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Optimization of Young Jackfruit-Based Meat Analogue using Sensory Profile by D-Optimal Mixture Design

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ABSTRACT: The growing population requires increased meat production to satisfy the protein requirement. Augmented meat production has a deleterious effect on the environment and human health and also affects animal habitats. This awareness popularizes the concept of veganism and thus created a surplus demand for innovative plant-based meat analogues in the food industry. In meeting the demand for this need, a meat analogue from young jackfruit, wheat gluten and jackfruit seed flour has been developed. The formula optimization of this young jackfruit-based meat analogue was employed by D-optimal mixture design of response surface methodology, using the sensory profile. For new product development, sensory analysis, especially the 9-point hedonic scale has an important role in interpreting the acceptability, desirability and preference of consumers towards the developed new product. In this work, the following sensory parameters viz., overall acceptability, chewiness, juiciness and tenderness were taken as responses for the runs generated. The sensory analysis for the respective runs was done by preparing gravy from the dried meat analogues produced through cold extrusion technology. The quadratic model was the best-fitted model for all the responses. Based on the desirability value and the sensory evaluation of the generated solutions, the optimized formulation for the preparation of meat analogue was found to be containing 65% young jackfruit, 25% wheat gluten and 10% jackfruit seed flour that contribute to human well-being. Thus, the optimized formulation of the young jackfruit-based meat analogue may satisfy the protein requirements of the growing population.

Keywords: Meat analogue, D-optimal mixture design, Response surface methodology, Sensory profile, young jackfruit, wheat gluten, jackfruit seed flour.

INTRODUCTION

The global population is increasing remarkably and to provide food security to this growing population meat production is also getting increased. The increased meat production needs more land and water resources and contributes to tremendous negative effects on global warming and human health (Poshadri and Pawar 2021; Reddy *et al*., 2022). The consumption of vegetarian food is getting popularised due to the increasing awareness about the detrimental greenhouse effect and food security consciousness for the growing population. Due to this, a surplus demand for plant-based meat analogues has arisen in recent years among consumers who have concerns about the health, ethics and ecology of humans, animals and the environment (Cosson *et al*., 2021; Szpicer *et al*., 2022). Plant-based meat analogues are the one which mimics the meat texture, flavour, aroma, colour and sensory properties by utilising protein-rich vegetarian sources including vegetables, cereals, legumes, algae, etc. (Singh *et al*., 2021).

Bearing this need in mind, a plant-based meat analogue was prepared in this study from young jackfruit (*Artocarpus heterophyllus* Lam.) (Ranasinghe *et al*., 2019), wheat (*Triticum aestivum*) gluten (Kyriakopoulou *et al*., 2021), jackfruit seed flour (Swami *et al*., 2012) and seaweed, *Gracilaria edulis* (red algae) (Debbarma *et al*., 2016; Arulkumar *et al*., 2018) which possess high nutritional(especially protein)value and features that can mimic the conventional meat.

The design of an experiment is a rational approach for studying the concept of mixtures. Experimental design using computer algorithms offers precise experimental procedures by providing an appropriate combination of factors (mixture components) and data for the investigation to obtain an objective conclusion (Squeo *et al*., 2021). Usually, in new product development, the vital pieces of information about the new food product developed including its quality, consumer acceptance and characteristics are obtained using food sensory analysis studies. Especially the hedonic scale is employed to determine the preference and acceptance of the consumers. For food sensory studies, the D-Optimal mixture design approach of experimental design using computer algorithms is carried out generally for optimizing the formulation of new food products effectively and efficiently via analysing the importance of each ingredient (Yu *et al*., 2018; Kamali Rousta *et al*., 2020).

The D-Optimal Mixture design approach of Response surface methodology was used in this study for optimising the young jackfruit-based meat analogue with the sensory profile analysis, as it is an efficient and economical approach with reduced experimental trials to determine the influence of all the factors employed, on each response that acts as the function of every factor (Keenan *et al*., 2014; Fahimeh *et al*., 2019). The aim of this current research work is, to formulate a meat analogue from young jackfruit, wheat gluten, jackfruit seed flour and *Gracilaria edulis* using the sensory profile by D-Optimal Mixture Design of Response Surface Methodology.

MATERIALS AND METHODS

Materials: Young jackfruit (*Artocarpus heterophyllus* Lam.) was sourced from Koyembedu Periyar Vegetable Market, Chennai. Urban Platter's Vital wheat gluten powder was purchased using the amazon online shopping application.Jackfruit seed powder was obtained from Kerala. The live form of seaweed (red algae) *Gracilaria edulis* was sourced from Palk Bay, India.

Meat Analogue Extrusion and Production Process: The production of meat analogue using a cold extrusion process is explained in the forthcoming paragraphs.

Extruder. The meat analogues in this study were extruded and texturised using the equipment, Pasta maker, Dolly – La Monferrina (Linepasta S.r.l., Italy) (cold extrusion machine or cold extruder). A special die was designed and fabricated to extrude the required meat analogue pieces in cuboid shapes, which has three square-shaped holes with an area of 1.96 cm^2 respectively.

Preparation of raw materials. The raw materials (young jackfruit and seaweed) were pre-processed for the production of meat analogue. After removing the outer part and cutting the young jackfruit flesh into small pieces, they were blanched in water for about 10 minutes at 80^oC - 100^oC (Anupama, 2017). After attaining room temperature, the drained and blanched small pieces of young jackfruit were minced (Wijegunawardhana *et al*., 2021) into acoarse form using a mixer grinder. The procured seaweed was rinsed with fresh water (about 5 times) and allowed to shade dry at 25 ± 2^oC till it gets completely dry (Arulkumar *et al*., 2018) for 2 weeks. The seaweed was then ground into powder form using a mixer grinder and was stored in an air-tight container.

Production process. The production process was carried out on a single screw extruder with some modifications in Ghangale *et al*. (2022). All the ingredients as per the proportions mentioned (Tables 1 and 6) were added to the vat along with 1% powdered salt in appropriate proportions and wereallowed to knead for 10 minutes. After 10 minutes, the meat analogue was extruded and cut into pieces of length not more than 2.5 cm. The extruded meat analogues were steamed in a steamer for 5 minutes and then dried at 60^oC for about 4 hours using a tray drier (Everflow Scientific Instruments, Chennai). Once the meat analogue pieces attain room temperature, the dried meat analogue pieces were packed in a food-grade transparent front and silver back stand-up pouch with a zipper for further studies at ambient temperature.

D-Optimal Mixture Design. The D-Optimal Mixture Design was used to optimize the proportions of raw ingredients involved to prepare desired meat analogue. To optimize the product, a Design Expert (Version 12.0.1.0) software was employed (Fahimeh *et al*., 2019). From the software, an Optimal (custom) mixture design was selected and 4 raw ingredients were used as the mixture components namely minced young jackfruit (YJF), wheat gluten powder (WG), jackfruit seed powder (JSF) and *Gracilaria edulis* seaweed powder (SW), to produce the optimized meat analogue. The design constraints of the mixture components were decided using the preliminary trials and they were fixed as follows (in grams): $50 \leq$ YJF (A) ≤ 70, $20 \leq$ WG (B) ≤ 40, $10 \leq$ JSF (C) ≤ 20 and $0\leq$ SW (D) ≤ 10, thus A+B+C+D = 100 (Fahimeh *et al*., 2019). In this design experiment, the study type and subtype weremixture and randomized mixture respectively. Here, the I-optimal type of design and Quadratic design model was employed to explain the relationship between the mixture components and the responses of the design. There were 10 required model points, 5 lack of fit points and 5 replicate points (Run 1,6,10; Run 2,3; Run 7,13 and Run 12,14) to form a sturdy model, in the generated 20 runs (Table 1). The responses of this design were 4 and were based on sensory characteristics, namely R1: OA (Overall Acceptability), R2: Chewiness, R3: Juiciness and R4: Tenderness. Finally, formula optimization and calculated values of responses were to be verified experimentally (Spicer *et al*., 2022).

The responses to this design were fed to the software after experimentally preparing the meat analogue (Table 2), as per the generated design experiment respectively and performing the sensory evaluation with a sensory panellist group of 10 members (Sharma *et al.*, 2022) who are semi-trained by presenting the 20 runs of meat analogue in the form of gravy.

The fitted response values were represented using the linear (1) and quadratic (2) model equation given below (Keenan *et al*., 2014 &Nikzade*et al*., 2012). In this design, the cubic model is aliased.

$$Y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 \quad (1)$$

$$Y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{34}x_3x_4 \quad (2)$$

where, Y – predictive dependant variable or response (OA, Chewiness, Juiciness and Tenderness), β – equation coefficient. x_1 – proportions of YJF, x_2 – proportions of WG, x_3 – proportions of JSF and x_4 – proportions of SW.

The data stated were deemed as untransformed if otherwise noted. Scheffe's test was the model type employed in the Analysis of variance (ANOVA) to determine the significance of the model (f and p (<0.05) value), lack of fit and determination coefficient (R^2) (Nikzade *et al*., 2012; Manyatsi *et al*., 2020; Sharma *et al*., 2022; Szpicer *et al*., 2022).

The optimization tool in the software was used to optimize the solution or solutions generated (Thiruchelvi *et al*., 2020) by fixing the criteria of both mixture components and responses including their goal, importance and corresponding lower and upper limits and weights (Table 3). Based on the optimization constraints, solutions were generated and this optimized solution was preferred to produce the optimized meat analogue product.

Sensory Analysis: The sensory analyses were performed among 10 semi-trained panellists (Sharma *et al*., 2022) by preparing the meat analogue in the form of gravy, for both the 20 runs of experimental design and also for the solutions generated by the Design Expert software for the experimental mixture design using a 9-point hedonic scale. The investigating parameters appearance, tenderness (Kumar *et al*., 2017), chewiness, juiciness, flavour and overall acceptability (Ghangale *et al*., 2022) were analysed statistically using one-way ANOVA through IBM SPSS® 22.0 software.

RESULTS AND DISCUSSION

Fitting for the best model: The different formulations (runs) generated by the experimental design were experimentally performed by following the procedure in 2.2.3 and their responses were manually entered into the software (Table 2). The selection of the best model was dependent on the low standard deviation, the minimum predicted sum of squares and the high R-squared values. The accepted model should have p-values lower than 0.05 ($p < 0.05$) to serve as the best-fitted model (Fahimeh *et al*., 2019; Kamali Rousta *et al*., 2021). The quadratic model was determined as the best model for the present experimental design, to explain all the responses (namely., OA, chewiness, juiciness and tenderness) of the design.

Influence of responses for design optimization through statistical screening of runs. The statistical analysis (F-value and p-value) for the responses of factors including their mean, standard deviation (SD), coefficient of determination (R^2), coefficient of variation (C.V.%), model and lack of fit analysed were displayed in Table 4 and the β Coefficients for the responses to the design of the experiment was mentioned in Table 5. According to table 4, the model was significant and its lack of fit was not-significant for all responses as per its p-value (Highly significant – $p \leq 0.01$, Significant – $0.01 \leq p \leq 0.05$ and Not-Significant – $p > 0.05$).

Overall Acceptability. The sensory parameter's overall acceptability for the generated runs was in the range between 4.29 and 8.71 on the hedonic scale, this parameter allows us to understand the acceptance, desirability and preference of a product by consumers in a nutshell (Sharma *et al*., 2022). The highest value was recorded for run 19 which consists of 64.20 g of YJF, 25.79 g of WG, 10 g of JSF and 0 g of SW with an 8.71 hedonic scale and the lowest value recorded was 4.29 on a hedonic scale for run 4 with 50 g of YJF, 40 g of WG, 10 g of JSF and 0 g of SW (Table 2). The degree of freedom for the model is 9 and C.V. % is 7.92. This model's mean ± SD was 6.90±0.54. The F-value and R^2 of the model, 11.83 and 0.9141, and the p-value of the model 0.0003 which is less than 0.5 indicate that the model is significant. Due to noise, the lack of fit's F-value, 3.35 and p-value, 0.1054 implied that it was not significant (Table 4). β Coefficients of D showed a negative significant effect and AC, BC and CD interpreted a negative non-significant effect. Factor A, B, C, AB and BD predicted a positive significant effect and AD showed a positive non-significant effect (Table 5 and Fig. 1a). This implied that the presence of young jackfruit, wheat gluten and jackfruit seed flour was the reason behind the acceptance of meat analogue. The presence of seaweed caused a negative effect on the overall acceptability of meat analogues, this was because of the excessive proteolytic activity of the protease enzyme present in *Gracilaria edulis* that leads to the development of bitter taste (Arbita, 2022) in the formulations of meat analogue products containing *Gracilaria edulis*.

Chewiness. The chewiness is the most important characteristic of the meat analogue that provides the mouthfeel of meat (Sasaki *et al*., 2012). The chewiness of the runs was in the range of 5.01 to 8.63 on the hedonic scale. The lowest value recorded is 5.01 on a hedonic scale for run 4 with 50 g of YJF, 40 g of WG, 10 g of JSF and 0 g of SW and the highest value is recorded for run 19 which consists of 64.20 g of YJF, 25.79 g of WG, 10 g of JSF and 0 g of SW with an 8.71 hedonic scale (Table 2). The mean ± SD of this model is 7.40±0.40 and C.V.% is 5.44. The degree of freedom for the model and lack of fit are 9 and 5 respectively. The model was significant because of the F-value and R^2 of the model, 9.94 and 0.8995, and the p-value of the model 0.0006 respectively. The lack of fit's F-value was 3.82 and the p-value was 0.0838,implyingnon-significance (Table 4). β Coefficients showed a positive significant effect on factors A, B, C, AB and BD. Factors AC and BC interpreted a negative non-significant effect and AD and CD show a positive non-significant effect (Table 5 and Fig. 1b). This showed that the presence of wheat gluten in the combination contributed chewiness of the meat analogue and a similar result was cited by Chiang *et al*. (2019).

Juiciness. Juiciness is one of the most important sensory parameters as it makes meat tasty while eating that depends on moisture content, water holding capacity, cooking method and other related properties (Aaslyng, 2009), so this parameter of juiciness should be replicated in the developed meat analogue too. The response juiciness for the generated runs was in the range between 6.39 being the lower value for run 2 (59.08 g of YJF, 20 g of WG, 11.99 g of JSF and 8.91 g of SW) and 8.69 being the higher value for run 19 (64.20 g of YJF, 25.79 g of WG, 10 g of JSF and 0 g of SW) on the hedonic scale (Table 2). The degree of freedom for the model and lack of fit are 9 and 5 respectively, and C.V.% is 3.29. This model's mean ± SD was 7.63±0.25. The F-value and R^2 of the model, 19.24 and 0.9454, and the p-value of the model <0.0001 implies that the model is significant. The lack of fit's F-value and p-value are 0.7170 and 0.6380 respectively (due to noise) indicating that itwas not significant (Table 4). β Coefficients of factors A, B, C, AB, AD and BD predicted a positive significant effect on juiciness. Factor AC and BC showed a negative non-significant effect and CD interprets a positive non-significant effect (Table 5 and Fig. 1c). This implied that the presence of young jackfruit and its combination with wheat gluten and seaweed increased the juiciness parameter in the meat analogue because, the young jackfruit imparted juiciness to the product and the juiciness of the meat analogue increases with an increase in the percentage of young jackfruit (Abdullah, 2017; Ghangale *et al*., 2022).

Tenderness. The sensory character tenderness increases the palatability of meat, thus required in meat analogue and tender meat provides a soft texture which makes the consumers easily chew and enjoy the eating process (Abdalla *et al*., 2013). The tenderness of the runs was in the range of 5.01 and 8.63 on the hedonic scale. The lowest value recorded was 6.11 on a hedonic scale for run 2 with 59.08 g of YJF, 20 g of WG, 11.99 g of JSF and 8.91 g of SW and the highest value 8.82 was recorded for run 19 which consists of 64.20 g of YJF, 25.79 g of WG, 10 g of JSF and 0 g of SW (Table 2). The mean ± SD of this model was 7.64±0.34 and C.V.% was 4.58. The degree of freedom for the model and lack of fit were 9 and 5 respectively. The model was significant because of the F-value and R^2 of the model, 11.76 and 0.9137, and the p-value of the model 0.0003 respectively. The F-value, 0.3842 and the p-value, 0.8414 indicated that the lack of fit was not significant (Table 4). β Coefficients showed a positive significant effect on factors A, B, C, AB, BC and BD, and D and BC interpreted a negative significant effect. Factors AD and CD showed a positive non-significant effect and AC implied a negative non-significant effect (Table 5 and Fig. 1d). This showed that the presence of seaweed provides a negative effect. The presence of young jackfruit and wheat gluten in the combination contributedto tenderness to the meat analogue as young jackfruit provides tenderness to the meat substitute patties (Abdullah, 2017).

Meat Analogue Optimization: The optimization of the meat analogue was done by providing the appropriate constraints (Table 3) to the software after analysing the sensory profile of the experimental design (Tables 7, 4 and 5). Depending on the constraints provided, 2 solutions were generated along with the predicted response values by the design of the experiment (Table 8). Based on the desirability value (0.916) and the response scores, solution no.1 (with the formulation combination of 65 g young jackfruit, 25 g wheat gluten and 10 g jackfruit seed flour) was selected.

The predicted responses OA, chewiness, juiciness, tenderness and desirability for solution 1 and solution 2 were 8.90±0.21, 8.76±0.23, 8.87±0.04, 8.963±0.19, 0.916 and 8.71±0.24, 8.58±0.22, 8.73±0.09, 8.725±0.21, 0.719 respectively (Table 6). It was further confirmed by experimentally performing the solutions as per the procedure mentioned in 2.2.3 and sensory analysis was carried out for the solutions by preparing gravy from the developed meat analogues. The sensory analysis of the parameters OA, chewiness, juiciness and tenderness for solution 1 and solution 2 were 8.80±0.08, 8.60±0.12, 8.90±0.06, 8.82±0.09 and 8.53±0.03, 8.40±0.06, 8.75±0.08, 8.54±0.05, respectively (Table 8). The sensory analysis results were similar to that of the predicted responses for the solutions.

Since both the selected solution by the design experiment and the preferred solution of sensory analysis using a 9-point hedonic scale were identical, the optimized formulation containing 65% of young jackfruit, 25% of wheat gluten and 10% of jackfruit seed flour for preparing the desired meat analogue was finalized (Table 6 and 8, Fig. 2).

The higher proportion of young jackfruit in the formulation accounted for an appropriate source for meat analogue because of its grain-like structure that mimics the chicken's texture. The tasteless and smooth characteristic of young jackfruit absorbed the flavour added to it and thus could provide a meaty flavour (Abdullah, 2017) to the meat analogue prepared from it. Both the young jackfruit and jackfruit seed contained high nutritional including high moisture content, protein, calcium, fibre, potassium, thiamine, riboflavin, carbohydrate and vitamin C (Swami and Kalse 2018). Especially, the seeds are a good source of dietary fibre and binding capacity (Zuwariah *et al.*, 2019). Wheat gluten used in this study for the formulation of meat analogue acted as a source of plant protein and it also possesses functions including structuring, water binding, stabilising, gelling, swelling, dough forming of meat analogue and also possesses vital proteinand other nutrition properties like carbohydrate and fat (Kyriakopoulou *et al*., 2021). Itwasan economical source (Samard and Ryu 2019), that forms a cohesive viscoelastic network that holds the fibre together in the matrix for the meat analogue that subsidizes the viscosity, strength, elasticity and texture of the meat analogue (Chiang *et al*., 2019; Nivetha *et al*., 2019; Schreuders *et al*., 2019). The red algae *Gracilaria edulis*, besides containing a good source of nutritional and functional properties (Arulkumar *et al*., 2018; Debbarma *et al*., 2016), cannot be used in the formulation of optimized meat analogue due to the bitter taste produced by the protease enzyme present in it (Arbita, 2022).

Sensory Profile Analysis. The sensory analysis for meat analogues was conducted among the sensory panellists for both the experimental runs (Table 7) and the solutions generated (Table 8) by the software in the form of gravy with the parameters including appearance, flavour, chewiness, juiciness, tenderness and overall acceptability. All the parameters viz., appearance, flavour, chewiness, juiciness, tenderness and overall acceptability were highly significant with F-values 14.539, 46.493, 62.576, 32.572, 41.358 and 51.008 respectively (Table 7) due to the varying combinations of mixtures involved for the preparation of meat analogue (Table 2). The appearance, flavour and overall acceptability for each run vary with different combinations, especially because of the seaweed (unappealing bitter taste) (Arbita, 2022) and jackfruit seed flour (nutty flavour, if present in excess amount) (Zuwariah *et al*., 2019) presence, as they negatively affect the above-mentioned parameters. The chewiness and texture of the meat analogue were affected widely by the presence of wheat gluten (Chiang *et al*., 2019). The juiciness and tenderness parameter of the meat analogue was mainly due to the moisture content present in young jackfruit (Abdullah, 2017).

The sensory analysis for the solutions generated (Table 6) was carried out with the following parameters including appearance, flavour, chewiness, juiciness, tenderness and overall acceptability with values 8.85±0.07, 8.75±0.08, 8.60±0.12, 8.90±0.06, 8.82±0.09, 8.80±0.08 and 8.60±0.06, 8.45±0.05, 8.40±0.06, 8.75±0.08, 8.54±0.05, 8.53±0.03 respectively for solution 1 and solution 2. For appearance, there was no significant difference because of the composition of raw materials with a t-value of 2.46. The t-value of chewiness (1.41), juiciness (1.40) and tenderness (2.58) parameters had significant differences between solutions 1 and 2. There exists a highly significant difference between solutions 1 and 2 in the sensory parameter's flavour (3.08) and overall acceptability (3.10) which determined consumer preference.

Table 1: Experimental design of the mixture components involved in preparing the desired meat analogue product.

Run	Component 1 A: YJF (g)	Component 2 B: WG (g)	Component 3 C: JSF (g)	Component 4 D: SW (g)
1.	50	29.8278	15.1085	5.06375
2.	59.0831	20	11.9999	8.91694
3.	59.0831	20	11.9999	8.91694
4.	50	40	10	0
5.	50	30	10	10
6.	50	29.8278	15.1085	5.06375
7.	60.1116	20	17.6652	2.22323
8.	50	20	20	10
9.	64.8304	20	10	5.16958
10..	50	29.8278	15.1085	5.06375
11.	70	20	10	0
12.	57.8489	28.9123	13.2388	0
13.	60.1116	20	17.6652	2.22323
14.	57.8489	28.9123	13.2388	0
15.	54.4366	23.6714	15.9184	5.97357
16.	57.3493	28.2652	10	4.3855
17.	50	34.8055	15.1945	0
18.	52.6496	33.7353	10	3.61515
19.	64.2049	25.7951	10	0
20.	51.3718	28.6282	20	0

Table 2: Experimental design of the mixture components involved in preparing the desired meat analogue product with responses.

Run	Component 1 A: YJF (g)	Component 2 B: WG (g)	Component 3 C: JSF (g)	Component 4 D: SW (g)	Response 1 OA	Response 2 Chewiness	Response 3 Juiciness	Response 4 Tenderness
1.	50	29.8278	15.1085	5.06375	6.26	7.21	7.79	7.58
2.	59.0831	20	11.9999	8.91694	5.44	5.95	6.39	6.11
3.	59.0831	20	11.9999	8.91694	5.64	5.95	6.43	6.11
4.	50	40	10	0	4.29	5.01	6.71	6.41
5.	50	30	10	10	5.26	6.24	6.48	6.59
6.	50	29.8278	15.1085	5.06375	6.26	7.19	7.79	7.58
7.	60.1116	20	17.6652	2.22323	8.37	8.27	8.41	8.62
8.	50	20	20	10	5.98	6.86	6.76	6.92
9.	64.8304	20	10	5.16958	7.01	7.62	7.57	7.83
10.	50	29.8278	15.1085	5.06375	6.26	7.21	7.81	7.58
11.	70	20	10	0	8.52	8.42	8.53	8.76
12.	57.8489	28.9123	13.2388	0	8.24	8.11	8.28	8.14
13.	60.1116	20	17.6652	2.22323	8.37	8.26	8.41	8.62
14.	57.8489	28.9123	13.2388	0	8.12	8.11	8.28	8.14
15.	54.4366	23.6714	15.9184	5.97357	6.59	7.42	7.43	7.62
16.	57.3493	28.2652	10	4.3855	7.88	7.89	8.07	8.21
17.	50	34.8055	15.1945	0	6.08	7.09	6.97	7.01
18.	52.6496	33.7353	10	3.61515	8.02	8.01	8.12	8.27
19.	64.2049	25.7951	10	0	8.71	8.63	8.69	8.82
20.	51.3718	28.6282	20	0	7.67	7.71	7.92	8.02

Table 3: Optimization constraints of the experimental design.

Sr. No.	Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
1	A: YJF	maximise	60	65	1	1	5
2	B: WG	is in range	20	25	1	1	4
3	C: JSF	is in range	10	12	1	1	4
4	D: SW	is in range	0	5	1	1	4
5	OA	maximise	8	9	1	1	5
6	Chewiness	maximise	8	9	1	1	5
7	Juiciness	maximise	8	9	1	1	5
8	Tenderness	maximise	8	9	1	1	5

Table 4: ANOVA Table for the responses to the design of the experiment.

Variables	df	OA		Chewiness		Juiciness		Tenderness	
		F-Value	p-Value	F-Value	p-Value	F-Value	p-Value	F-Value	p-Value
Model	9	11.83	0.0003	9.94	0.0006	19.24	<0.0001	11.76	0.0003
Linear Mixture	3	23.61	<0.0001	17.15	0.0003	38.49	<0.0001	22.86	<0.0001
AB	1	18.26	0.0016	14.77	0.0032	21.03	0.0010	9.46	0.0117
AC	1	2.31	0.1592	0.6234	0.4481	0.2569	0.6233	2.59	0.1383
AD	1	1.64	0.2290	2.72	0.1301	4.98	0.0497	4.12	0.0699
BC	1	3.71	0.0830	0.0757	0.7888	1.20	0.2981	4.57	0.0581
BD	1	8.42	0.0158	13.53	0.0043	22.15	0.0008	17.03	0.0021
CD	1	0.2976	0.5973	1.01	0.3381	2.58	0.1391	0.2143	0.6533
Lack of fit	5	3.35	0.1054	3.82	0.0838	0.7170	0.6380	0.3842	0.8414
R^2		0.9141		0.8995		0.9454		0.9137	
Adjusted R^2		0.8369		0.8090		0.8963		0.8360	
Predicted R^2		-0.1831		-0.5691		0.6645		0.4867	
Mean		6.90		7.40		7.63		7.64	
SD		0.5463		0.4023		0.2513		0.3497	
C.V.%		7.92		5.44		3.29		4.58	

Table 5: β Coefficients for the responses to the design of the experiment.

Factor	OA	Chewiness	Juiciness	Tenderness
A-YJF	8.29**	8.40**	8.46**	8.72**
B-WG	4.86**	5.46**	6.80**	6.62**
C-JSF	14.93**	10.32**	9.78**	12.63**
D-SW	-1.36**	0.26**	0.85**	-0.07**
AB	8.86**	5.87**	4.37**	4.08**
AC	-8.46^{NS}	-3.23^{NS}	-1.29^{NS}	-5.73^{NS}
AD	6.84^{NS}	6.48^{NS}	5.48*	6.93^{NS}
BC	-10.38^{NS}	-1.09^{NS}	-2.72^{NS}	-7.38*
BD	14.60**	13.63**	10.89**	13.29**
CD	-4.09^{NS}	5.55^{NS}	5.54^{NS}	2.22^{NS}

** = Highly significant – $p \leq 0.01$, * = Significant – $0.01 \leq p \leq 0.05$ and ^{NS} = Non-Significant – $p > 0.05$; OA – Overall Acceptability.

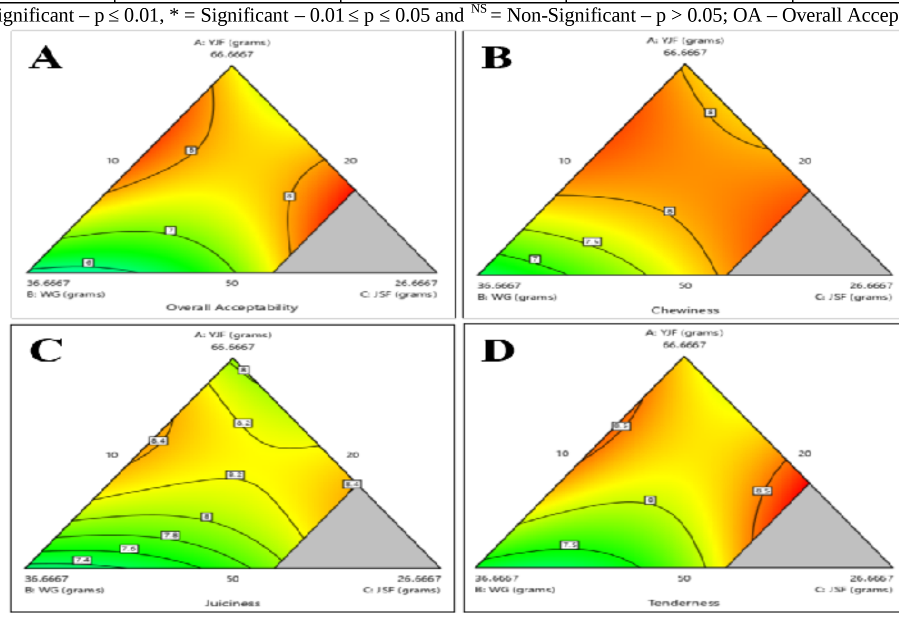

Fig. 1. The Contour plots explaining the interaction effect of factors including young jackfruit (A: YJF), wheat gluten (B: WG), jackfruit seed flour (C: JSF) and seaweed (D: SW-3.33334) with Responses: A – Overall Acceptability (OA) [varying from blue to red ranging respectively from 4.29 to 8.71], B – Chewiness [varying from blue to red ranging respectively from 5.01 to 8.634], C – Juiciness [varying from blue to red ranging respectively from 6.39 to 8.82] and D – Tenderness [varying from blue to red ranging respectively from 6.11 to 8.82] respectively.

Table 6: Solutions generated after optimizing the constraints of experimental design.

Solution Number	YJF	WG	JSF	SW	OA	Chewiness	Juiciness	Tenderness	Desirability	
1	65.00	25.00	10.00	0.00	8.90±0.21	8.76±0.23	8.87±0.04	8.963±0.19	0.916	Selected
2	64.39	23.68	11.91	0.00	8.71±0.24	8.58±0.22	8.73±0.09	8.725±0.21	0.719	

Responses predicted by the software are reported in means ± standard error of the measurements; OA – Overall Acceptability.

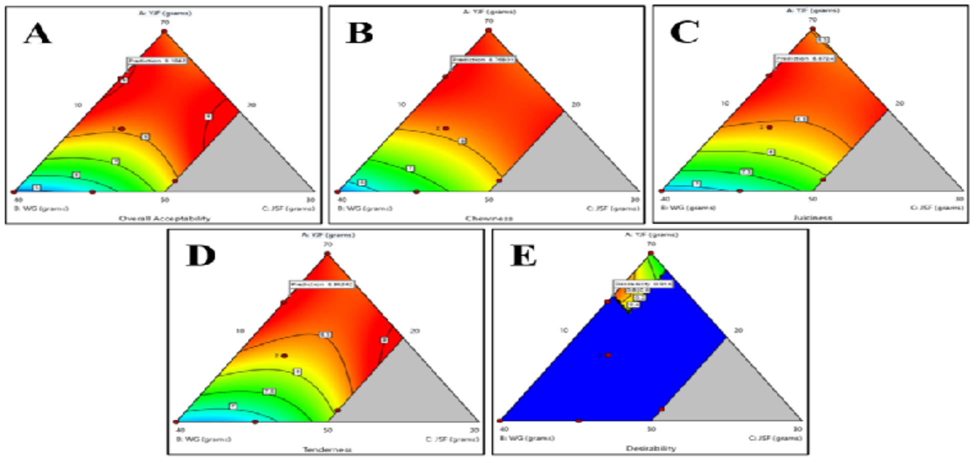

Fig. 2. The Contour plots explaining the interaction effect of factors including young jackfruit (A: YJF), wheat gluten (B: WG), jackfruit seed flour (C: JSF) and seaweed (D: SW-0) with Responses: A – Overall Acceptability (OA) [varying from blue to red ranging respectively from 4.29 to 8.71], B – Chewiness [varying from blue to red ranging respectively from 5.01 to 8.634], C – Juiciness [varying from blue to red ranging respectively from 6.39 to 8.82], D – Tenderness [varying from blue to red ranging respectively from 6.11 to 8.82] and E – Desirability [varying from blue to red ranging respectively from 0 to 1] respectively for the optimized solution no. 1.

Table 7: Sensory profile analysis for experimental runs generated by D-Optimal mixture design of Response Surface Methodology.

Runs	Appearance	Flavour	Chewiness	Juiciness	Tenderness	OA
1	7.83 ± 0.09^{fg}	7.49 ± 0.15^{gh}	7.21 ± 0.11^{gh}	7.79 ± 0.13^{efg}	7.59 ± 0.11^{e}	6.26 ± 0.25^{fg}
2	7.51 ± 0.14^{g}	6.42 ± 0.15^{j}	5.95 ± 0.17^{i}	6.39 ± 0.16^{i}	6.11 ± 0.12^{h}	5.44 ± 0.18^{i}
3	7.51 ± 0.14^{g}	6.42 ± 0.15^{j}	5.41 ± 0.17^{j}	6.43 ± 0.16^{i}	6.11 ± 0.12^{h}	5.64 ± 0.19^{hi}
4	8.38 ± 0.14^{cde}	6.57 ± 0.18^{j}	5.01 ± 0.07^{k}	6.71 ± 0.18^{hi}	6.41 ± 0.12^{gh}	4.29 ± 0.10^{j}
5	7.47 ± 0.15^{g}	5.59 ± 0.20^{k}	6.24 ± 0.13^{i}	6.48 ± 0.14^{i}	6.69 ± 0.15^{fg}	5.26 ± 0.18^{i}
6	7.83 ± 0.09^{fg}	7.49 ± 0.15^{gh}	7.19 ± 0.10^{gh}	7.79 ± 0.13^{efg}	7.58 ± 0.09^{e}	6.26 ± 0.25^{fg}
7	8.84 ± 0.07^{ab}	8.69 ± 0.07^{abc}	8.27 ± 0.13^{abc}	8.41 ± 0.12^{abc}	8.62 ± 0.14^{ab}	8.38 ± 0.0^{abc}
8	7.73 ± 0.13^{g}	7.17 ± 0.15^{hi}	6.86 ± 0.07^{h}	6.76 ± 0.13^{hi}	6.92 ± 0.21^{f}	5.98 ± 0.20^{gh}
9	7.69 ± 0.16^{g}	7.92 ± 0.10^{ef}	7.62 ± 0.15^{ef}	7.57 ± 0.18^{fg}	7.83 ± 0.20^{de}	7.01 ± 0.19^{e}
10	7.83 ± 0.09^{fg}	7.51 ± 0.14^{gh}	7.21 ± 0.11^{gh}	7.81 ± 0.13^{efg}	7.58 ± 0.09^{e}	6.26 ± 0.25^{fg}
11	8.62 ± 0.15^{abcde}	8.81 ± 0.07^{ab}	8.42 ± 0.14^{ab}	8.53 ± 0.14^{ab}	8.76 ± 0.08^{a}	8.52 ± 0.13^{ab}
12	8.75 ± 0.13^{abc}	8.23 ± 0.10^{de}	8.11 ± 0.14^{bc}	8.28 ± 0.09^{abcd}	8.14 ± 0.15^{cd}	8.24 ± 0.13^{abc}
13	8.89 ± 0.06^{ab}	8.69 ± 0.11^{abc}	8.26 ± 0.13^{abc}	8.41 ± 0.12^{abc}	8.62 ± 0.14^{ab}	8.37 ± 0.08^{abc}
14	8.74 ± 0.13^{abcd}	8.23 ± 0.11^{de}	8.11 ± 0.14^{bc}	8.41 ± 0.12^{abc}	8.14 ± 0.15^{cd}	8.12 ± 0.17^{bcd}
15	8.22 ± 0.10^{ef}	7.78 ± 0.07^{fg}	7.42 ± 0.17^{fg}	7.43 ± 0.19^{g}	7.62 ± 0.16^{e}	6.59 ± 0.16^{ef}
16	8.32 ± 0.13^{de}	$8.41\pm0.14h^{bcd}$	7.89 ± 0.06^{cde}	8.07 ± 0.05^{cde}	8.21 ± 0.15^{cd}	7.88 ± 0.11^{cd}
17	7.86 ± 0.20^{fg}	7.04 ± 0.11^{i}	7.09 ± 0.06^{gh}	6.97 ± 0.08^{h}	7.01 ± 0.10^{f}	6.08 ± 0.25^{fgh}
18	8.47 ± 0.17^{bcde}	8.38 ± 0.15^{cd}	8.01 ± 0.08^{cd}	8.12 ± 0.06^{bcde}	8.27 ± 0.09^{bc}	8.02 ± 0.25^{bcd}
19	8.92±0.05a	8.89 ± 0.07^{a}	8.63 ± 0.13^{a}	8.69 ± 0.11^{a}	8.82 ± 0.09^{a}	8.71 ± 0.08^{a}
20	8.61 ± 0.14^{abcde}	8.14 ± 0.12^{def}	7.71 ± 0.10^{def}	7.92 ± 0.07^{def}	8.02 ± 0.07^{cd}	7.67 ± 0.16^{d}
F-Value	14.539**	46.493**	62.576**	32.572**	41.358**	51.008**

@ Triplicates, n=10; ** Highly significant – $p \leq 0.01$; Means bearing different superscripts within columns differ significantly and read from right to left; Results reported in means ± standard error of the measurements; OA – Overall Acceptability.

Table 8: Sensory analysis for the solutions generated by the experimental design to optimize the formulation of meat analogue.

Runs	Appearance	Flavour	Chewiness	Juiciness	Tenderness	OA
1	8.85±0.07	8.75±0.08	8.60±0.12	8.90±0.06	8.82±0.09	8.80±0.08
2	8.60±0.06	8.45±0.05	8.40±0.06	8.75±0.08	8.54±0.05	8.53±0.03
t-Value	2.46^{NS}	3.08**	1.41*	1.40^{*}	2.58*	3.10**

@ Triplicates, n=10; ** = Highly significant – $p \leq 0.01$, * = Significant – $0.01 \leq p \leq 0.05$ and ^{NS} = Non-Significant – $p > 0.05$; Results reported in means ± standard error of the measurements; OA – Overall Acceptability.

CONCLUSION

By employing the D-Optimal mixture design of response surface methodology, the optimization of young jackfruit-based meat analogue using the sensory profile analysis was formulated. The optimized formulation of young jackfruit-based meat analogue consists of 65% young jackfruit, 25% wheat gluten and 10% jackfruit seed flour will satisfy the demand for meat alternatives in the food sector.

FUTURE SCOPE

The soya-based meat analogues were available in the market for a remarkable amount of time which is quite exploited and the need for innovations in plant-based meat analogues is expanding among consumers. Thus, theformulated young jackfruit-based meat analogue could be one such innovation and satisfy the need of the target market.

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Conflict of Interest. None.

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