EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–11
doi: 10.3897/ejfa.2024.124770

RESEARCH PAPER

Texture profile analysis of heat-processed tender jackfruit (*Artocarpus heterophyllus* Lam.) and its potential use as a meat analog

José de Jesús González-Regalado[1], Efigenia Montalvo-González[1], Herenia Adilene Miramontes-Escobar[1], Maribel Jiménez-Fernández[2], María de Lourdes García-Magaña[1], Martina Alejandra Chacón-López[1], Jaza AlShammari[3], Rosa Isela Ortiz-Basurto[1]

1 *Laboratorio Integral de Investigación en Alimentos, TecNM-Instituto Tecnológico de Tepic, Av. Tecnológico 2595, Col. Lagos del Country C.P. 63175, Tepic, Nayarit, Mexico*
2 *Centro de Investigación y Desarrollo en Alimentos, Universidad Veracruzana, Av. Dr. Luis Castelazo Ayala s/n. Col. Industrial-Animas, CP. 91000, Xalapa, Veracruz, Mexico*
3 *College of Public Health and Health Informatics, University of Hail, P.O. Box 2440, Hail, Saudi Arabia*

Corresponding author: Efigenia Montalvo-González (emontalvo@ittepic.edu.mx); Rosa Isela Ortiz-Basurto (riobasurt@ittepic.edu.mx)

Academic editor: Angelo Maria Giuffrè ♦ **Received** 16 April 2024 ♦ **Accepted** 13 May 2024 ♦ **Published** 17 June 2024

Abstract

Thermal processing is the most efficient and economical technique for the long-term preservation of tender jackfruit in ready-to-cook form on a commercial-scale. The present study investigated the effect of boiling (80, 90 and 100 °C for 5, 10 and 15 min) and steaming processing (121 °C, 1.5 atm for 5, 10 and 20 min) on the texture profile of tender jackfruit sections (core, cortex and perianth). In addition, the thermal conditions to process tender jackfruit sections were compared with cooked animal meats as references measuring the texture profile. Finally, an edible formulation using processed tender jackfruit as a meat analog was performed and characterized. The hardness, chewability and shear force values of tender jackfruit sections decreased with the highest temperature and processing time; however, core section exhibited the highest texture values followed by perianth and cortex. All jackfruit sections exhibited similar texture parameters to meat references when they were processed from 90 to 100 °C for 5–15 min by boiling process and 121 °C for 5–10 min by steaming process. The sterilized edible formulation exhibited good content of ashes, total protein and dietary fiber; as well as a high digestibility (88.92%). Moreover, this formulation conserved soluble phenols with antioxidant capacity, without microbial growth during 15 days of storage at 25 °C and with high sensorial acceptation. According to this, whole tender jackfruit has a potential use as an analog of different animal meats.

Keywords

Plant-based meat analogue, sensory analysis, thermal processing, animal meats, edible formulation

Introduction

The vegetarian population has increased in large proportion, and with it, subsequently, the demand for plant-based foods that provide the protein requirements to supplement a good diet. In addition, the consumption of meat analogs has increased in recent years to decrease the environmental damage caused by the production of animal meat and the health problems associated with its consumption (Rout et al. 2024).

Jackfruit (*Artocarpus heterophyllus* Lam.) is cultivated in several countries worldwide, such as Sri Lanka, Thailand, Malaysia, Burma, Philippines, Indonesia, Brazil, Burma, Bangladesh, United States, Mexico, among others (Swami and Kalse 2018). It is a highly appreciated fruit for its nutritional characteristics (Morelos-Flores et al. 2023; Afotey et al. 2024). During the jackfruit grown, tender jackfruits, whose maturity state is between the second and third week of maturity after anthesis, are removed from the tree. The removal is made to reduce the number of fruits on the tree. Thus, the development of other fruits is better, and they are selected for exportation. However, the producers report that the removal is approximately 60% of tender jackfruits per tree. In addition, it generates a large amount of waste that pollutes the environment and, at the same time, is a source of pathogenic microorganisms for jackfruits destined for commercialization. Therefore, tender jackfruits are an alternative to generate new foods such as meat analogs (Nova et al. 2023).

Meat analogs are structurally similar to animal meat but different in composition. They are formulated to have similar organoleptic properties and macronutrients as animal meat (Bohrer 2019; Kyriakopoulou et al. 2019). In this regard, tender jackfruits are used in traditional Yogyakarta cuisine, called "gudeg". In some countries, tender jackfruit is used as a vegetable, especially in curries or cooking with coconut milk, and as a meat variant for vegetarians. In Asian countries, the tender jackfruit is used as a pork analog, obtaining meat for burgers, sausages, and nuggets (Jagtap and Bapat 2010). However, a thermal treatment to vegetal raw material is necessary before developing any meat analog to achieve a good texture.

Extrusion is the most widely used technique for formulating meat analogs (Guyony et al. 2023). However, with new raw materials and the increasing demand for vegetarian foods, other methods are used to obtain a good texture in vegetal products. These can be obtained from thermal processes between them: steaming and boiling (Grahl et al. 2018). Steaming is a method of heat transfer by convection where the food is on steam. Steaming is a particularly gentle cooking method because it does not remove flavor and is an excellent choice for vegetables, fish, and delicate foods such as meatballs (Bishop 2013). On the other hand, boiling is used to change the texture of vegetal foods in boiling water; large bubbles vigorously break the surface of the liquid at a rapid and steady rate (Mathijssen et al. 2023).

Once the texturized vegetable raw material has been obtained, it must be ensured that it has consumer-acceptable textural characteristics because providing a consumer-pleasing texture in a food product is one of the most complicated tasks (Lelieveld et al. 2016). Therefore, it is interesting to perform texture profiling of the raw material to be used to formulate a meat analog; in addition to demonstrating the quality parameters such as appearance (color, shape, size, gloss), taste, and odor (Lelieveld et al. 2016).

The objective of this work was to evaluate different conditions of two thermal treatments on the texture profile of tender jackfruit. In addition, some conditions to process tender jackfruit of each treatment were selected to be statistically compared with different animal meats. Moreover, two conditions of both treatments to treat tender jackfruit were selected to evaluate sensorial parameters and determine its potential use as a meat analog. Finally, a formulation using processed tender jackfruit as a meat analog was evaluated.

Materials and methods

Raw material

Tender jackfruit (*Artocarpus heterophyllus* Lam.) 'Agüitada' genotype, with two weeks of growth after anthesis (flowering), were harvested in an orchard located in the town "El Llano", San Blas, Nayarit, Mexico. Characteristic for having a warm-subhumid climate, with reddish-brown clay soils (Luvisols Chromic), representative of the geomorphological environment of Nayarit Neovolcanic Belts (Herrera-Romero et al. 2020). The fruits were sampled from trees between 10–12 years of age, which receive organic fertilizer and N, P and K once a year and micro-irrigation twice a week.

First, jackfruits were washed and disinfected with a sodium hypochlorite solution at 25 mg/L for 15 min. Then, the peel was removed manually, and the rest of the fruit was used. Next, the peeled jackfruit was divided into three sections: cortex (C), core (N), and perianth (P) (Suppl. material 1: fig. S1), and each section was cut in cubes of approximately 2×2 cm. After, the samples were dipped in 1% citric acid solution to prevent browning. Suppl. material 1: table S1 shows the physicochemical composition of the raw material.

The investigation was carried out by three stages. In the first stage, completely randomized factorial design was evaluated to obtain the best conditions of boiling processing from tender jackfruit evaluating changes in texture. In the second stage, a factorial design was performed to obtain the best conditions of steaming processing from tender jackfruit evaluating changes in texture. Finally, un the third stage, the best conditions of both treatments were compared with the texture profile of animal meats to evaluate the potential use as meat analog and a formulation using processed tender jackfruit as a meat analog was evaluated. 12–15 fruits were harvested for each experimental design. Texture, microbiological and sensory analyses were carried out on the day of the respective process. The rest of the sample was vacuum packed in a trilaminated bag and frozen (-80 °C) until analysis in a period of no more than one week.

Tender jackfruit processed with boiling

A factorial design 3^3 was used. The effect of jackfruit sections (Cortex, core and perianth), temperature (80, 90 and 100 °C) and time (5, 10 and 15 min) was evaluated to find the best boiling conditions on shear force, hardness, and chewiness from tender jackfruit. Each section from tender jackfruit (200 g) was placed into a recipient with 500 ml of purified water. Then the samples were heated according to the factorial design. Finally, the samples were cooled and analyzed.

Texture profile

Shear force, hardness, and chewiness were measured with a texturometer (TA, TX PLUS, London, England). Shear force was performed with warner bratzler shear Blade (WBSB) with a diameter of 3 mm at 1.5 cm of cut, (Honikel 1998; Kethavath et al. 2019). Hardness was performed with volodkevich bite jaws (VBJ), the result was obtained by the highest point on the curve generated by the VBJ. Chewiness was performed with volodkevich bite jaws (VBJ) with compression of 90% with two repetitions (Pflanzer et al. 2019). Chewiness is calculated by multiplying cohesiveness × elasticity × hardness, using Newton (N) as unit of measurement from mechanical curves with the maximum force applied.

Response surface methodology of texture profile data

The texture profile data were analyzed for RSM. The analysis resulted in second-order polynomial equations, that can be used to calculate the predicted responses (Equation 1).

$$Y = \beta 0 + \sum_{i=A}^{E} \beta i X i + \sum_{i=A}^{E} \sum_{j=A \neq i}^{E} \beta ij X i + E \qquad (1)$$

Where Y is the predicted response (Shear force, hardness, or chewiness), Xi is the value of each factor (Jackfruit part, temperature, and time), β0 is a constant, βi are the principal effect coefficients for each variable, and βij are the interaction effect coefficients.

Tender jackfruit processed with steaming

A factorial design (3×4) was performed evaluating the effect of jackfruit sections (Cortex, core and perianth) and time (5, 10 and 15 min) on the mentioned texture profile from tender jackfruit. The samples (200 g of each section) of tender jackfruit were introduced into a manual vertical autoclave (Novatech EV-36, Guadalajara, Mexico). The autoclave was heated at a temperature of 120 °C and 1.5 atm. Posteriorly, the samples were kept for 5, 10, 15, and 20 min. Finally, the samples were cooled and analyzed.

Comparison of texture profile between tender jackfruit processed with boiling or steaming treatments and animal meat references

The texture profile values from tender jackfruit processed with boiling or steaming treatments that exhibited similarity with values of animal meat references were statistically analyzed to corroborate that there was not significant difference.

Animal meats (beef, pork, shrimp and chicken) were purchased in auto service store. Then, they were griddle cooking (by induction of heat). The cooked temperatures were 67 °C/15 min for beef, 62.8 °C/20 min for pork, 62.7 °C/5 min for shrimp and 74 °C/10 min for chicken according to reported conditions (FSIS-USDA 2018). The texture profile analysis was performed in all samples.

Edible formulation using processed tender jackfruit as a meat analog and its characterization

Edible formulation

Seventy grams of whole tender jackfruit (processed at 121 °C/10 min, 1.5 atm) was used for each 130 g of formulation. Seasonings ("guajillo" chili, white onion, garlic, black pepper, oregano and bay leaf), red tomato, salt, spirulina alga (10 g), jackfruit seeds isolate (10 g) and water were used.

The formulation was packed in a glass container (50 ml) and subjected to sterilization (121 °C/10 min, 1.5 amt). An accelerated shelf-life test was performed at three temperatures 4, 25 and 45 °C evaluating microbiological assays at 0, 3, 5, 10 and 15 days of storage.

Characterization of the edible formulation

Proximal chemical composition

Moisture (Method 934.06), ash (Method 940,.26), protein (Method 978.04), and fat (Method 950.54) contents in the edible formulation were determined by using the official AOAC methods (AOAC 2005). Total carbohydrates were quantified by difference. The total dietary fibre was analysed by Mañas and Saura-Calixto (1993). The data were reported as grams per 100 g of fresh weight (%).

Protein digestibility

The protein digestibility method was determined using the technique proposed by Melito and Tovar (1995), with some modifications. The sterilized edible formulation (5 g) was dried at 40 °C for 48 h. The sample (500 mg) was mixed with 10 mL HCl (0.1N, pH 4.5). Then an acid hydrolysis with pepsin was performed, using an aliquot of 1 mL of a pepsin solution (25 mg/mL in 0.1 N HCl) and 0.5 mL of a 5% (w/v) alcoholic sodium mercurothiosalicylate solution was added. Subsequently, the mixture was incubated for 3 h in a bath-water at 26 °C with continuous agitation. At the end of the incubation period, 4.5 mL of NaOH 0.1 N were added, adjusting the pH to 7.5–7.9. Then a second hydrolysis was performed with 1 mL of pancreatin solution (100 mg/mL in NaOH 0.1 N) for 24 h in a bath-water at 40 °C with continuous agitation. Concluding this second hydrolysis, 2 mL of 30% trichloroacetic acid (TCA) solution was added. The samples were centrifuged and 5 mL of the supernatant were taken for nitrogen determination by the Kjeldahl method of the AOAC (2005). The same procedure was developed for a blank, only with the variation that TCA was added before the enzymes. The percentage (%) of digestibility was calculated according to the following equation:

$$Digestibility\ (\%) = \frac{SB - SDG}{SB} * 100$$

Where:
SB = Sample blank
SDG = Sample after digestion

Total soluble phenols (TSP) and antioxidant capacity (AOX)

An organic aqueous extraction (acidified methanol: water, 50:50 v/v) was performed to obtain TSP following the protocol proposed by Pérez-Jiménez et al. (2008). The absorbance of the extracts was read at 750 nm. TSP was expressed as mg of gallic acid equivalent per 100 g of fresh weight (mg/100 g FW) (Montreau 1972). AOX was evaluated in aliquots from phenolic extracts by FRAP (ferric reducing/antioxidant power) assay (Benzie and Strain 1996), ABTS (2,2´-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) assay (Re et al. 1999) and DPPH (2,2-Diphenyl-1-picryl-hidrazyl) radical assay (Prior et al. 2005), respectively. Trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic) was used as a standard. The antioxidant capacity was reported in micromole equivalent of Trolox per 100 g of fresh weight (μmol/100 g FW).

The absorbances of TSP content and antioxidant capacity were evaluated using a microplate reader (Biotek®, 800TS, Winooski VT, USA) with Gen5 software.

Microbiological analysis

Microbial counting for aerobic mesophilic bacteria, total coliforms, yeast and molds was performed according to the Bacteriological Analytical Manual (FDA 2001a, 2001b; respectively). One milliliter of the homogenized sample was 10-fold serially diluted using sterile peptone water, and 0.1 mL of the appropriate dilutions was pour-plated into appropriate selective media. Mesophilic bacteria count was determined using plate count agar, cultures were incubated at 35 °C for 48 h, for yeast and molds, potato dextrose agar was used; dishes were incubated at 25 °C for 5 days. Samples were also pour-plate in violet red bile glucose for total coliforms and incubated at 35 °C for 24 h (FDA 2001c). Results were expressed as log colony-forming units per gram of formulation (log CFU/g).

Sensory analysis

The sterilized edible formulation was subjected to sensory analysis (at initial of its processing) with 30 untrained judges with hedonic structured scale (1 = extremely dislike; 2 = strongly dislike; 3 = moderately dislike; 4 = slightly dislike; 5 = neither like nor dislike; 6 = slightly like; 7 = moderately like; 8 = strongly like; 9 = extremely like). The panelists determined the degree of acceptance or rejection of odor, color, flavor and texture of the product (Lelieveld et al. 2016).

Statistical analysis

Data of the factorial design 3^3 were analyzed by response surface methodology and analysis of variance (ANOVA) using the statistic software (v. 10 Statsoft®, Tulsa, Oklahoma, USA) to determine the effects of significant interactions in the model ($p < 0.05$) and by quantification of the coefficient of determination (R-squared and R-adjust). The Fisher-LSD test was used to verify the differences between means ($p < 0.05$). The factorial design (3×4) we analyzed, using ANOVA ($p < 0.05$). All means comparison was performed by Fisher LSD test ($p < 0.05$). Statistical analysis was realized using the statistic software (v. 10 Statsoft®, Tulsa, Oklahoma, USA).

Results and discussion

Texture profile from tender jackfruit processed with boiling

The texture profile obtained by boiling treatments from cortex, core, and perianth of tender jackfruit are shown in Table 1. Statistical differences ($p < 0.05$) were observed between treatments. The hardness, chewability and shear-force were dependent on the experimental conditions. It can be observed that core from tender jackfruit exhibited greater values of hardness, chewiness and shear force than perianth and cortex, independently of condition process. It is due to that this jackfruit section is a woody part and has a greater amount of cellulose and lignin than to the other jackfruit sections (Trilokesh and Uppuluri 2019).

On the other hand, the hardness, chewability and shear-force values decreased when tender jackfruit was processed at 100 °C for 15 min, independently of each tender jackfruit section. It is attributed to that the combination of high temperature and time caused the higher degradation of polysaccharides and starch gelatinization than minor values of temperature and time (Peng et al. 2017). Sushama et al. (2022) reported that firmness of tender jackfruit decreased considerably when was subjected to thermal processing. Moreover, the textural properties were mostly affected when tender jackfruit was treated to the highest temperature. Nonetheless, in the case of perianth there was difficult to measure the shear-force due to the elastic fibers that this section of jackfruit presents.

Table 1. Hardness, chewability and shear force of tender jackfruit processed with boiling treatments.

Run	Jackfruit section	Boiling conditions		Response variables (Newtons)		
		Temperature (°C)	Time (min)	Hardness	Chewability	Shear force
1	C	100	5	32.34 ± 2.73c	6.30 ± 0.96c	9.47 ± 1.27b
2	C	100	10	16.24 ± 1.82b	1.09 ± 0.07a	4.25 ± 0.58a
3	C	100	15	3.53 ± 1.15a	0.64 ± 0.47a	2.39 ± 0.64a
4	C	90	5	60.30 ± 3.51d	10.1 ± 1.62d	27.19 ± 2.01d
5	C	90	10	24.72 ± 1.83bc	3.79 ± 1.35ab	15.81 ± 0.68c
6	C	90	15	17.47 ± 1.60b	1.91 ± 0.15a	11.35 ± 1.03bc
7	C	80	5	77.02 ± 8.47e	19.94 ± 2.59e	43.33 ± 3.97e
8	C	80	10	51.95 ± 6.33d	4.98 ± 0.69bc	28.40 ± 0.60d
9	C	80	15	27.69 ± 1.88bc	5.72 ± 0.95c	26.50 ± 1.17d
10	N	100	5	88.33 ± 2.09d	4.71 ± 0.48a	22 ± 2.27b
11	N	100	10	35.70 ± 1.54b	1.02 ± 0.64a	14.02 ± 1.69a
12	N	100	15	18.57 ± 1.05a	1.25 ± 0.56a	14.02 ± 1.69a
13	N	90	5	114.91 ± 2.17e	11.55 ± 0.78b	33.99 ± 2.30c
14	N	90	10	57.47 ± 1.60c	6.29 ± 0.84a	27.19 ± 2.01b
15	N	90	15	51.86 ± 2.54c	3.53 ± 0.62a	53.16 ± 1.67d
16	N	80	5	156.65 ± 10.10f	15.7 ± 4.98b	116.49 ± 2.08f
17	N	80	10	121.54 ± 6.88e	17.89 ± 4.40bc	67.33 ± 1.89e
18	N	80	15	92.94 ± 1.61d	17.14 ± 2.04bc	54.29 ± 3.37d
19	P	100	5	12.62 ± 0.67ab	1.94 ± 0.4a	NR
20	P	100	10	9.25 ± 1.25a	1.42 ± 0.94a	NR
21	P	100	15	7.21 ± 1.06a	2.74 ± 0.58a	NR
22	P	90	5	24.03 ± 4.15c	3.81 ± 0.50a	NR
23	P	90	10	18.14 ± 2.57c	10.33 ± 0.90b	NR
24	P	90	15	17.98 ± 1.91bc	9.44 ± 0.86b	NR
25	P	80	5	52.45 ± 2.99e	8.62 ± 0.82b	NR
26	P	80	10	35.64 ± 3.88d	13.92 ± 2.47c	NR
27	P	80	15	25.14 ± 1.97c	9.77 ± 1.75b	NR

C = Cortex, N = Nucleus, P = Perianth. NR = Not reported because the perianth has a higher shear force than the texturometer support. Data are expressed as means ± standard deviation (n = 3). Different letters by column indicate significant statistical differences. The mean comparison is between treatments of each jackfruit section (α = 0.05).

Response surface analysis of texture profile data of tender jackfruit processed wit boiling treatment

The response surface analysis on the texture profile as a function of the independent variables (tender jackfruit part, temperature and time) was performed with a multiple regression. The analysis of variance (ANOVA) showed that temperature and time were significant ($p < 0.05$) on hardness, chewability and shear force for each tender jackfruit part. Also, ANOVA corroborated that experimental data have significant correlation coefficients and adjusted correlation coefficients with the resultant models (Suppl. material 1: table S2). Moreover, β-coefficients of the fitted quadratic polynomial models for data texture profile were significant ($p < 0.05$). The lack of fit (Adjust R^2) showed the adequacy of the model ($p > 0.05$), indicating approximation to the real system. According to the regression model, the hardness, chewability and shear force can be predicted with the quadratic polynomial equations (Suppl. material 1: table S2) at a 95% confidence level.

The significant interactions of temperature and time on the texture profile are shown in Fig. 1. The three-dimensional (3D) response surface (Fig. 2) plots show elliptical contour shapes due to the interactions between the corresponding variables.

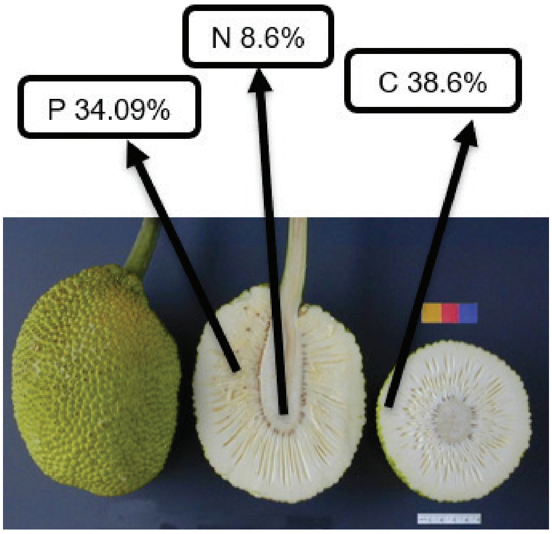

Figure 1. Sections of unripe jackfruit. P = perianth, N = core, C = cortex.

In general, the combinations of the highest temperature and time caused the lowest values of texture parameters for cortex section (Fig. 2a, d, 2), core (Fig. 2b, e h) and perianth sections (Fig. 2c, f). Pareto plots (Suppl. material 1: fig. 1S) corroborate the effect of the independent variables and their interaction on texture parameters at a 95%

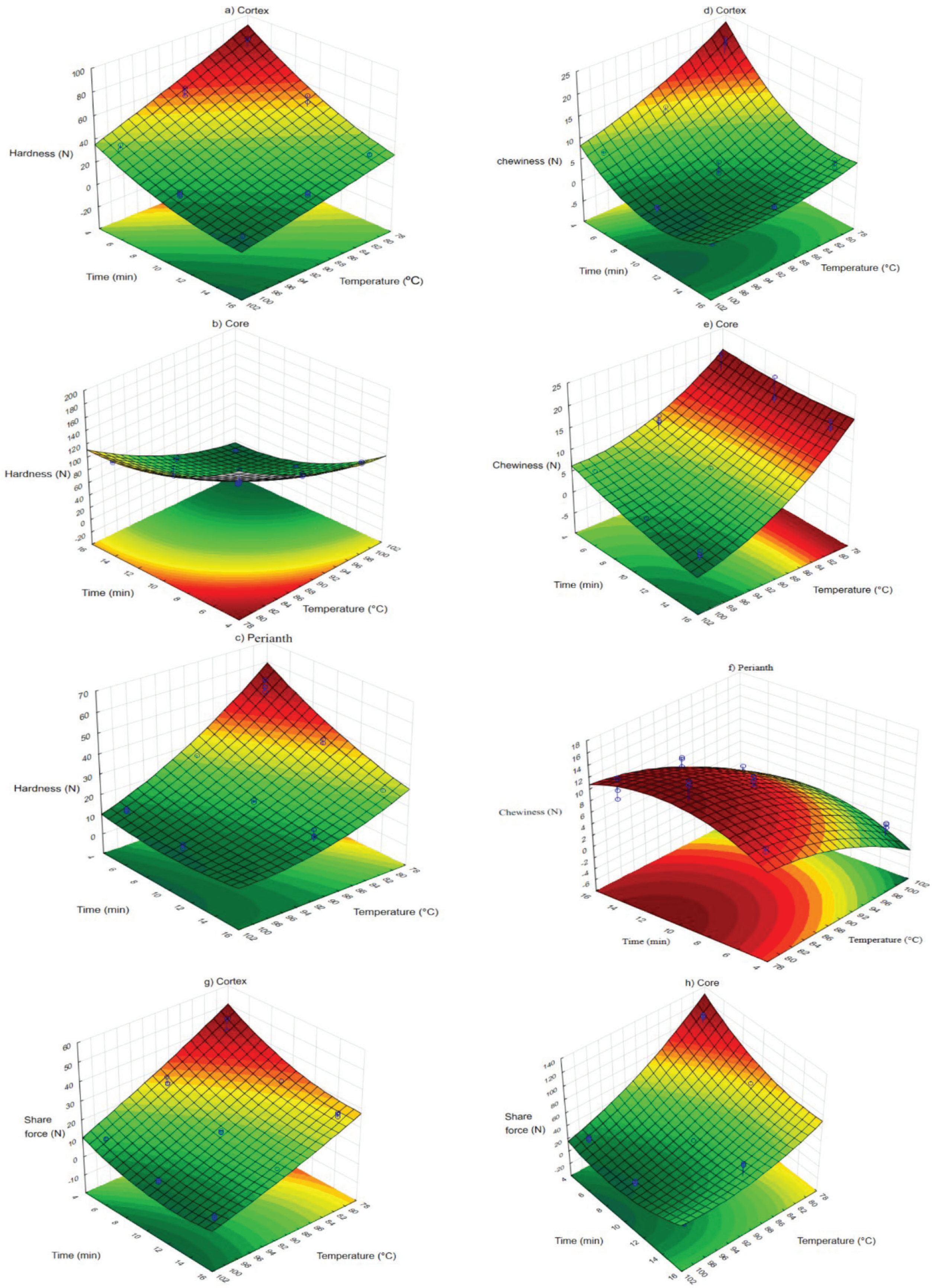

Figure 2. Response surface plots indicating the effect of boiling treatments on hardness of cortex (**a**), core (**b**) and perinath (**c**); chewiness of cortex (**d**), core (**e**) and perinath (**f**); share force of cortex (**g**) and core (**c**) from tender jackfruit.

confidence level. The principal effects of temperature or time (linear or quadratic) was dependent of each tender jackfruit section. To the best of our knowledge, it is the first study using thermal treatments to evaluate the texture profile from tender jackfruit sections. However, the hardness results of this experiment coincided with Babu and Sudheer (2020). The authors studied the effect of boiling processing (90 °C, 19 min) on firmness of tender jackfruit in slices. They authors reported that the treatment caused a decreased firmness to 33–37 N, because the cell wall compartmentalization is modified by heating.

Texture profile from tender jackfruit processed with steaming

The hardness, chewability and shear force values of tender jackfruit processed with steaming conditions (Table 2), shows a significant effect ($p < 0.05$) of jackfruit section and processing time. Core section exhibited the highest values of texture profile followed by perianth and cortex, independently of processing time. As above was mentioned, high temperature (121 °C) by large time period causes degradation of compounds in cell wall such as cellulose and lignin (Peng et al. 2017; Sushama et al. 2022); however, the decrease of texture is also dependent of raw material, cortex is a jackfruit section softener than core and perianth.

Table 2. Hardness, chewability and shear force of tender jackfruit processed with steaming treatments.

Run	Steaming conditions		Response variables (Newtons)		
	Jackfruit section	Time (min)	Hardness	Chewability	Shear force
1	C	5	37.47 ± 2.63d	2.81 ± 0.15d	14.91 ± 0.72d
2	N	5	51.51 ± 2.35e	3.37 ± 0.29e	46.55 ± 0.74e
3	P	5	40.01 ± 1.13a	1.62 ± 0.26c	NR
4	C	10	28.43 ± 1.51c	1.55 ± 0.05c	9.68 ± 0.37c
5	N	10	35.12 ± 3.2d	0.63 ± 0.28ab	14.41 ± 0.65d
6	P	10	26.76 ± 1.41d	0.85 ± 0.17c	NR
7	C	15	15.73 ± 1.08a	1.33 ± 0.19c	4.18 ± 0.63ab
8	N	15	18.2 ± 2.58b	0.62 ± 0.10ab	5.7 ± 0.81b
9	P	15	12.54 ± 1.65b	0.67 ± 0.83b	NR
10	C	20	4.25 ± 0.76a	1.26 ± 0.10c	2.94 ± 0.38a
11	N	20	9.22 ± 1.83a	0.48 ± 0.17ab	4.70 ± 1.13ab
12	P	20	7.7 ± 1.76b	0.15 ± 0.05a	NR

NR = Not reported because the perianth has a higher shear force than the texturometer support. Data are expressed as means ± standard deviation (n = 3). Different letters by column indicate significant statistical differences between treatments (α = 0.05).

On the other hand, the texture profile values from treated jackfruit sections with steaming processing decreased ~67%, compared to values from treated jackfruit sections with boiling processing. It is attributed to high heat energy (121 °C) and the pressure (1.5 atm) generated by sterilization. Another factor that can be decisive is that the jackfruit sections, not being in contact with the liquid medium, which could directly influence the cohesiveness and elasticity of the sample (Bhadra et al. 2019).

Comparison of texture profile between tender jackfruit processed with boiling or steaming treatments and animal meat references.

The texture profile values of animal meat references samples (Table 3) were compared statistically with predicted values calculated by polynomial models (see Suppl. material 1: table S2) for the optimal boiling conditions according to the response surface analysis.

Table 3. Texture profile from tender jackfruit processed with boiling treatments without significant statistical differences ($p > 0.05$) respect to cooked animal meats as a reference.

Meat	Optimal conditions procesing	Hardness	Chewability	Shear force
Beef	67.0 °C / 15 min	32.67 ± 2.11	13.70 ± 3.93	43.70 ± 1.06
Pork	62.8 °C / 20 min	25.39 ± 3.44	7.11 ± 1.77	19.26 ± 1.41
Chicken	74.0 °C / 10 min	12.24 ± 1.31	3.03 ± 0.85	12.64 ± 0.58
Shrimp	62.7 °C / 5 min	15.02 ± 2.61	4.81 ± 0.2	11.48 ± 0.45

Therefore, Table 4 describes all optimal boiling conditions that does not present significant differences ($p > 0.05$) on hardness, chewability and shear force compared to animal meat references.

These results are very important for food industry because depending of type of meat analog that the consumer want to prepare from tender jackfruit, the boiling treatments are different for each section. Respect to the steaming conditions the treatments that did not present significant differences ($p > 0.05$) on hardness, chewability and shear force compared to animal meat references were from 1 to 7 (see Tables 1, 2). Therefore, it was concluded that all jackfruit sections exhibited similar texture parameters to meat references when they were processed at 90–100 °C for 5–15 min by boiling process and 121 °C for 5–10 min by steaming process. Thus, to obtain the edible formulation was used whole tender jackfruit that was processed by steaming processing (121 °C/10 min, 1.5 atm).

Characterization of an edible formulation using processed tender jackfruit as an analog meat

The analysis of the proximal chemical composition of the formulated edible feed is presented in Table 5. The product is high in moisture, protein, ashes and total dietary fiber, but low in fat and carbohydrates. The protein results (11.62 ± 0.18%) coincided in the range of meat analogous foods according to published by Kyriakopoulou et

Table 4. Optimal conditions by response surface analysis of the boiling treatments on jackfruit sections no significant differences (p > 0.05) on hardness (H), chewability (C) and shear force (SF) compared with animal meat references.

Jackfruit section	Optimal conditions and response (N)	Beef	Pork	Shrimp	Chicken
Hardness					
Cortex	Temperature (°C)	100	100	100	100
	Time (min)	5.3	6.9	10.5	10.5
	Predicted hardness	33.28	23.85	15.52	15.52
Perianth	Temperature (°C)	80	90	90	100
	Time (min)	15.5	7.5	16	5
	Predicted hardness	32.30	22.36	16.34	12.78
Nucleus	Temperature (°C)	100	100	100	100
	Time (min)	11	13	15	15
	Predicted hardness	34.7	23.85	19.05	19.05
Chewability					
Cortex	Temperature (°C)	90	100	90	90
	Time (min)	4.2	5	10	12
	Predicted chewability	11.47	6.09	5.06	3.31
Perianth	Temperature (°C)	80	90	90	90
	Time (min)	10	10	5	5
	Predicted chewability	12.08	5.89	5.36	5.36
Nucleus	Temperature (°C)	80	90	100	100
	Time (min)	10	12	5.6	10
	Predicted chewability	13.68	7.16	5.21	3.39
Shear force					
Cortex	Temperature (°C)	80	90	90	90
	Time (min)	5	7.5	14	14
	Predicted shear force	51.63	14.96	9.6	9.6
Nucleus	Temperature (°C)	90	100	100	100
	Time (min)	6	15	15	15
	Predicted shear force	47.68	17.46	17.46	17.46

Table 5. Characterization of an edible formulation using processed tender jackfruit as a meat analog.

Parameters	Mean values ± standard deviation
Proximal chemical composition (% FW)	
Moisture	77.70 ± 0.25
Ash	1.74 ± 0.11
Total carbohydrates	8.14 ± 2.1
Protein	11.62 ± 0.18
Fat	1.62 ± 0.20
Total dietary fiber	6.72 ± 0.084
Protein digestibility (%)	88.92 ± 0.02
Total soluble phenols (mg/100 g FW)	201.10 ± 1.31
Antioxidant capacity (μmol/100 g FW)	
ABTS	4542.42 ± 2.12
DPPH	2963.12 ± 1.50
FRAP	3890.16 ± 1.71

al. (2019). Edible formulation of this experiment contains higher concentration than existing popular foods in the market such as Quorn brand chicken Nuggets (10.17%) (Rosas et al. 2019). In contrast, lower concentration than Morning Star farms grillers Burger (25.00%) (Rosas et al. 2019). Likewise, the product exhibited a good dietary fiber content (6.72%). The World Health Organization (WHO) recommends a daily intake of 27 to 40 g of dietary fiber while the Food and Drugs Administration (FDA) proposes to adult individuals an intake of 25 g of fiber per day. This formulation contains approximately 25% of the total fiber required in a day for a healthy individual.

The protein digestibility in the sterilized edible formulation was 88.92 ± 0.015%. The digestibility of hydrolyzed protein from heat-treated soybean grain was 72%, while in the corn and wheat proteins the digestibility values were 66% and 85% respectively (Zahir et al. 2018). The protein digestibility value from spirulina alga (*Spirulina maxima*) is 85% (Gutierrez-Salmeán et al. 2015; Zuwariah et al. 2018). Furthermore, in the meat animals, the protein digestibility values range from 82 to 93% depending on the type of muscle tissue and the heat treatment applied (Gutiérrez-Salmeán et al. 2015; Zuwariah 2018). The high digestibility in the edible formulation is attributed to the protein denaturation, hydrogen bond breakage and amino acid release caused by the heat treatment applied to process the tender jackfruit, together with commercial sterilization (Gutiérrez-Salmean et al. 2015; Zuwariah 2018).

TSP and AOX were measured in the edible formulation due to the addition of vegetable ingredients rich in antioxidants. The TSP content was 201.10 mg/100 g FW, while the AOX values were from 2963.12 to 4542.42 μmol/100 g FW, depending on the assay being ABTS>FRAP>DPPH. The highest AOX by ABTS assay is possible because in the organic-aqueous extract, there were hydrophilic and hydrophobic compounds that could neutralize this radical (George et al. 2022). The extract also had compounds with chelating capacity using the FRAP assay; those compounds may be flavonoids or tannins that may be able to chelate metal ions because of the large number of hydroxyl groups (Guo et al. 2003). DPPH radical is principally neutralized by the hydrogen donation of hydrophilic phenolic compounds (Pérez-Jiménez et al. 2008; Dermican et al. 2023) that could be extracted in methanolic extract but in minor proportion. García-Moncayo (2023) reported that the addition of spirulina alga at 5% produce a pasta rich in proteins (19.27%), fiber (41.89%), and increased TPS(3.88), ABTS (48%), FRAP (66.09%). Likewise, AOX by DPPH (Shalaby and Shanab 2013) and ABTS (Tamayo-Tenorio et al. 2018) assays have been reported in this alga. In addition, chili, garlic, onion, tomato and spices are rich in antioxidants (Grahl et al. 2018); therefore, it can be inferred that edible formulation conserved antioxidants in spite of the thermal treatment.

It is necessary to evaluate the product for longer storage time to predict its shelf-life; however, we can infer that the product could have a long shelf life, since during storage at 45 °C for 15 days, there was no growth of microorganisms.

Fig. 3 shows the sensory analysis of sterilized edible formulation. Odor, flavor and texture were qualified with average values of 8.0 (strongly like), while color was qualified with average value of 7.0 (moderately like). Color cannot be strongly accepted because spirulina alga gives a dark-green color to product.

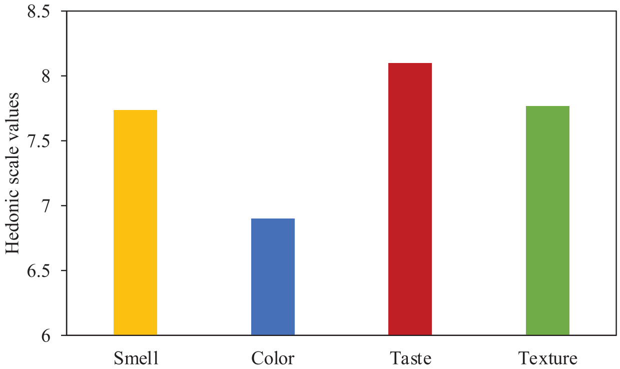

Figure 3. Sensory analysis of the edible formulation using processed tender jackfruit as a meat analog.

Conclusions

To the best of our knowledge, it is the first study using boiling and steaming treatments to evaluate the texture profile. The hardness, chewability and shear force values of tender jackfruit sections depended of thermal treatments; however, although existed differences in the thermal conditions to process tender jackfruit sections with similarity to animal meat references, it was concluded that all jackfruit sections exhibited similar texture parameters to meat references when they were processed at 90–100 °C for 5–15 min by boiling process and 121 °C for 5–10 min by steaming process. The sterilized edible formulation using processed tender jackfruit as a meat analog exhibited good content of dietary fiber, ashes and protein with high digestibility. Moreover, this formulation conserved antioxidants and was microbiologically stable during 15 days of storage and was accepted sensorially.

Credit roles authorship contribution statement

Ortiz-Basurto R.I. and Montalvo-González E.: Conceptualization the original idea, supervision, funding acquisition and wrote the draft manuscript. González-Regalado J.J.: Carried out the investigation experiments. All authors helped supervise the project and verified the analytical methods validations, discussed the results and contributed to review & editing of the manuscript.

Conflicts of interest

The authors confirm that they have no conflicts of interest concerning the work described in this manuscript.

Acknowledgments

The authors thank the Tecnológico Nacional de México for partial financing project. To CONAHCyT-Mexico for grant to José de Jesús González-Regalado. To “Frutos Tropicales de la Bahía S.P.R. de R.L.”, Carlos Sánchez Villegas owner of Rancho Los Parajes, and jackfruit producers from Nayarit, México for providing jackfruits.

References

Afotey B, Yuorkuu, E, Akinie S, Eshun F, Sufyan M (2024) Determination of health and nutritional benefits of jackfruits (*Artocarpus heterophyllus*). Journal of the Ghana Institution of Engineering 24(1): 33–40. https://www.ajol.info/index.php/jgie/article/view/267808

AOAC (2005) In: W. Horwitz (Ed.) Association of Official Agricultural Chemists. Official Methods of Analysis Washington, DC, USA.

Babu PS, Sudheer KP (2020) Quality evaluation of thermal processed tender jackfruit during storage. Journal of Tropical Agriculture 58(1): 22–32. https://jtropag.kau.in/index.php/ojs2/article/view/901

Benzie FFI, Strain JJ (1996) Determination of optimal extraction conditions for phenolic compounds from: *Pistacia atlantica* leaves using the response surface methodology. Analytical Methods 8: 70–76. https://doi.org/10.1039/C6AY01739H

Bhadra S, Mohan N, Parikh G, Nair S (2019) Possibility of *Artocarpus heterophyllus latex* as an alternative source for natural rubber. Polymer Testing 79(August): 106066. https://doi.org/10.1016/j.polymertesting.2019.106066

Bishop J (2013) The Science of Good Cooking. Journal of Chemical Information and Modeling 53(9): 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Bohrer BM (2019) An investigation of the formulation and nutritional composition of modern meat analogue products. Food Science and Human Wellness 8(4): 320–329. https://doi.org/10.1016/j.fshw.2019.11.006

Demircan B, Velioglu YS, Giuffrè AM (2023) Bergamot juice powder with high bioactive properties: Spray-drying for the preservation of antioxidant activity and ultrasound-assisted extraction for enhanced phenolic compound extraction. Journal of Food Science 88(9): 3694–3713. https://doi.org/10.1111/1750-3841.16706

FDA [Food and Drug Administration] (2001a) FDA center for food safety and applied nutrition, bacteriological analytical manual (8th ed.). https://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm063346.htm

FDA [Food and Drug Administration] (2001b) FDA center for food safety and applied nutrition, bacteriological analytical manual (8th ed.). Chapter 18: Yeasts, molds and Mycotoxins. https://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm071435.htm

FDA [Food and Drug Administration] (2001c) FDA center for food safety and applied nutrition, bacteriological analytical manual (8th ed.). Chapter 4: Enumeration of Escherichia coli and the coliform bacteria. https://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm064948.htm

FSIS-USDA (2018) Highlights Accomplishments in Protecting Public Health. United States Department of Agricultue 22: 12.

García-Moncayo A, Rodríguez-Martínez E, Ochoa-Reyes E, Sáenz-Hidalgo H, Sepúlveda D, Buenrostro-Figueroa J, Alvarado-González M (2023) Nutritionally improved pasta with Arthrospira platensis: effect of cooking on antioxidant capacity and pigments content. Emirates Journal of Food and Agriculture 35(9): 782–790. https://doi.org/10.9755/ejfa.2023.3147

George J, Edwards D, Pun S, Williams D (2022) Evaluation of antioxidant capacity (ABTS and CUPRAC) and total phenolic content (Folin-Ciocalteu) assays of selected fruit, vegetables, and spices. International Journal of Food Science 1: 1–18. https://doi.org/10.1155/2022/2581470

Grahl S, Palanisamy M, Strack M, Meier-Dinkel L, Toepfl S, Mörlein D (2018) Towards more sustainable meat alternatives: How technical parameters affect the sensory properties of extrusion products derived from soy and algae. Journal of Cleaner Production 198: 962–971. https://doi.org/10.1016/j.jclepro.2018.07.041

Guo C, Yang J, Wei J, LiY, Xu J, Jiang Y (2003) Antioxidant activities of peel, pulp and seed fractions of common fruits as determined by FRAP assay. Nutrition Research 23(12): 1719–1726. https://doi.org/10.1016/j.nutres.2003.08.005

Gutiérrez-Salmeán G, Fabila-Castillo L, Chamorro-Cevallos G (2015) Nutritional and toxicological aspects of Spirulina (*Arthrospira*). Nutricion Hospitalaria 32(1): 34–40. https://doi.org/10.3305/nh.2015.32.1.9001

Guyony V, Fayolle F, Jury V (2023) High moisture extrusion of vegetable proteins for making fibrous meat analogs: A review. Food Reviews International 39(7): 4262–4287. https://doi.org/10.1080/87559129.2021.2023816

Herrera-Romero JA, Bojórquez-Serrano JI, Hernández-Jiménez A, Can-Chulim A (2020) Geomorfoedaphological landscapes and regularities of soil distribution in San Blas Nayarit, Mexico. Revista Bio Ciencias 7: e706. https://doi.org/10.15741/revbio.07.e706

Honikel KO (1998) Reference methods for the assessment of physical characteristics of meat. Meat Science 49(4): 447–457. https://doi.org/10.1016/S0309-1740(98)00034-5

Jagtap UB, Bapat VA (2010) *Artocarpus*: A review of its traditional uses, phytochemistry and pharmacology. Journal of Ethnopharmacology 129(2): 142–166. https://doi.org/10.1016/j.jep.2010.03.031

Kethavath SC, Bihi J, Claus JR (2019) Warner-Bratzler Shear Force Comparison between Strip and Core Steak Sampling Methods. Meat and Muscle Biology 2(2). https://doi.org/10.22175/rmc2018.042

Kyriakopoulou K, Dekkers B, van der Goot AJ (2019) Plant-Based Meat Analogues. In Sustainable Meat Production and Processing. Elsevier Inc. https://doi.org/10.1016/B978-0-12-814874-7.00006-7

Lelieveld H, Holah J, Gabrić D (2016) Preface to the Second Edition. In Handbook of Hygiene Control in the Food Industry, Second Edition. https://doi.org/10.1016/B978-0-08-100155-4.00050-9

Mañas E, Saura-Calixto F (1993) Ethanolic precipitation: A source of error in dietary fibre determination. Food Chemistry 47: 351–355. https://doi.org/10.1016/0308-8146(93)90176-G

Mathijssen AJTM, Lisicki M, Prakash VN, Mossige EJL (2023) Culinary fluid mechanics and other currents in food science. Reviews of Modern Physics 95(2): 1–76. https://doi.org/10.1103/RevModPhys.95.025004

Melito C, Tovar J (1995) Cell walls limit in vitro protein digestibility in processed legume seeds. Food Chemistry *53*(3): 305–307. https://doi.org/10.1016/0308-8146(95)93937-M

Montreau F (1972) Sur le dosage des composés phénoliques totaux dans les vins par la methode Folin-Ciocalteau. Connaissance de la vigne et du vin 24: 397–404. https://doi.org/10.20870/oeno-one.1972.6.4.2071

Morelos-Flores DA, Chacón-López MA, Montalvo-González García-Magaña ML, Nolasco-González Y, Hernández-Fuentes LM, González-Hernández H (2023) Effect of 1-methylcyclopropene on jackfruit with marketing simulation at 8 °C. Emirates Journal of Food and Agricultue 35(10): 0–0. https://doi.org/10.9755/ejfa.2023.3150

Nova PS, Lakshmy, Seeja T, Panjikkara KCA (2023) Standaradization of meat analogues incorporated with tender jackfruit. The Journal of Research ANGRAU 51(2): 63–71. https://doi.org/10.58537/jorangrau.2023.51.2.07

Peng J, Tang J, Barrett DM, Sablani SS, Anderson N, Powers JR (2017) Thermal pasteurization of ready-to-eat foods and vegetables: critical factors for process design and effects on quality Critical Reviews in Food Science and Nutrition 57: 2970–2995. https://doi.org/10.1080/10408398.2015.1082126

Pérez-Jiménez J, Arranz S, Tabernero M, Díaz-Rubio ME, Serrano J, Goñi I, Saura-Calixto F (2008) Updated methodology to determine antioxidant capacity in plant foods, oils and beverages: Extraction, measurement and expression of results. Food Research International Journal 41: 274–285. https://doi.org/10.1016/j.foodres.2007.12.004

Pflanzer SB, Gomes CL, de Felício PE (2019) Delayed carcass chilling improves tenderness of the beef gluteus medius muscle. Pesquisa Agropecuaria Brasileira: 54. https://doi.org/10.1590/s1678-3921.pab2019.v54.00099

Prior RL, Wu X, Schaich K (2005) Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. Journal of Agricultural and Food Chemistry 53(10): 4290–4302. https://doi.org/10.1021/jf0502698

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M , Rice-Evans C (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology and Medicine 26: 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3

Rosas VT, Monserrat JM, Bessonart M, Magnone L, Romano LA (2019) Comparison of β-carotene and Spirulina (*Arthrospira platensis*) in mullet (*Mugil liza*) diets and effects on antioxidant performance and fillet colouration. Journal of Applied Phycology 31: 2391–2399. https://doi.org/10.1007/s10811-019-01773-1

Rout S, Sowmya RS, Srivastav PP (2024) A review on development of plant-based meat analogues as future sustainable food. International Journal of Food Science and Technology 59(1): 481–487. https://doi.org/10.1111/ijfs.16627

Shalaby AR, Anwar MM, Sallam EM, Emam WH (2016) Quality and safety of irradiated food regarding biogenic amines: ras cheese. International Journal of Food Science & Technology 51: 1048–1054. https://doi.org/10.1111/ijfs.13058

Sushama BP, Kundukulangara P, Jaganath S (2022) Effect of thermal processing on quality of tender jackfruit in tin-free-steel cans. Journal of Food Science Technology 59: 2035–2046. https://doi.org/10.1007/s13197-021-05218-x

Swami SB, Kalse SB (2018) Jackfruit (*Artocarpus heterophyllus*): Biodiversity, Nutritional Contents, and Health. Bioactive Molecules in Food: 1–23. https://doi.org/10.1007/978-3-319-54528-8_87-1

Tamayo Tenorio A, Kyriakopoulou KE, Suarez-Garcia E, van den Berg C, van der Goot AJ (2018) Understanding differences in protein fractionation from conventional crops, and herbaceous and aquatic biomass - Consequences for industrial use. Trends in Food Science and Technology 71: 235–245. https://doi.org/10.1016/j.tifs.2017.11.010

Trilokesh C, Uppuluri KB (2019) Isolation and characterization of cellulose nanocrystals from jackfruit peel. Scientific Reports 9(1): 1–8. https://doi.org/10.1038/s41598-019-53412-x

Zahir M, Fogliano V, Capuano E (2018) Food matrix and processing modulate: In vitro protein digestibility in soybeans. Food and Function 9(12): 6326–6336. https://doi.org/10.1039/C8FO01385C

Zuwariah I, Noor Fadilah MB, Hadijah H, Rodhiah R (2018) Comparison of amino acid and chemical composition of jackfruit seed flour treatment. Food Research *2*(6): 539–545. https://doi.org/10.26656/fr.2017.2(6).106

Supplementary material

Supplementary material 1

Physicochemical parameters of unprocessed tender jackfruit (table S1); The mathematical models to determinate predicted values of hardness, chewability and shear force (Newtons) from unripe jackfruit sections after boiling processing (table S2); Pareto chart indicating the effect of boiling treatment on hardness of cortex (a), core (b) and perinath (c); chewiness of cortex (d), core (e) and perinath (f); share force of cortex (g) and core (c) from tender jackfruit (figure S1). (docx)

Link: https://doi.org/10.3897/ejfa.2024.124770.suppl1