

Texture and Flavour Optimization of Plant Based Meat Analogue

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Research Article

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Abstract

Meat analogue is a food product developed from vegetable proteins and having texture and flavour like animal meat. This paper deals with optimization of oven based texturization method for developed four formulations of meat analogue and further enhancement of meaty flavor in these meat analogue formulations. The meat analogue formulations S2, S8, S19 and S22 were developed in laboratory using Defatted soy flour, Kabuli chickpea flour, Button mushroom and Jackfruit flour in various combination. These developed meat analogue formulations were then subjected to texturization using oven method and the condition of texturization was optimized for time and temperature, based on analyzing their textural parameters like Hardness, Cohesiveness, Adhesiveness, Chewiness, Springiness and gumminess, using Texture Analyzer (Texture Pro CT V1.7 Build 28 Brookfield Engineering Labs. Inc.). The meat analogue formulations, texturized at optimized condition were then subjected to meaty flavour enhancement by incorporating Yeast extract and Hydrogenated Vegetable Protein (HVP) individually as well as in various combination and the best level of incorporation was decided on the basis of sensory evaluation. The optimized condition obtained for oven texturization method was 180°C for 20 minutes for both the formulations S2 and S8, whereas for S19 it was 165°C for 30 minutes and for S22, 195°C for 30 minutes. The optimum level of Yeast extract incorporation in S2, S8, S19 and S22 was found to be 3%, 2.5%, 3% and 2.5% respectively. The optimum level of HVP incorporation in all the formulations was found to be 4%. The sensory score for HVP was found to be better in terms of flavour than that of yeast extract for all the four formulations. The optimized combination of Yeast extract and Hydrolyzed vegetable protein in S2, S8, S19 and S22 were observed to be 1% +2.5%, 1% +2.25%, 1% +2.5%, 1% +2.25% respectively. Yeast extract and Hydrolyzed vegetable protein in combination shown better overall sensory score as compared to individual incorporation.

Introduction

The definition of meat analog refers to the replacement of the main ingredient with other than meat. It also called a meat substitute, meat alternatives, fake or mock meat, and imitation meat. The increased importance of meat analogue in the current trend is due to the health awareness among consumers in their diet and for a better future environment [1]. Recently, there have been increased studies of plant-based meat analogue as an alternative protein source to substitute the traditional animal-based food in various parts of the world. This may be due to the rising world population and limited natural resources, causing animal meat production to be an unsustainable practice [2].

Common meat analogue available in market are made from soybean sources like tofu and in combination with wheat gluten are also used. Different types of proteins can impact the final product's appearance, nutrition, flavors, and health effects. Hence, one of the critical aspects of developing a plant-based meat analog is selecting a suitable protein source. Although many plant-based proteins are used for meat analogue production, soy protein, chickpeas, and wheat gluten are commonly used for meat analog production. Due to their low-cost reasons and possession of the ability to give the desired texture and other characteristics as animal meat [3]. Mushroom is another option used in meat analogue manufacturing as it is rich in sulfur-containing amino acids that help to attain meat flavor [4]. Further, the physiological and nutritional quality of the meat can be enhanced by exploring new protein sources and replacing it partially or completely with the traditional alternatives. One such suitable ingredient for this purpose is jackfruit.

As the meat analogue is produced from plant based proteins it does not contain the meaty flavour, so as to impart meaty flavour like meat some flavour enhancers are used. Yeast extract pastes are popular sources of flavour for a range of savoury food products, particularly when a meaty aroma is required [5]. Ames reported that yeast extracts were a source of amino acids, peptides, sugars, nucleotides, lipids and B-group vitamins, all of which could act as meat flavour precursors [6]. HVP is a meat-like flavour that has been used for over a century [7]. In the preparation of HVP, either enzymatically or by acid hydrolysis, the proteins are converted into peptides and amino acids, sugars are formed from carbohydrates, resulting in the formation of products like hydroxymethylfurfurals and levulinic acid.

Likewise the different plant based sources, methods of texturization are also different such as **steaming**: is a moist-heat cooking process that transforms food by using hot water vapor to transfer heat, causing significant structural changes to proteins and starches, which results in a solid, tender, and moist texture [8]. **Frying**: is a complex food processing technique involving simultaneous, high-temperature heat and mass transfer, where food is immersed in oil typically heated between 150°C

and 200°C. The process transforms food by removing water (dehydration) and transferring oil into the product, resulting in a unique combination of a crisp, porous crust and a moist interior [9]. **Extrusion:** The food extrusion process is a high-temperature, short-time (HTST) technology that forces raw ingredients—usually dry flours, starch, and protein—through a die, resulting in a continuous product that is simultaneously cooked, mixed, and shaped. The product gets its unique, often airy or fibrous texture through a combination of extreme shear, intense pressure, and heat within a screw-barrel system [10]. **Oven cooking:** It is a dry-heat process that transforms raw, often soft, and moist ingredients into firm, browned, and flavorful products through a combination of heat transfer (convection, conduction, and radiation) and chemical reactions. The primary texturizing mechanism involves removing surface moisture to create crispness while simultaneously triggering protein coagulation and starch gelatinization to set the structure [11].

Therefore, the goal of this research was to create the ideal blend of plant-based protein and other ingredients to create a plant-based meat analogue by optimization of texture and flavour to obtain desired meat-like properties.

Materials and Methods

Raw materials used for the preparation of meat analogue were Kabuli Chickpea, Jackfruit, Mushroom purchased from local market of Jalgaon. Deoiled soy cake was received from Sanjay Soy Pvt. Ltd. Industry, Avdhan MIDC, Dhule. to make defatted soy flour. Binding agent carrageenan of lampure and guar gum of Naturesharvest were used. Flavour enhancer yeast extract of Urban platter brand and Hydrolyzed vegetable protein of Agriclub brand were used in the formulation.

Table 1 Selected meat analogue Formulation				
Sample	A:Defatted soy flour	B:Chickpea flour	C:Mushroom	D:Jackfruit flour
Code	%	%	%	%
S2	40	20	20	20
S8	28.6	28.6	28.6	14.2
S19	30	10	30	30
S22	21.4	21.4	35.7	21.4
*Above formulation include binding agent (carrageenan and guar gum) 0.5% each and water (as per need)				

Preparation of Meat analogue

Optimization of time and temperature

Four different plant based protein meat analogue formulation received after screening of 24 RSM [12, 13]formulations as mentioned in Table 1 were S2, S8, S19 and S22, prepared by the addition of defatted soy flour, Chickpea flour, Jackfruit flour, mushroom paste and binding agent (carrageenan and guar gum). The dough was prepared by addition of water and cooked in Oven for different time (15, 20, 25, 30 min) and temperature (150°C, 165°C, 180°C, 195°C) so as to optimized process parameters [14, 15, 16]. After cooking meat analogue sample were cooled down for further analysis.

Optimization of Flavour enhancer

Four different plant based protein meat analogue formulation as mentioned in Table 1 were prepared by the addition of defatted soy flour, Chickpea flour, Jackfruit flour, mushroom paste, binding agent (carrageenan and guar gum) and flavour enhancer (yeast extract and hydrolyzed vegetable protien) in different concentration from 2.5%, 3%, 3.5% and 4% [17, 18, 19, 20]. The dough was prepared by addition of water and cooked in Oven at optimized time and temperature. After cooking meat analogue sample were cooled down for further analysis.

Results and Discussion

Texture Profile results with respect to time

Hardness Characteristics: Hardness values ranged from 3.98 to 6.71 across all samples and time points. Sample S19 demonstrated the highest initial hardness at 6.71 (15 minutes), while S2 showed the lowest hardness of 3.98 at 30 minutes. All three samples exhibited a general declining trend in hardness over time, with S19 dropping from 6.71 to 4.37, S8 fluctuating between 5.53 and 4.72, and S2 decreasing from 5.95 to 3.98 shown in Table 2.

Adhesiveness and Cohesiveness: Adhesiveness measurements were relatively low across all samples, ranging from 0.29 to 1.29. Sample S19 showed the highest adhesiveness at 1.29 (15 minutes), while S8 demonstrated the lowest values, particularly at 0.29 for both 20 and 25 minutes. Cohesiveness varied considerably, with S8 showing notably high values of 0.91 and 0.86 at 15 and 30 minutes respectively, while S19 and S2 displayed more moderate cohesiveness ranging between 0.48 and 0.75.

Secondary Texture Parameters: Springiness remained relatively stable across samples, ranging from 2.68 to 4.14 minutes. Gumminess values showed significant variation from 2.31 to 5.61, with S8 at 15 minutes achieving the highest value. Chewiness displayed the widest range from 7.83 to 16.69, with S8 at 30 minutes recording the maximum value of 16.69 and S19 at 25 minutes showing the minimum of 7.83.

Processing time appears to significantly influence texture properties. The most pronounced effect is the consistent reduction in hardness across all samples as time increases. This softening pattern suggests thermal or enzymatic breakdown during the cooking process. However, the relationship between time and other parameters is less linear, with gumminess and chewiness showing non-monotonic changes that likely reflect complex structural transformations occurring at different stages of processing. The optimized time for S2 is 20min, S8 is 20min, S19 is 30min and S22 is 30min

Table 2
Texture profile results (Duncan Multiple Range Test for the responses of the Meat Analogue Sample w.r.t Time)

Meat Analogue sample	Time (min)	Hardness (mm)	Adhesiveness (mJ)	Cohesiveness	Springiness (mm)	Gumminess (g)	Chewiness (mJ)
Control	20	6.24	1.4	1.1	4.06	6.86	27.87
S2	15	4.8 $\pm 3.07^{ab}$	0.83 $\pm 0.39^{ab}$	0.64 $\pm 0.21^a$	3.64 $\pm 0.34^{ab}$	2.7 $\pm 0.82^a$	9.93 $\pm 3.7^a$
	20	5.95 $\pm$ 3.05 ^{ab}	0.81 $\pm$ 0.27 ^{ab}	0.64 $\pm$ 0.09 ^a	3.78 $\pm$ 0.17 ^a	3.58 $\pm$ 1.16 ^a	13.50 $\pm$ 4.68 ^a
	25	4.59 $\pm$ 0.43 ^{ab}	0.79 $\pm$ 0.22	0.63 $\pm$ 0.16 ^a	3.18 $\pm$ 0.91 ^{ab}	2.87 $\pm$ 0.79 ^a	9.23 $\pm$ 3.61 ^a
	30	3.98 $\pm$ 0.81 ^{ab}	0.74 $\pm$ 0.25 ^{ab}	0.75 $\pm$ 0.09 ^a	4.14 $\pm$ 0.29 ^a	2.97 $\pm$ 0.59 ^a	12.36 $\pm$ 3.14 ^a
S8	15	5.53 $\pm$ 2.91 ^{ab}	0.54 $\pm$ 0.34 ^{ab}	0.91 $\pm$ 0.33 ^a	3.28 $\pm$ 0.69 ^{ab}	5.61 $\pm$ 5.07 ^a	16.18 $\pm$ 11.45 ^a
	20	5/07 $\pm$ 2.95 ^{ab}	0.30 $\pm$ 0.22 ^b	0.85 $\pm$ 0.33 ^a	3.46 $\pm$ 0.99 ^{ab}	4.91 $\pm$ 4.88 ^a	14.59 $\pm$ 10.75 ^a
	25	5.17 $\pm$ 1.07 ^{ab}	0.29 $\pm$ 0.09 ^b	0.48 $\pm$ 0.24 ^a	3.57 $\pm$ 1.33 ^{ab}	2.31 $\pm$ 0.75 ^a	8.69 $\pm$ 5.14 ^a
	30	4.72 $\pm$ 2.09 ^{ab}	0.75 $\pm$ 0.31 ^{ab}	0.86 $\pm$ 0.23 ^a	3.58 $\pm$ 0.43 ^{ab}	4.39 $\pm$ 3.33 ^a	16.69 $\pm$ 15.04 ^a
S19	15	6.71 $\pm$ 0.58 ^a	1.29 $\pm$ 0.61 ^{ab}	0.72 $\pm$ 0.39 ^a	2.68 $\pm$ 0.77 ^{ab}	4.97 $\pm$ 3.06 ^a	12.21 $\pm$ 5.88 ^a
	20	6.44 $\pm$ 0.59 ^a	0.85 $\pm$ 0.83 ^{ab}	0.66 $\pm$ 0.23 ^a	3.42 $\pm$ 0.73 ^{ab}	4.23 $\pm$ 1.49 ^a	14.20 $\pm$ 5.62 ^a
	25	4.37 $\pm$ 1.96 ^{ab}	0.61 $\pm$ 0.40 ^{ab}	0.60 $\pm$ 0.03 ^a	3.14 $\pm$ 0.44 ^{ab}	2.59 $\pm$ 1.05 ^a	7.83 $\pm$ 1.98 ^a
	30	6.33 $\pm$ 1.08 ^{ab}	0.42 $\pm$ 0.26 ^b	0.55 $\pm$ 0.27 ^a	2.91 $\pm$ 1.19 ^{ab}	3.61 $\pm$ 2.24 ^a	12.27 $\pm$ 11.81 ^a
S22	15	3.91 $\pm$ 0.39 ^{ab}	1.03 $\pm$ 0.35 ^{ab}	1 $\pm$ 0.20 ^a	3.11 $\pm$ 1.02 ^{ab}	3.88 $\pm$ 0.61 ^a	12.44 $\pm$ 5.34 ^a
	20	4.53 $\pm$ 1.19 ^{ab}	2.30 $\pm$ 2.80 ^a	0.73 $\pm$ 0.09 ^a	3.19 $\pm$ 1.19 ^{ab}	3.33 $\pm$ 1.19 ^a	11.19 $\pm$ 6.31 ^a
	25	3.24 $\pm$ 1.54 ^b	1.85 $\pm$ 2.79 ^{ab}	0.95 $\pm$ 0.85 ^a	2.02 $\pm$ 1.70 ^a	3.02 $\pm$ 2.29 ^a	6.72 $\pm$ 5.49 ^a
	30	4.59 $\pm$ 0.51 ^{ab}	0.72 $\pm$ 0.25 ^{ab}	0.67 $\pm$ 0.27 ^a	4 $\pm$ 1.12 ^a	3.15 $\pm$ 1.42 ^a	13.82 $\pm$ 8.52 ^a

Means that do not share a common letter in one column are significantly different.

Texture Profile results with respect to temperature

Hardness: Hardness measurements reveal significant variation across temperatures, with 180°C consistently producing the highest values. Sample S8 at 180°C showed the highest hardness (8.1 $\pm$ 1.59), closely followed by sample S2 at the same temperature (7.5 $\pm$ 2.8). The control sample recorded 6.24 at 180°C. Lower temperatures (150°C and 165°C) generally produced softer textures across all samples, with values ranging from 3.5 to 5.47.

Adhesiveness and Cohesiveness: Adhesiveness remained relatively consistent across samples and temperatures, with values ranging from 0.36 to 1.4. The control sample showed the highest adhesiveness at 1.4. Cohesiveness varied more substantially, with sample S8 at 180°C demonstrating notably higher cohesiveness (1.04 ± 0.51) compared to other conditions. Most samples maintained cohesiveness values between 0.51 and 0.81.

Springiness: Springiness measurements showed moderate variation, with values ranging from 2.76 to 4.3. Sample S8 at 150°C achieved the highest springiness (4.3 ± 0.74), while the same sample at 180°C recorded the lowest (2.76 ± 0.99). The control sample demonstrated springiness of 4.06 at 180°C.

Gumminess and Chewiness: Gumminess and chewiness exhibited the most dramatic differences. Sample S8 at 180°C showed exceptionally high gumminess (9.07 ± 5.17) and chewiness (26.4 ± 15.94 mJ), approaching the control sample values of 6.86 and 27.87 mJ respectively. Other conditions produced substantially lower values, with gumminess typically between 2.3 and 3.75, and chewiness between 8.26 and 14.23 mJ.

Temperature Effects: The 180°C cooking temperature consistently produced the most pronounced textural changes across samples, particularly in hardness, gumminess, and chewiness. Lower temperatures (150°C and 165°C) yielded more similar textural profiles, while 195°C showed intermediate characteristics. This suggests 180°C may represent a critical threshold for protein structure modification in these meat analogues.

Sample Performance: Sample S8 demonstrated the widest range of textural responses to temperature changes, particularly at 180°C where it achieved values closest to the control sample. Sample S2 showed more moderate responses, while sample S19 data was limited to 150°C in the provided excerpt. The statistical significance markers indicate meaningful differences between temperature treatments within each sample type. The optimized temperature for S2 is 180°C, S8 is 180°C, S19 is 165°C, and S22 is 195°C

Table 3: Texture profile results (Duncan Multiple Range Test for the responses of the Meat Analogue Sample w.r.t Temperature)

Meat analogue sample	Temperature (°C)	Hardness (mm)	Adhesiveness (mJ)	Cohesiveness	Springiness (mm)	Gumminess (g)	Chewiness (mJ)
Control	180	6.24	1.4	1.1	4.06	6.86	27.87
S2	150	3.73±0.47b	0.74±0.24a	0.66±0.12ab	3.88±0.13ab	2.43±0.49b	9.46±2.1b
	165	3.98±0.53b	0.81±0.18a	0.67±0.02ab	3.80±0.30abc	2.68±0.45b	10.14±1.53b
	180	7.5±2.8a	0.87±0.45a	0.51±0.14b	3.59±1.15abc	3.75±1.22b	14.23±6.97b
	195	4.07±0.83b	0.73±0.19a	0.81±0.07ab	3.4±0.31abc	3.2±0.46b	11.22±1.33b
S8	150	3.5±1.61b	0.57±0.16a	0.73±0.16ab	4.3±0.74a	2.4±0.4b	10.71±3.5b
	165	4.44±0.93b	0.36±0.38a	0.75±0.06ab	3.20±0.19abc	3.35±0.78b	10.78±2.57b
	180	8.1±1.59a	0.45±0.36a	1.04±0.51ab	2.76±0.99abc	9.07±5.17a	26.4±15.94a
	195	4.36±0.64b	0.49±0.33a	0.55±0.17b	3.5±0.27abc	2.3±0.64b	8.26±1.68b
S19	150	5.47±1.4ab	1.32±0.68a	0.56±0.14b	3.14±0.43abc	2.99±0.88b	9.59±4.08b
	165	5.84±1.74ab	0.68±0.28a	0.56±0.23b	3.67±0.41abc	3.29±1.90b	12.62±8.80b
	180	6.55±1.01ab	0.60±0.87a	0.76±0.40ab	2.64±0.90bc	5.18±3.16b	14.04±8.69b
	195	5.86±2.06ab	0.61±0.17a	0.67±0.07ab	2.61±0.91bc	4.03±1.68b	9.57±2.30b
S22	150	3.58±0.93b	2.19±2.54a	1.16±0.69a	2.22±1.65c	3.86±1.57b	8.65±7.23b
	165	4.46±0.25b	0.90±0.13a	0.76±0.13ab	4.04±0.58ab	3.39±0.63b	13.81±3.86b
	180	3.67±1.96b	1.82±3.12a	0.71±0.44ab	2.52±1.64bc	2.88±2.24b	9.89±9.33b
	195	4.56±0.25b	0.92±0.30a	0.70±0.24ab	3.62±0.88abc	3.21±1.12b	12.21±6.66b

Means that do not share a common letter in one column are significantly different.

Sensory Analysis of individual addition of yeast extract (YE) and Hydrolyzed vegetable protein (HVP)

Figure 5 summarizes that Yeast extract (YE) appear to show a declining trend in sensory scores as YE concentration increases from 2.5% to 4%. For example, Appearance decreases from approximately 5.1 to 4.3, and Overall Acceptability falls from 5.3 to 4.3. This suggests higher YE concentrations may negatively impact sensory quality. Whereas, hydrolyzed vegetable protein (HVP) Scores generally increase with HVP concentration. Appearance moves from about 5.6 (2.5%) up to 7.6 (3.5%), Colour from 5.7 to 7.9, and Overall Acceptability improves markedly from 5.6 to 8.1. This trend indicates higher HVP levels may enhance sensory appeal. This shows that YE addition tends to reduce sensory scores as concentration grows and HVP addition tends to improve sensory scores with increasing concentration. The optimum levels of Yeast extract and HVP are 3% and 4% respectively.

From Fig 6 it concludes that lower and higher YE concentrations (2.5% and 3%) generally improve sensory qualities across attributes compared to the Control, with increased Average Overall Acceptability. YE levels (3% and 4%) show consistent declines in sensory scores, particularly in Colour, Flavour, Texture, and Overall Acceptability, indicating a potential threshold where YE negatively impacts product appeal. Whereas, the sensory evaluation clearly shows that increasing HVP concentration from 2.5% to 4% enhances the sensory attributes across the board for the product tested. The 4% HVP level achieved better scores in appearance, colour, flavour, texture, and overall acceptability, with less variability in panelist responses, suggesting improved product consistency and appeal. Therefore 2.5% YE and 4% HVP are optimum for enhancing flavour of meat analogue sample S8

As shown in fig 7, adding yeast extract (YE) at around 3% produces the best sensory results in this trial. Increased YE or HVP above this level reduces panel acceptability. The optimal sensory quality was observed for the formulation with 3% yeast extract

and 4% Hydrolyzed vegetable protein in meat analogue sample S19

Conclusion

The current study finds that good quality meat analogues can be prepared using defatted soy flour, Kabuli chickpea flour, mushroom paste, and jackfruit flour, while maintaining texture and sensory attributes. The optimized condition obtained for oven cooking method was 180°C for 20 minutes for both the formulations S2 and S8, whereas for S19 it was 165°C for 30 minutes and for S22, 195°C for 30 minutes. The optimum level of Yeast extract incorporation in S2, S8, S19 and S22 was found to be 3%, 2.5%, 3% and 2.5% respectively. The optimum level of HVP incorporation in all the formulations was found to be 4%. The sensory score for HVP was found to be better in terms of flavour than that of yeast extract for all the four formulations. The optimized combination of Yeast extract and Hydrolyzed vegetable protein in S2, S8, S19 and S22 were observed to be 1% +2.5%, 1% +2.25%, 1% +2.5%, 1% +2.25% respectively. Yeast extract and Hydrolyzed vegetable protein in combination shown better overall sensory score as compared to individual incorporation.

Declarations

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval

Not applicable

Informed consent

Not applicable

Funding

Not applicable

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Figures

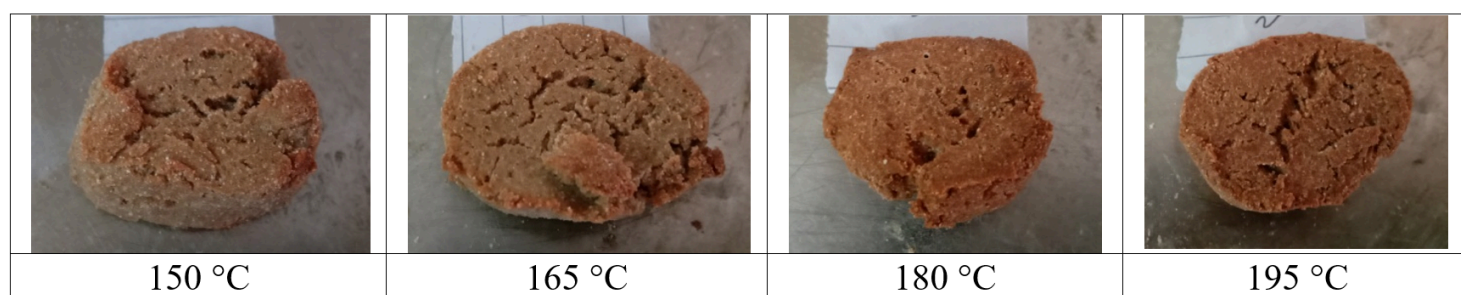


Figure 1

Meat analogue sample S2 oven cooked at different temperature for time 20 min

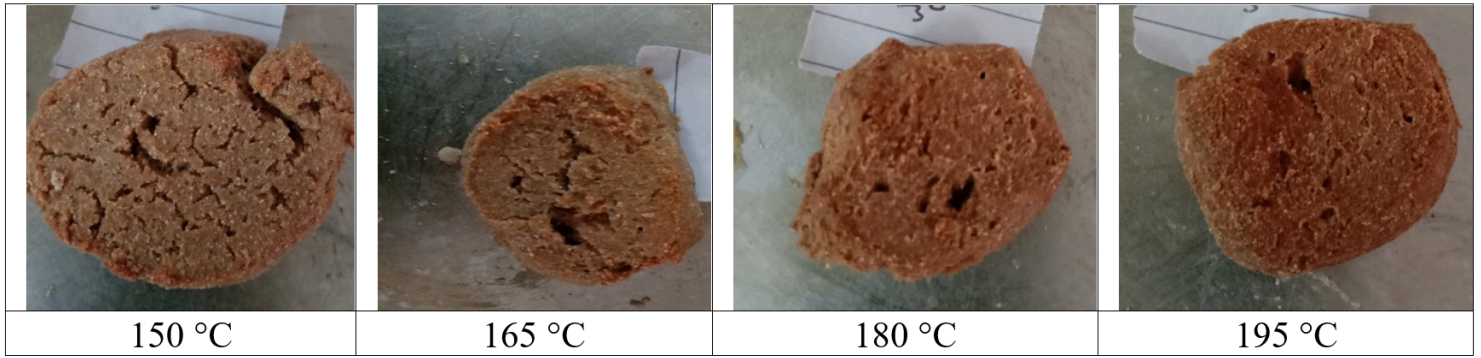


Figure 2

Meat analogue sample S8 oven cooked at different temperature for time 30 min

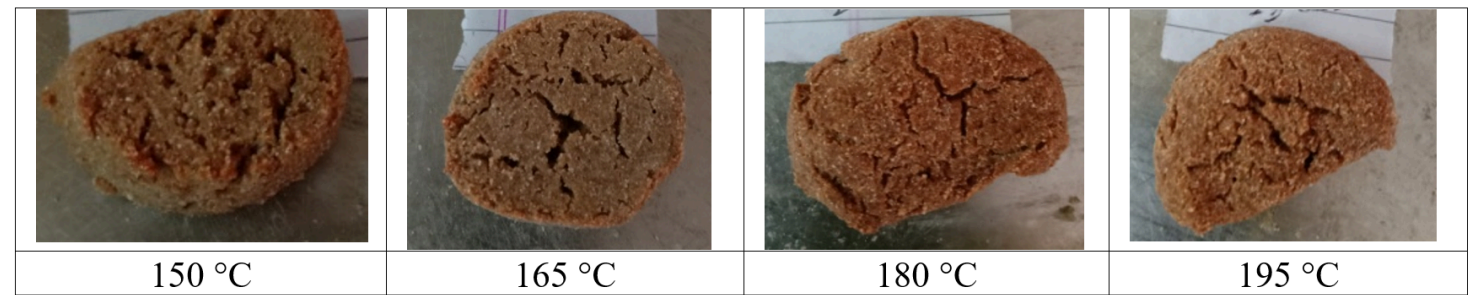


Figure 3

Meat analogue sample S19 oven cooked at different temperature for time 20 min

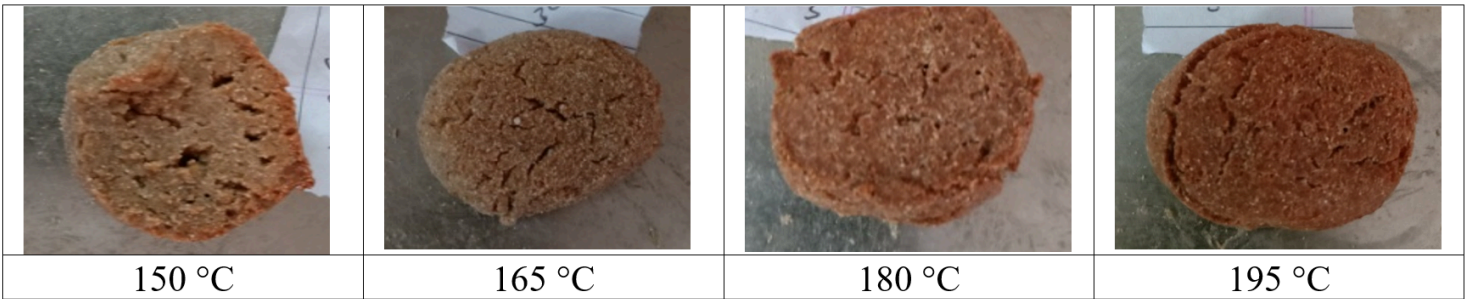


Figure 4

meat analogue sample S22 oven cooked at different temperature for time 30 min

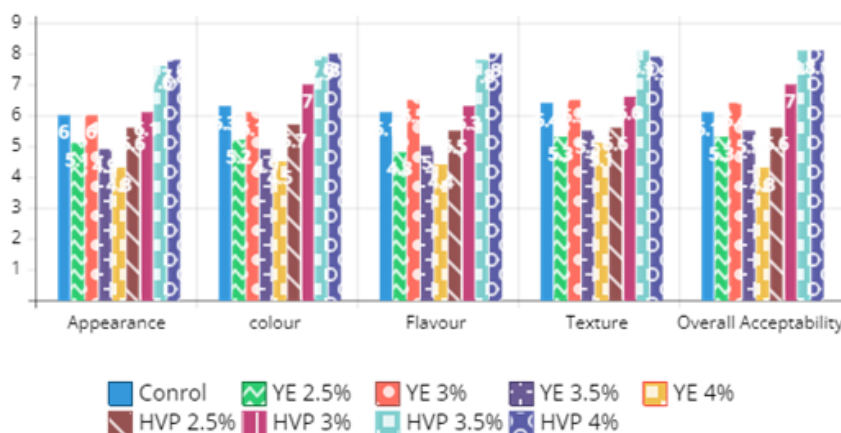


Figure 5

Sensory Evaluation of Oven Cooked Meat Analogue Sample S2 Incorporated with different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

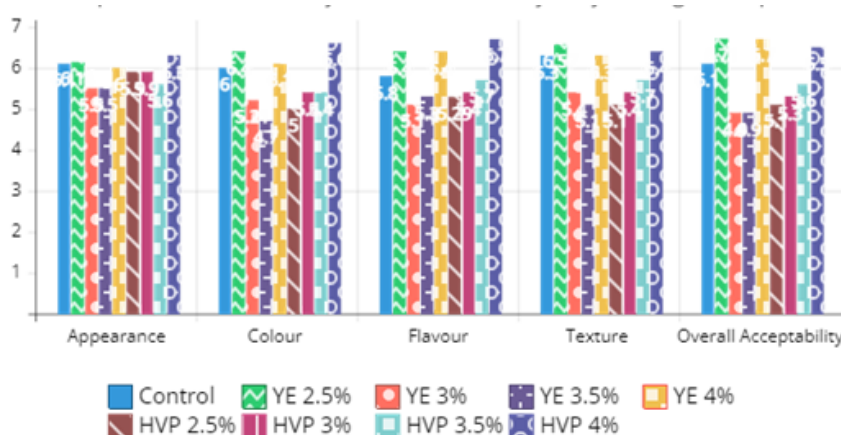


Figure 6

Sensory Evaluation of Oven Cooked Meat Analogue Sample S8 Incorporated with different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

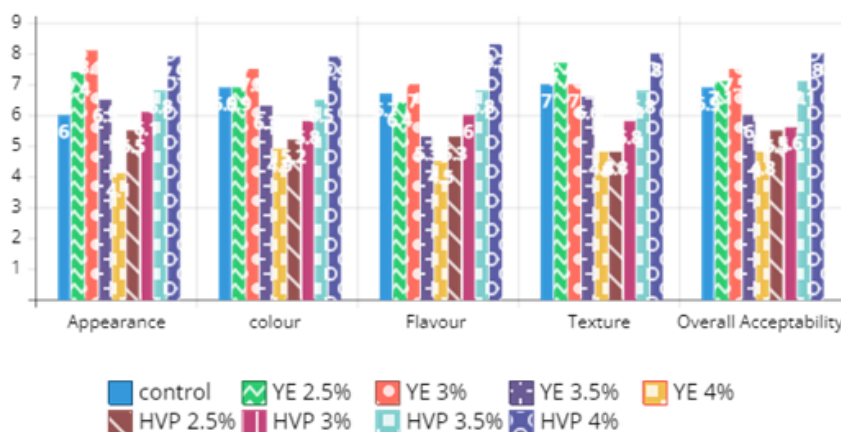


Figure 7

Sensory Evaluation of Oven Cooked Meat Analogue Sample S19 Incorporated with different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

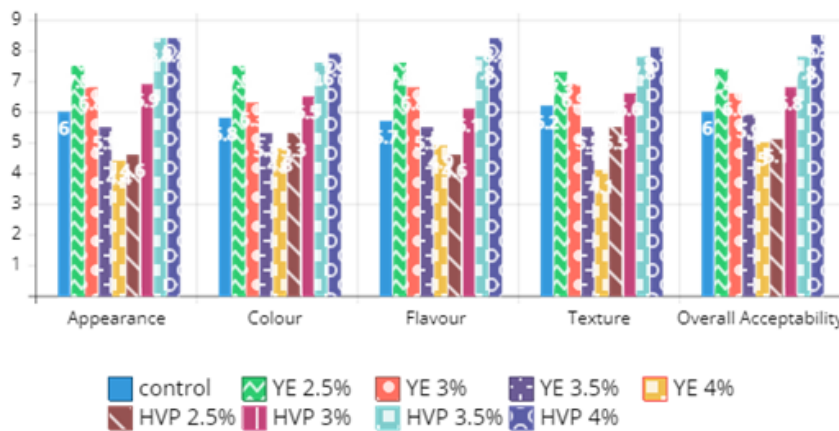


Figure 8

Sensory Evaluation of Oven Cooked Meat Analogue Sample S22 Incorporated with different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

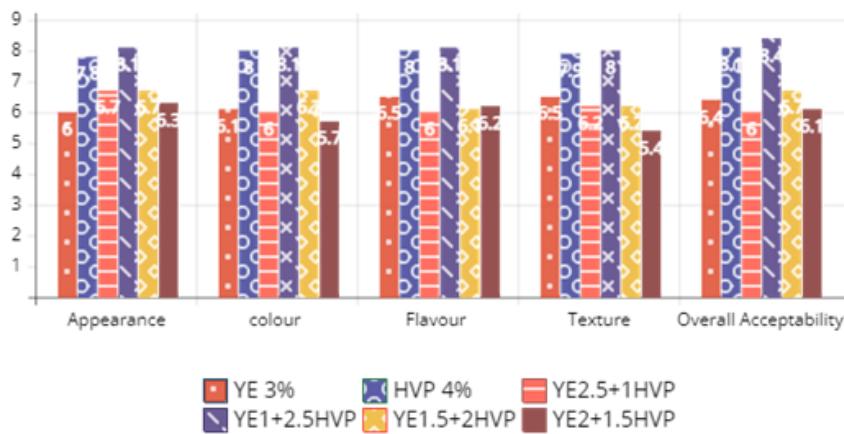


Figure 9

Sensory Evaluation of Oven Cooked Meat Analogue Sample S2 Incorporated with combination of different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

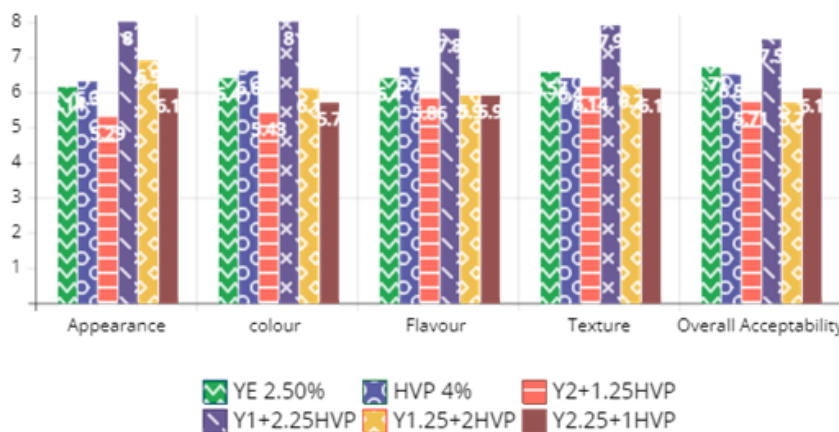


Figure 10

Sensory Evaluation of Oven Cooked Meat Analogue Sample S8 Incorporated with combination of different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

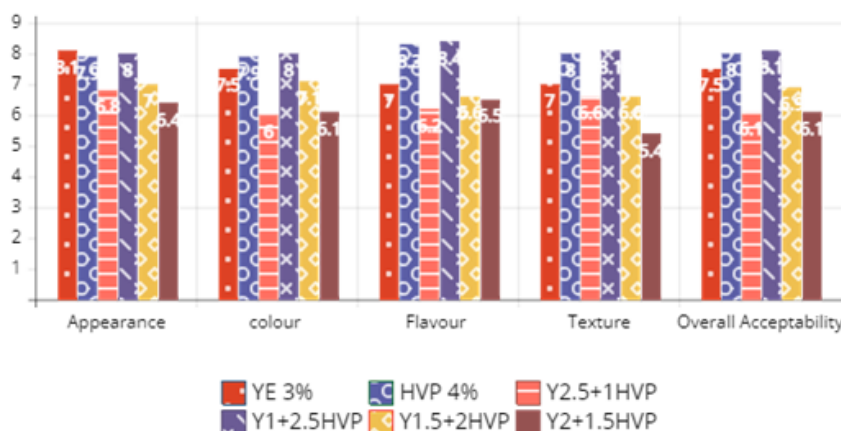


Figure 11

Sensory Evaluation of Oven Cooked Meat Analogue Sample S19 Incorporated with combination of different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

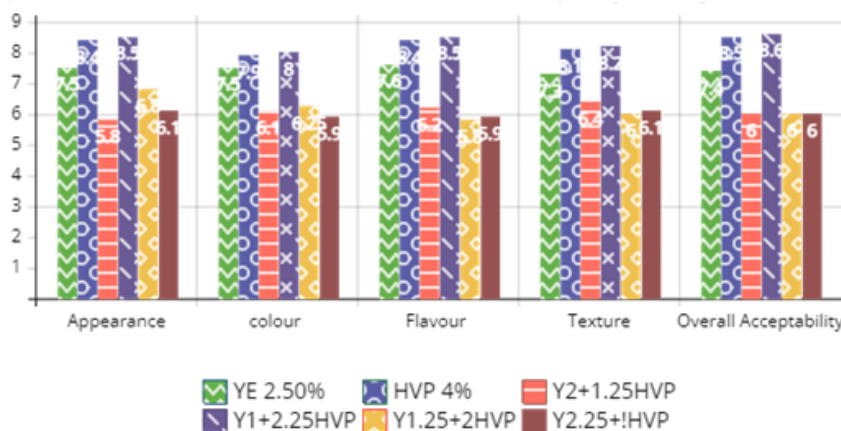


Figure 12

Sensory Evaluation of Oven Cooked Meat Analogue Sample S22 Incorporated with combination of different percent of Yeast Extract (YE) and Hydrolyzed Vegetable Protein (HVP)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Appendices.docx](#)