest and most cohesive texture after cooking, and T₅ received the highest sensory scores for all attributes on a 9-point hedonic scale. The standard plate count and yeast and mould count were lowest in T₄ and within safe limits for all the samples. The study shows that jackfruit-SPI-PPI based meat analogues, particularly T₄ and T₅, can serve as a nutritious and acceptable plant-based alternative to conventional meat products.

Keywords: Plant based meat analogue, jackfruit flour, soy protein isolate, pea protein isolate, meat analogue, extrusion

1. Introduction

Meat analogues are plant-based food products that resemble meat in terms of flavour, texture, and appearance; they are increasing being used due to the increase in world population and changes in consumer behaviour nowadays, with people being more concerned about their health, environmental effects and animal welfare issues, including limitations based on religion (Apostolidis and Mcleay, 2016) [2]. Plant-based meat alternatives have emerged as a result of the growing demand for sustainable food sources worldwide. These substitutes address issues related to traditional meat production that affect human health, animal welfare, and the environment (Santo *et al.*, 2020) [8].

According to consumer studies, consumers tend to choose meat alternative which accurately mimics the desired sensory attributes of conventional meat. Consumers interested in meat alternatives are people who are concerned about their well-being and health, as well as those who are aware of the environmental, social, and ethical ramifications of eating animal meat. The actual meat analogue content is a protein that accounts for 50-95% of dry matter. The structural organization of plant-based meat analogue also depends on properties of proteins like gelation, solubilizing capabilities, and the ability to retain liquid (Mishal, S *et al.*, 2022) [5].

Soy protein isolates have been a key ingredient in plant-based meat alternatives due to their high nutritional value and excellent abilities to form gels and emulsions (Nowacka *et al.*, 2023) [6]. These isolates, made from soybeans, provide a complete amino acid profile similar to animal proteins, receiving a score of 1.0 on the Protein Digestibility Corrected Amino Acid Score. Soy proteins help form disulphide-linked polymers during processing, which improves viscosity and structural strength in extruded products (Sengar *et al.*, 2023) [9].

Pea protein isolates present a hypoallergenic option, offering high protein content (20-25%) and beneficial properties like foaming and gel formation (Nowacka *et al.*, 2023) [6].

Pea proteins contain globulins and albumins, which can form stable fibrous networks through hydrophobic interactions and hydrogen bonds when subjected to high-moisture extrusion ("Sengar *et al.*, 2023")^[9].

Incorporating tender jackfruit, soy protein, and pea protein isolates into meat alternatives requires careful management of process variables like moisture content (over 40%) and barrel temperatures (around 100 °C) to encourage gel formation and fiber creation (Sengar *et al.*, 2023)^[9]. The extrusion process helps separate and align the proteins, with jackfruit providing natural tenderness while soy and pea blends supply the structural base (Nowacka *et al.*, 2023)^[6]. The aim of this research project is to develop and improve a plant-based meat alternative that includes tender jackfruit, soy protein isolate, and pea protein isolate. The goal is to create a sustainable, nutritious, and appealing alternative to traditional animal-derived meat products.

2. Materials and Methods

2.1 Raw Materials

Raw materials used in the present study namely Tender jackfruit was procured from Vijayawada, A.P. Soy protein isolate, pea protein isolate, potato starch, methyl cellulose, gum Arabic, calcium chloride, sunflower oil, baking soda, salt, seasonings and spices were collected from local market of Bapatla.

2.2 Preparation of Raw Jackfruit flour

Fresh raw jackfruit at the mature unripe stage was thoroughly washed with potable water to remove adhering dirt and foreign matter. The jackfruit was peeled, cut into small pieces, and subjected to blanching at a temperature of 85°C for 5 minutes. The blanched pieces were dried in a hot air oven at a temperature of 60 °C for 10 hours until the desired moisture level of 7% was achieved. The dried material was ground into fine flour using a grinder and sieved to obtain a uniform particle size. The prepared jackfruit flour was packed in airtight containers and stored until further use.

2.3 Formulation of Jackfruit Based Meat Analogue Chunks

Table 1: Formulation table for Jackfruit based Meat Analogue Chunks

Ingredient	T ₀ (Control)	T ₁	T ₂	T ₃	T ₄	T ₅
Tender Jackfruit	65	50	50	50	50	50
Soy Protein Isolate	-	12	14	16	18	20
Pea Protein Isolate	-	16	14	12	10	08
Soy Flour	3	3	3	3	3	3
Potato Starch	18	5	5	5	5	5
Gum Arabic	1	1	1	1	1	1
Calcium chloride	1	1	1	1	1	1
Sunflower oil	4	4	4	4	4	4
Salt	1	1	1	1	1	1
Seasonings and Spices	3	3	3	3	3	3
Water	4	4	4	4	4	4

2.4 Extrusion Processing

Jackfruit flour, soy protein isolate, pea protein isolate, soy flour, potato starch, gum arabic, calcium chloride, sunflower oil, salt, seasonings and spices, and water were weighed according to the formulations presented in Table 1. The ingredients were thoroughly blended in a batch mixer for 15 min to obtain a homogeneous mixture. The prepared feed

mixture was fed into the extruder and processed under three temperature zones. The barrel temperatures were maintained at 40-55 °C in Zone 1, 65-90 °C in Zone 2, and 100-105 °C in Zone 3. The extruded product was collected, mini chunk shaped pieces, and dried in a hot air oven at 60 °C for 5 h until the moisture content reached approximately 5%. The dried meat analogue chunks were cooled to room temperature and packed in low-density polyethylene (LDPE) pouches. The pouches were sealed using a heat sealer and stored under ambient conditions for further analysis and shelf-life studies.

2.5 Physical Analysis

3.5.1 Bulk Density (Kaur and Singh 2005)^[4]

Bulk density was calculated using a slightly modified version of the approach outlined by. A 50 mL graduated measuring cylinder that was dry and clean was weighed (W₁). The plant-based meat analogue sample was then carefully added to the cylinder until it reached the 50 mL threshold without compacting the substance. To ensure that the sample settled uniformly, the cylinder was gently tapped ten times at a height of around two centimeters. The cylinder containing the sample was weighed once again (W₂) after the final volume occupied by the sample was noted. The ratio of sample mass to sample volume was used to compute bulk density.

$$\text{Bulk Density} = \frac{w_2 - w_1}{v}$$

Where,

W₁ = Weight of empty measuring cylinder (g), W₂ = Weight of cylinder + sample (g), V = Volume occupied by sample (cm³ or mL)

3.5.2 Diameter and thickness reduction (%) (Mishal *et al* 2022)^[5]

Change in plant-based meat analogue diameter was determined by using the following equation.

$$\text{Diameter reduction (\%)} = \frac{D_1 - D_2}{D_1} \times 100$$

Where,

D₁ = Diameter of raw meat analogue D₂ = Diameter of cooked meat analogue

$$\text{Thickness reduction (\%)} = \frac{T_1 - T_2}{T_1} \times 100 \quad \dots \text{eq (1)}$$

Where,

T₁ = Thickness of raw meat analogue, T₂ = Thickness of cooked meat analogue

3.5.3 Hydration Rate and Time (Mishal *et al* 2022)^[5]

The hydration time and rate are very important to determine the quality of texturized meat analogue. 10 grams of meat analogue was soaked in 50 ml of water at room temperature. During hydration, the weight was constantly observed every 2 minutes to achieve full hydration, which provides soft textured meat analogue. The time was recorded, and the hydrated sample was weighed to calculate the hydration rate. Hydration rate was calculated by the formula:

$$\text{Hydration rate} = \frac{\text{final weight} - \text{initial weight}}{\text{hydration time}}$$

3.5.4 Determination of pH (AOAC 2005) ^[1]

The pH of all treatments was determined using pH meter in triplicate manner. First Calibrate the pH meter using the standard buffer solutions (pH 4, 7 & 10) before measuring the pH of the sample. Then prepare the sample by mixing with distilled water to create a solution Now rinse the pH electrode with distilled water and gently blot it with a soft tissue. Insert the pH electrode to the sample, making sure its fully submerged wait for the readings to stabilize (usually one to two minutes). Take note of the pH readings on the meter.

3.5.5 Determination of Water Activity (AOAC 978.18)

The Water activity of the samples is determined using water activity meter in a triplicate manner. The water activity meter is first calibrated at 25 °C room temperature and then the required sample (1-2g) is placed into the cup provided with meter for the measurement of its water activity. Usually, water activity varies from 0 to 1 for any sample.

3.5.6 Determination of cooking yield (El-Magoli *et al.* 1996) ^[3]

The cooking yield of plant-based meat analogue (PBMA) was determined by measuring the weight of samples for each treatment and calculating the difference in weight before and after cooking.

$$\text{Cooking yield (\%)} = \frac{\text{Weight of cooked MA}}{\text{Weight of precooked MA}} \times 100$$

3.5.7 Sensory Analysis

Sensory analysis of different meat analogue samples was carried out in this experiment. A control sample 10 was compared with other formulations (T₁, T₂, T₃, T₄ & T₅) using hedonic 9-point scale (Ranganna, 1986) ^[7]. Sensory testing was conducted in Sensory Evaluation Laboratory of the

Department of Food Technology. During evaluation the panellists were provided with 5 coded plates and 1 as control. Sensory evaluation carried out under ambient conditions in a comfortable and quiet area without disturbance. Water was supplied to clean the plate between sample evaluations. The attributes evaluated were points hedonic scale was adopted for sensory evaluation of meat analogue samples for Appearance, taste, colour, texture, flavour, mouthfeel, chewiness, and overall acceptability.

2.8 Statistical Analysis

Statistical analysis was performed using Minitab Statistical Software (Version 21.0). One-way Analysis of Variance (ANOVA) was used to determine significant differences among the treatments. When significant differences were observed, mean separation was carried out using Tukey's test. Differences were considered statistically significant at $p < 0.05$. All experiments were conducted in triplicate, and the results were expressed as mean $\pm$ standard deviation.

3. Results and Discussion

3.1 Bulk Density

According to Table 1, the bulk density values (g/cm³) for the control, T₁, T₂, T₃, T₄, and T₅ were 0.81, 0.74, 0.71, 0.69, 0.66, and 0.68. As SPI concentration increased, bulk density steadily decreased; T₄ had the lowest value (0.66 g/cm³). The jackfruit-dominant control had the highest bulk density, which makes sense given its tight cellulose structure and small amount of extensible protein. The globular proteins of SPI and PPI are denatured by thermal and shear forces during low-moisture extrusion, resulting in protein-protein crosslinks that produce a lighter fibrous network. This is probably why the bulk density decreases with higher protein isolate levels.

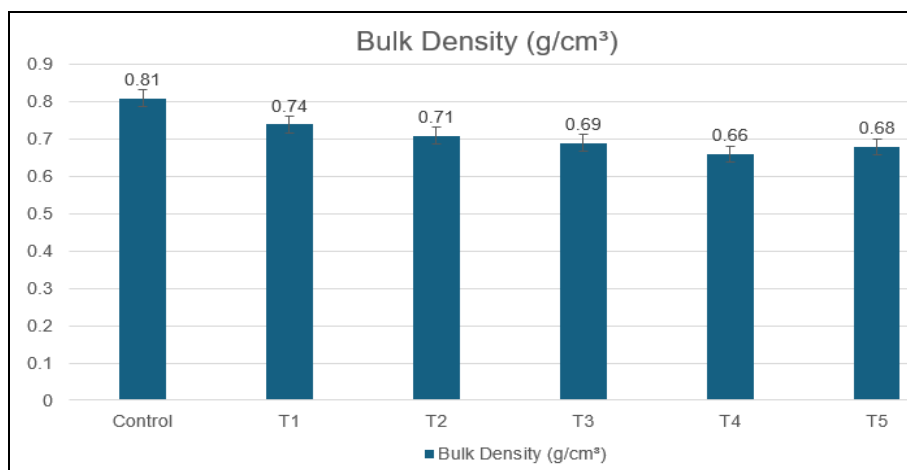


Fig 1: Bulk density Values of Plant-Based Meat Analogue Formulations

3.3 Cooking Yield (%), Diameter and Thickness Reduction

The data in Table 2 shows the cooking yield, diameter reduction and thickness reduction of the developed meat analogue samples. The cooking yield (%) for the control, T₁, T₂, T₃, T₄ and T₅ samples are 78.70, 82.36, 84.30, 85.70, 87.46 and 86.40 respectively. The diameter reduction (%) for the same samples are 12.40, 9.80, 10.30, 8.40, 7.86 and 8.80 respectively, and the thickness reduction (%) are 14.66, 11.83, 12.53, 10.73, 9.23 and 10.63 respectively. The

cooking yield is highest for T₄ and lowest for the control, while the diameter and thickness reductions are lowest for T₄ and highest for the control. This may be due to the protein network formed by SPI and PPI, which holds water better and provides more dimensional stability during cooking than the jackfruit-dominant matrix. As shown in Table 2, the differences among samples for cooking yield, diameter reduction and thickness reduction were all found to be significant ($p < 0.001$).

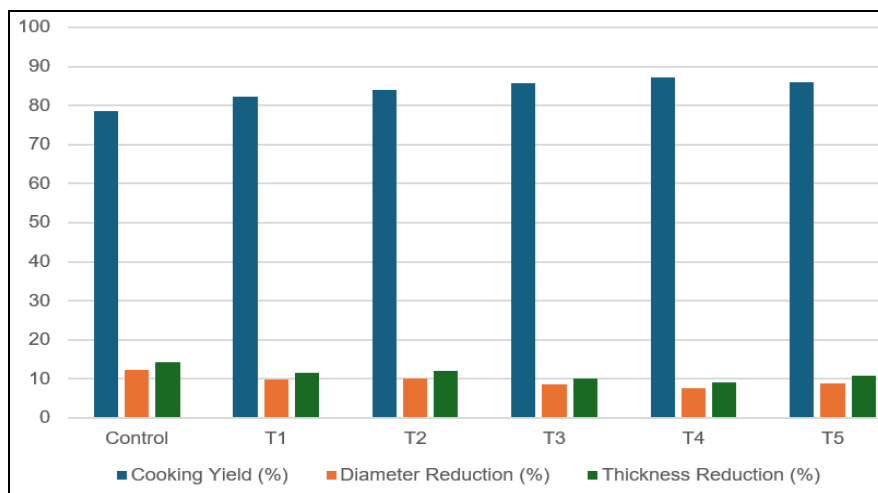


Fig 2: Cooking Yield, Diameter Reduction, and Thickness Reduction of Meat Analogue Samples

3.2 Hydration Rate and Time

The data in Table 2 shows the values of hydration rate and hydration time for the developed meat analogue samples. The hydration rate (g/min) for the control, T₁, T₂, T₃, T₄ and T₅ samples are 2.30, 2.51, 2.50, 2.46, 2.43 and 2.60 respectively. The hydration time (min) for the same samples are 18.53, 13.67, 14.83, 12.67, 12.83 and 13.00 respectively. The control sample took the longest time to hydrate, which may be due to the dense fibrous jackfruit matrix restricting

water movement into the product, whereas the addition of SPI and PPI in T₁-T₅ formed a more porous structure that allowed faster water uptake. As shown in Table 2, the difference in hydration rate among the samples was not found to be significant ($p = 0.903$), whereas the difference in hydration time among the samples was found to be significant ($p = 0.012$), with the control differing significantly from T₁, T₃, T₄ and T₅.

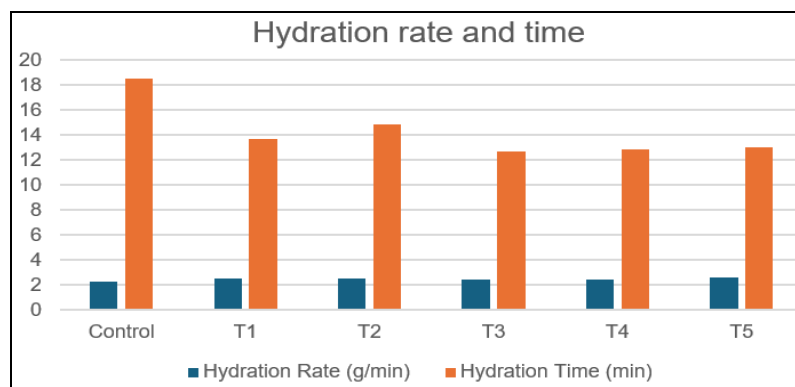


Fig 3: Hydration rate and time Values of Plant-Based Meat Analogue Formulations

3.2 pH

The data in Table 2 shows the pH values of the developed meat analogue samples. The pH for the control, T₁, T₂, T₃, T₄ and T₅ samples are 6.02, 6.23, 6.28, 6.31, 6.35 and 6.35 respectively. The pH increased with increasing SPI content, which may be due to the alkaline nature of soy protein

isolate compared with the mildly acidic jackfruit-dominant control. As shown in Table 3, the difference in pH was found to be significant ($p < 0.001$); the control differed significantly from T₁-T₅, while T₁ to T₅ did not differ significantly among themselves.

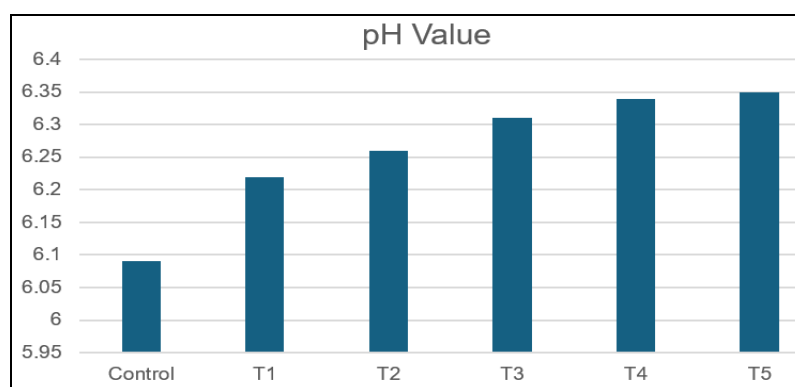


Fig 4: pH Values of Plant-Based Meat Analogue Formulations

Table 2: Physical properties of Jackfruit based Meat Analogue Chunks

Sample	Hydration Rate	Hydration Time	pH	Cooking Yield (%)	Diameter Reduction (%)	Thickness Reduction (%)	Bulk Density (g/cm ³)
Control	2.30±0.26 ^a	18.53±0.45 ^a	6.02±0.11 ^b	78.70±0.72 ^d	12.40±0.50 ^a	14.66±1.07 ^a	0.81±0.02 ^a
T ₁	2.51±0.35 ^a	13.66±1.52 ^b	6.23±0.04 ^a	82.36±0.60 ^c	9.80±0.40 ^{bc}	11.83±0.49 ^{bc}	0.74±0.02 ^b
T ₂	2.50±0.30 ^a	14.83±1.25 ^{ab}	6.28±0.05 ^a	84.30±0.64 ^b	10.30±0.55 ^b	12.53±0.50 ^b	0.71±0.01 ^{bc}
T ₃	2.46±0.32 ^a	12.67±2.08 ^b	6.31±0.03 ^a	85.70±0.65 ^{ab}	8.40±0.55 ^d	10.73±0.56 ^{bcd}	0.69±0.01 ^c
T ₄	2.43±0.34 ^a	12.83±2.52 ^b	6.35±0.03 ^a	87.46±0.73 ^a	7.86±0.25 ^d	9.23±0.35 ^d	0.66±0.01 ^c
T ₅	2.60±0.30 ^a	13.0±2.00 ^b	6.35±0.02 ^a	86.40±0.52 ^a	8.80±0.45 ^{cd}	10.63±0.76 ^{cd}	0.68±0.02 ^c

Values are mean±standard deviation (n = 3). Means with different superscript letters within a column differ significantly (p<0.05) according to Tukey's HSD test."

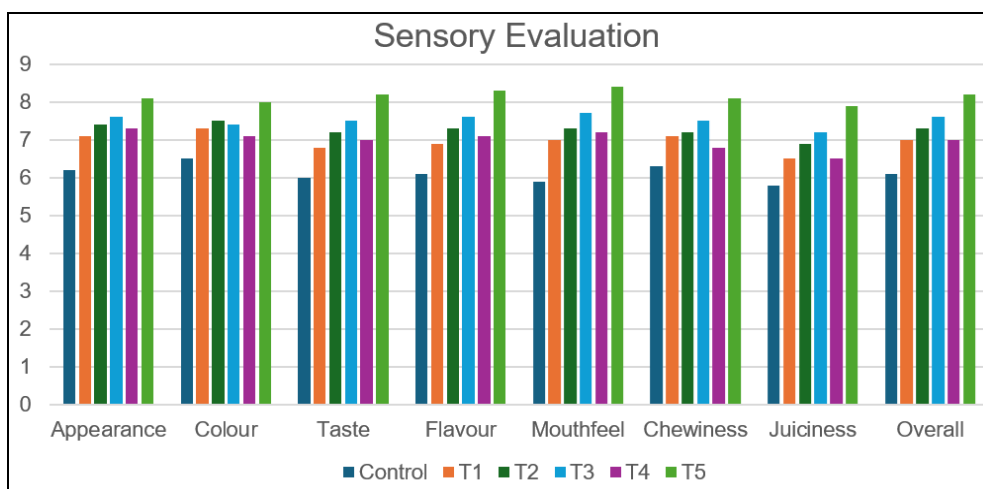
3.5 Sensory Evaluation

The sensory evaluation was conducted using a 9-point hedonic scale with a panel of 10 semi-trained panellists (aged 18-30 years), assessing eight attributes: appearance, colour, taste, flavour, mouthfeel, chewiness, juiciness, and overall acceptability. Across all eight sensory attributes, T₅ consistently received the highest hedonic scores: appearance (8.1±0.15), colour (8.0±0.14), taste (8.2±0.16), flavour (8.3±0.15), mouthfeel (8.4±0.18), chewiness (8.1±0.15), juiciness (7.9±0.20), and overall acceptability (8.2±0.16).

These scores, all falling in the 'like very much' category of the 9-point scale, indicate that T₅ achieved the highest level of panellist satisfaction among all formulations. The high taste and flavour scores of T₅ are attributed to the synergistic seasoning uptake facilitated by its porous, well-textured matrix, combined with the effective masking of residual SPI and PPI off-flavours (beany, grassy notes) by the seasonings and jackfruit's naturally mild, subtly sweet flavour profile.

Table 3: Sensory Evaluation of Jackfruit based Meat Analogue Chunks

Sample	Appearance	Colour	Taste	Flavour	Mouthfeel	Chewiness	Juiciness	Overall
Control	6.2±0.32 ^a	6.5±0.28 ^a	6.0±0.35 ^a	6.1±0.30 ^a	5.9±0.38 ^a	6.3±0.29 ^a	5.8±0.40 ^a	6.1±0.33 ^a
T ₁	7.1±0.25 ^{ab}	7.3±0.22 ^a	6.8±0.28 ^{ab}	6.9±0.26 ^{ab}	7.0±0.30 ^{ab}	7.1±0.24 ^{ab}	6.5±0.32 ^b	7.0±0.27 ^{ab}
T ₂	7.4±0.20 ^a	7.5±0.18 ^a	7.2±0.22 ^a	7.3±0.21 ^a	7.3±0.25 ^a	7.2±0.20 ^a	6.9±0.28 ^a	7.3±0.22 ^a
T ₃	7.6±0.18 ^a	7.4±0.20 ^a	7.5±0.20 ^a	7.6±0.19 ^a	7.7±0.22 ^a	7.5±0.18 ^a	7.2±0.25 ^a	7.6±0.20 ^a
T ₄	7.3±0.22 ^a	7.1±0.24 ^b	7.0±0.26 ^{ab}	7.1±0.24 ^{ab}	7.2±0.27 ^b	6.8±0.26 ^b	6.5±0.30 ^b	7.0±0.25 ^{ab}
T ₅	8.1±0.15 ^{ab}	8.0±0.14 ^{ab}	8.2±0.16 ^{ab}	8.3±0.15 ^{ab}	8.4±0.18 ^a	8.1±0.15 ^{ab}	7.9±0.20 ^b	8.2±0.16 ^{ab}

**Fig 5:** Sensory Profile of Plant-Based Meat Analogue Formulations (9-Point Hedonic Scale)

4. Conclusion

The present study showed that a plant-based meat analogue with good cooking quality, nutritional value, texture and sensory acceptability can be developed using tender jackfruit flour, soy protein isolate and pea protein isolate. Increasing the SPI level from 12% to 20% while decreasing the PPI level from 16% to 8% improved the cooking yield, reduced shrinkage during cooking, and increased the protein content of the product, while the carbohydrate and crude fibre content decreased. The texture profile analysis of the cooked samples showed that T₄ (18% SPI, 10% PPI) had the firmest, most cohesive and chewiest structure among the formulations, while the sensory evaluation showed that T₅ (20% SPI, 8% PPI) was the most preferred formulation by the panellists for appearance, taste, flavour, mouthfeel,

chewiness, juiciness and overall acceptability. The microbial counts of all the formulations were within safe limits, confirming that the extrusion process produced a microbiologically safe product. Based on these results, T₄ and T₅ are recommended as the most suitable formulations for further development of jackfruit-based plant meat analogues, offering a sustainable, nutritious and consumer-acceptable alternative to conventional meat products.

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