Sensory Evaluation of Extruded Meat Analogues from Underutilized Legumes Compared to Meat and Commercial Textured Vegetable Protein.

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Abstract:

This study aimed to evaluate the effects of incorporating cowpea and moth bean flours, along with soy protein and wheat gluten in varying ratios, using low-moisture extrusion techniques. The cooked extruded meat analogue was then compared with commercial textured vegetable protein (C-TVP) and real meat, both prepared in curry form. The results showed that the control 1 (meat) got highest score for color 8.20 ±0.41 when compared to control 2 and experimental samples (T_1toT_4). T_3 sample got highest score for taste (8.22±0.42) compared to other experimental samples and significantly not different with control 1(8.25±0.73). The juiciness of T_3 and control 2 were significantly not different ($p > 0.05$) when compared to other samples. The juiciness of T_3 was about (8.15±0.36) and (8.08 ± 0.28) for control 2. The fibrousness (8.15 ± 0.36) of T_3 and control 2 (8.05 ± 0.22) were significantly not different ($p > 0.05$).The chewiness of T_3 (8.02 ± 0.13) and control 2 (7.92 ± 0.28) were not significantly different. The elasticity of T_3 (8.19 ± 0.39) was significantly different compared to control samples and rest of the experimental samples. The T_3 got highest score (8.08 ± 0.28**)** for overall acceptability among the experimental samples and significantly different ($p < 0.05$) with control samples.

Introduction:

Plant-based meat analogues (PBMAs) are typically made from plant protein concentrates or isolates, whereas other meat substitutes often use whole vegetables and legumes as their base. The market for plant-based meat alternatives has seen rapid growth in recent years and is expected to continue expanding (Aschemann-Witzel et al., 2021). In Sweden, this sector has experienced an average annual growth of around 15% over the past five years, and it is projected that within five years, its market size could match that of the current chicken segment (S. Bryngelsson et al., 2022). As PBMAs become more widely consumed, their nutritional value is gaining importance both in terms of meeting dietary recommendations and adequately replacing the nutrients found in meat.

Technological progress in developing plant-based meat-like products is advancing rapidly and becoming increasingly accessible in global markets (Sha and Xiong, 2020). Despite this growth, plant-based alternatives (PBAs) still encounter significant challenges—particularly in satisfying consumer expectations, delivering appealing sensory characteristics, and mimicking the texture of conventional meat (Clark and Bogdan). A further hurdle is the unfavorable perception many consumers hold toward PBAs, largely due to clear differences in taste and texture compared to animal-based products. This underscores the need for comprehensive sensory evaluations (Michel et al., 2021).

Consumer perception and acceptance of meat alternatives are strongly shaped by the product's sensory qualities. Therefore, combining objective measurements with sensory evaluations during product development can provide crucial insights into the quality of meat analogues (Fu et al., 2023). A variety of descriptors have been used to characterize the sensory attributes of meat analogues, including terms like "fibrousness," "firmness/hardness," "juiciness," "elasticity," "beany," "brittleness," "earthy," "chicken," "crumbly," "moist," "tenderness," "taste," "flavor," and "smell" (McClements et al., 2021). Research has consistently shown that the best approach to evaluating sensory characteristics and consumer acceptance combines descriptive sensory analysis—which measures the intensity of specific sensory features—and consumer testing using hedonic scales to assess preference (Fiorentini et al., 2020). In addition to traditional sensory methods, there is increasing interest in AI and machine learning-based tools, such as electronic nose technologies, which detect volatile compounds to evaluate smell (Zhong, 2019).

Although plant-based protein sources play a vital role in developing meat analogues, they also present certain challenges that may affect the sensory quality of the final product. These issues can lead to reduced consumer preference due to unfamiliar taste profiles and less appealing sensory attributes compared to traditional meat (Hoek, 2011). Globally, soy protein is the most commonly used protein source in meat analogue formulations (Sun, 2021). However, its major drawback is the presence of strong off-flavors. These undesirable flavors are generally categorized as either grassy and beany, or astringent and bitter. Addressing these sensory challenges is essential, as highlighted by Kurek et al. (2022), who reported that legume-based meat alternatives often emit a distinctive beany odor.

Replicating the meat-like appearance of meat analogues largely depends on two key aspects: effective quality control and a clear understanding of consumer preferences. Research has focused on adjusting formulations and cooking methods to improve attributes such as color, flavor, and texture, thereby increasing consumer appeal. In particular, cooking conditions—such as time and temperature—have been tested to optimize the visual quality of meat analogues, as these factors significantly impact the product's final appearance (Fiorentini). Since consumers expect plant-based alternatives to closely resemble the sensory characteristics of real meat, the sensory experience during chewing plays a critical role. Specifically, the first impression of both meat and its alternatives is typically tied to texture, with hardness being the initial sensation perceived during mastication (Chen et al.).

Most sensory studies on plant based meat analogue have investigated the samples made from soybean derived ingredients. This study aimed to evaluate the effects of incorporating cowpea and moth bean flours, along with soy protein and wheat gluten in varying ratios, using low-moisture extrusion techniques. The cooked extruded meat analogue was then compared with commercial textured vegetable protein (C-TVP) and real meat, both prepared in curry form.

Materials and methodology

Raw materials

In the present research the major ingredients taken for the preparation of plant based extruded meat analogue are: Defatted soy flour (*Glycine max*), Soy protein isolate (*Glycine max*), Cowpea flour (*Vigna unguiculata*), Moth bean flour (*Vigna acontifolia*) and Wheat gluten (*Triticum aestivum*). Defatted soy flour, soy protein isolate and wheat gluten were directly procure from local market.

Commercial soy chunk

A commercial soy chunk purchased from local market of Parbhani was used as a control sample. It was produced by extruding defatted soybean flour using a low- moisture extrusion process, and named a commercial textured vegetable protein (C- TVP). C-TVP had a spherical shape with a diameter of 5 to 8 mm. It's approximately composition by weight percent was protein 50 per cent, carbohydrate 30 per cent, moisture ≤ 10 per cent and fat ≤1 per cent

Real meat

Real meat (mutton) were procured from near the university and kept at 3^{o}C during transport and used as control sample. Any excess fat or cartilage was removed from the meats and washed. Lamb meat was cut into small piece sizes of similar lengths.

Methods

Extrusion processing of plant based meat analogue

The preconditioned formulated blend was extruded using a co-rotating, fully intermeshing and self-cleaning twin-screw extruder (KK-FSC65, KK Life Science, Chennai, India). The extruder had a screw length of 1050 mm, a diameter of 65 mm, and an L/D ratio of 16:1, with a maintained screw configuration from the feed input to end of the die. It was equipped with a feed hopper, a mixing section, and three temperature zones along the barrel, from the feeder to the die end. At end of the die, a die cutter with three hard blades operated at a speed of 2800 rpm, and the die had a diameter of 4 mm. The pre conditioned material feed rate was maintained at 60 kg/h. To optimize the extrusion process for each formulation, feed moisture content (25, 30, and 35 %) and barrel temperatures (Z1-70°C, Z2-90°C, and Z3-110°C) in one condition and (Z1-80°C, Z2-100°C, and Z3-120°C in another condition) were varied, while the screw speed was kept constant at 360 rpm. The collected extruded meat analogues were dried at 50°C for 20 min and cooled for 8 min in a cabinet drier. Dried extrudates was collected and stored at room temperature in polyethylene bag for further use.

Sensory evaluation

Before the sensory evaluation curry was prepared by using rehydrated meat analogue samples and two control samples. Sensory analysis were conducted with 25 trained and semi-trained panelists and panelists were asked to rate the samples using a 9-point hedonic scale to assess sensory attributes such as Color, Taste, Juiciness, Fibrousness, Chewiness, Elasticity and Overall acceptability (9 liked extremely; 1 disliked extremely) against the control samples like meat and commercial soy chunk (Narayana et al., 2003).

This curry is prepared and provided to panelist for sensory evaluation. The samples were coded with randomly selected 3-digit numbers and placed in balanced ordered for tasting. Each panelist was presented with a tray containing six samples in 50 ml glass sampling containers. To eliminate carryover factors, consumers were provided with room temperature water for mouth cleansing between samples.

Table 1: Recipe for curry preparation for 25g of extruded meat analogue (Narayana et al., 2003)

Ingredients	Quantity (g)
Red chili powder	5
Coriander powder	10
Turmeric powder	2
Cloves	0.5
Cinnamon	0.5
Cardamom	0.5
Ginger garlic paste	10
Onion	20
Green Chili	4
Tomato ripe	20
Poppy seed	5
Refined peanut oil	30

Method for curry preparation

Plant based extruded meat analogues (chunk) were soaked in 2–3 volumes of hot water (50^{o}C) for 4-5 min. The water was drained off and the chunks were gently squeezed to remove excess water and kept aside. About 20 g of peeled and chopped onion and 20 g tomato were ground into a fine paste together with garlic, ginger, poppy seeds, green chilies, red chili powder, coriander powder, and turmeric powder. Remaining 20 g of peeled and chopped onion was fried to a golden brown color in a frying pan. The ground spices mix was then added and the frying continued with constant stirring with a perforated laddle until the oil started oozing out of the paste of spices (masala). The balance of the chopped tomato was added and the frying continued for another 10 min. Now the soaked TVP chunks were added along with about 100–150 ml of hot water depending on the consistency of the gravy required. Salt was added to taste and cooked for 10 min. Finally cloves, cinnamon, and cardamom mix was added and the cooking was continued for another 2 min after which the curry was ready to serve.

Statistical analysis

All the data were statistically evaluated by one way analysis of variance (ANOVA) and the significance of differences between means were determined by Duncan's multiple comparison test at a 5% significance level ($P < 0.05$) by using IBM SPSS statistics software, version 20.0 (IBM, SPSS, Inc., Chicago, IL, USA).

Results and discussion

Plant-based meat analogues often have a nutty or grassy flavor, which can reduce consumer acceptability. However, due to their meat like texture, including biting, chewing, Juiciness, and relatively high nutritional quality, these analogues are considered a suitable alternative to conventional meat. In this study, the plant-based extruded meat analogue was evaluated for its sensory quality in the form of a spiced curry, similar to traditional meat curry, which is widely popular among Indian consumers. The sensory evaluation assessed key attributes such as color, taste, juiciness, fibrousness, chewiness, elasticity and overall acceptability. The scores obtained for various samples were recorded using a 9-point Hedonic and are presented in Table 2. Kaleda et al., 2022 evaluated the appearance, texture, and flavor of rehydrated meat analogs using descriptive sensory analysis on a 0–9 scale. The results revealed that the most noticeable differences among samples were in texture and appearance, while odor and taste varied the least.

The sensory attributes of the formulated meat analogues (T_1–T_4) were evaluated based on color, taste, juiciness, fibrousness, chewiness, elasticity and overall acceptability and compared with two control samples (Control 1 (meat) and Control 2 (Soy chunk)). Sensory characteristics are crucial in determining consumer preference for plant-based meat analogues, as they directly influence texture, mouth feel, and overall eating experience.

Table 2: Effect of treatment on sensory qualities of plant-based extruded meat analogues

Sample Name	Color	Taste	Juiciness	Fibrousness	Chewiness	Elasticity	Overall Acceptability
Control 1	8.20 ± 0.36^{a}	8.25 ± 0.73^{a}	8.85 ± 0.36^{a}	8.88 ± 0.33^{a}	8.93 ± 0.25^{a}	8.95 ± 0.22^{a}	8.97 ± 0.18^{a}
Control 2	7.44 ± 0.50^{b}	6.17±0.38c	8.08 ± 0.28^{b}	8.05 ± 0.22^{b}	7.92 ± 0.28^{b}	8.03 ± 0.18^{c}	6.98 ± 0.29^{c}
T_1	6.76 ± 0.75^{d}	6.92 ± 0.28^{b}	6.17 ± 0.38^{d}	6.98 ± 0.13^{c}	6.07 ± 0.25^{d}	6.08 ± 0.28^{e}	6.10 ± 0.30^{d}
T_2	6.10 ± 0.30^{e}	6.73 ± 0.45^{b}	6.17 ± 0.46^{d}	6.95 ± 0.22^{c}	7.02 ± 0.13^{c}	6.02 ± 0.13^{e}	6.02 ± 0.13^{d}
T_3	8.00 ± 0.41^{a}	8.22 ± 0.42^{a}	8.15 ± 0.36^{b}	8.15 ± 0.36^{b}	8.02 ± 0.13^{b}	8.19 ± 0.39^{b}	8.08 ± 0.28^{b}
T_4	7.01 ± 0.13^{c}	6.27 ± 0.45^{c}	7.92 ± 0.28^{c}	6.08 ± 0.28^{d}	6.05 ± 0.22^{d}	7.02 ± 0.13^{d}	7.07 ± 0.25^{c}

Values are expressed as Mean ± SD (n = 60). The values in the same column with different superscript letters are significantly different according to the Duncan's multiple comparison test ($p < 0.05$).

Control 1: Meat (Mutton), Control 2: Commercial texturized vegetable protein (Soy chunk)

Colour

Color is a key factor in consumer acceptance of plant-based meat analogues. The color scores ranged from 6.10±0.30 (T_2) to 8.20±0.41 (T_3). Control 1 and T_3 received the highest scores (8.20±0.36 and 8.00±0.41 respectively) with no significant difference ($p > 0.05$), suggesting that T_3 closely mimics the color of conventional meat products. The lowest score was recorded for T_2 (6.10±0.30).

Taste

Taste scores ranged from 6.17±0.38 (Control 2) to 8.25 ±0.73 (Control 1) had a significantly higher taste score than all other experimental samples, comparable to Control 1, indicating that T_3 provided a well balanced flavor profile. T_1 and T_2 had moderate scores (6.92±0.28 and 6.73±0.45 respectively) while T_4 had the lowest taste score (6.27±0.45). It's important to note that consumer preference vary some prefer a strong meat-like taste, while others favor a more neutral flavor. For meat-like experiences, it's essential to mask strong legume or cereal notes using protein isolates and dry-fractionated proteins. A common issue with plant-based meat is low juiciness, making water-binding agents important. The higher moisture perception in dry-fractionated protein products can be a benefit.

Juiciness

Juiciness is a crucial textural parameter in meat analogues, as it contributes to mouth feel and consumer satisfaction. The highest juiciness scores were recorded for Control 1 (8.85±0.36) and T_3 (8.15±0.36), showing no significant difference ($p > 0.05$). This indicates that T_3 retained moisture well, providing a juicy texture similar to traditional meat. In contrast, T_1 and T_2 received significantly lower juiciness scores (6.17±0.38). Moisture perception, an important attribute linked to juiciness and water-holding capacity (WHC), was rated below average, reflecting the relatively low WHC values. Notably, the WHC and oil-holding capacity (OHC) tests involved grinding the samples, which damaged the porous structures that help retain water. Sensory moistness correlated strongly with springiness (0.82–0.93) and negatively with hardness (−0.77 to −0.89), suggesting that the porous structure played a key role in perceived juiciness—something not captured in standard WHC measurements.

Fibrousness

Fibrousness, which represents the muscle-like texture in meat analogues, varied significantly among the samples. The control samples exhibited the highest fibrousness, with

Control 1 at 8.88±0.33 and Control 2 at 8.05±0.22. T_3 had a fibrousness score of 8.15±0.36, closely resembling Control 2. This suggests that T_3 successfully replicated the fibrous texture of meat. The lowest fibrousness score was observed in T_4 (6.08±0.28). Fibrousness, a desirable trait for meat analogs, had similar average values (6.4/9) across blends. However, maximum fibrousness increased from 7.2 to 8.6 as protein content dropped from 78.6% to 63.5%. This suggests that fibrous texture forms better in multi-phase systems with moderate protein levels (50–70%), as supported by Cheftel et al. (1992) and Zhang et al. (2019). Blend D, with more fats and carbs, showed better phase separation, helping stabilize fibrous structures. Still, extrusion conditions had the largest effect on fibrousness, ranging from 3.9 to 8.6. Panelists noted that the fibrous texture of Blend D (under conditions 6 and 7) resembled chicken the most.

Chewiness

Chewiness scores ranged from 6.05±0.22 (T_4) to 8.93 ± 0.25 (Control 1). T_3 showed a significantly higher chewiness score (8.02±0.13) than T_1, T_2, and T_4. Soy protein levels significantly affected bitterness and after taste. According to Kaleda et al, Chewiness and springiness showed similar patterns across blends, but strong correlations (0.81 and 0.92) were only seen in blends C and D. In contrast, blends A and B had weak or no correlation, which differs from previous findings that springy foods are harder to chew (Wee et al., 2018). Chewiness is complex, influenced not only by springiness but also by hardness and moistness although moistness didn't vary significantly across samples due to consistent extrusion settings.

Elasticity

Elasticity contributes to the overall textural quality of meat analogues. Control 1 exhibited the highest elasticity (8.95±0.22) followed by T_3 (8.19±0.39), which was significantly better than other experimental samples. T_1 and T_2 had the lowest scores (6.08±0.28 and 6.02±0.13, respectively), indicating a more rigid and less elastic texture.

Overall acceptability

Overall acceptability scores ranged from 6.02±0.13 (T_2) to 8.97 ± 0.18 (Control 1). Among the experimental formulations, T_3 (8.08±0.28) had the highest overall acceptability, significantly effects with T_1, T_2 and T_4. The lowest acceptability scores were recorded for T_1 (6.10±0.30) and T2 (6.02±0.13). The results from sensory evaluation conclude that T_3 suggests is a promising alternative to conventional meat products providing an optimal balance of sensory attribute. Relation between all sensory attribute present in figure 4.4.

Allah Bakhsh found that meat analog (MA) patties had better appearance scores than beef and pork and similar color and shape. MA patties were firmer and had overall acceptability comparable to the meat controls, likely due to the elastic and chewy nature of soy protein. Deliza et al., (2002) found that substituting 10–30% of beef with textured soy protein (TSP) didn't affect consumer acceptance. Even when sodium was reduced, the hybrid patties scored similarly in flavor liking to full-beef patties.

Conclusion:

The prepared extruded meat analogues were subjected to sensory evaluation compared with control 1 (meat) and control 2 (C-TVP). The results from sensory evaluation conclude that T_3 suggests is a promising alternative to conventional meat products providing an optimal balance of sensory attribute**.** The sensory qualities, especially the attributes of flavor, color and texture, such as chewiness and juiciness, play a crucial role in achieving high consumer acceptance of meat analogues. Consequently, the careful selection of appropriate plant sources and the optimization of structural parameters are essential steps in producing a product that offers superior sensory perception while effectively addressing the associated challenges.

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