JOURNAL OF FOOD, CULINARY, AND NUTRITION

RESEARCH ARTICLE

Development and Characterization of A Plant-Based Jerky from Indonesian Local Crops as A Sustainable Meat Analogue

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ABSTRACT

Plant-based meat products have gained increasing attention as sustainable alternatives to animal-based foods. However, achieving a texture comparable to meat remains a major challenge. This study aimed to develop a plant-based jerky using cassava leaves (*Manihot esculenta*), okra (*Abelmoschus esculentus*), and sago flour as locally available Indonesian commodities. The product was formulated at a ratio of 2:2:1 (cassava leaves : okra : sago flour) and processed through grinding, steaming, molding, marinating, and cabinet drying. Texture profile analysis showed that the developed plant-based jerky exhibited properties comparable to commercial beef jerky, with hardness values of 2281.3 and 2200.3 gf, respectively. Color analysis revealed L*, a*, and b* values of 23.85, 1.07, and 5.12, respectively. Proximate analysis indicated moisture, carbohydrate, fiber, protein, and fat contents of 17.25%, 59.53%, 13.45%, 5.32%, and 4.45%, respectively. The combination of cassava leaf proteins, okra mucilage, and sago starch successfully produces a compact and chewy structure resembling conventional jerky. These findings demonstrate the potential of local plant-based ingredients to produce an affordable and sustainable jerky alternative, supporting food diversification and the utilization of indigenous agricultural resources.

KEYWORDS: *Cassava leaves, Local food, Okra, Plant-based jerky, Sago flour*

Introduction

Plant-based meat (meat analogue) is a plant-based product designed to resemble the characteristics of animal meat, but its development still faces challenges in forming complex structures to produce a texture that closely resembles meat, which is a key factor in consumer acceptance (Ismail *et al.*, 2020). Cassava leaves (*Manihot esculenta*) are a part of the cassava plant that is rich in protein. Their abundant availability has attracted considerable attention as an alternative source of protein and as a functional food ingredient. Cassava leaf protein has film-forming properties because when heated, the protein denatures and opens reactive groups which then bind together to form a compact three-dimensional network, resulting in a dense and stable structure (Suhartatik & Mustofa, 2018). Okra (*Abelmoschus esculentus*) is widely used in the food industry as a thickening agent, stabilizer, and binder due to its protein content with hydrophobic and hydrophilic substances (Adhiwono *et al.*, 2024). Okra mucilage has the ability to retain large amounts of water and can increase viscosity, thereby strengthening the food matrix network and producing a more elastic and cohesive structure (Yonsen, 2022). Sago flour is a starch source with high gelatinization properties. When heated, sago flour starch can form an elastic gel that can be used as a binder and help form a firm and chewy texture (Rahmawati *et al.*, 2019).

Innovative plant-based jerky made from cassava leaves, okra, and sago flour as local Indonesian commodities highlights the strategic use of abundant and regionally available raw materials. According to Badan Pusat Statistik (BPS, 2023), cassava production in 2023 reached 16.76 million tons, increasing by 1.81 million tons compared to 2022 (14.95 million tons), indicating stable and substantial national availability. At the regional level, Anjasmara *et al.* (2025) reported okra production reaching approximately 13,000 tons in 2022, while studies in Kepulauan Meranti and Indragiri Hilir show that sago production is relatively sufficient to supply domestic market demand (Kusumawaty *et al.,* 2024). The stable availability of these local commodities supports sustainable raw material supply for product development. Moreover, this plant-based jerky offers a clean-label solution through a simpler processing method, the use of natural ingredients, and less intensive stages compared to conventional analogue meat. Appropriate formulation through ingredient ratio adjustment, mixing, marinating, and drying can produce texture and taste comparable to commercial meat jerky (Ishaq *et al.*, 2022). Its development is also environmentally relevant, as livestock meat production has a high carbon footprint (Parlasca & Qaim, 2022), while plant-based meat alternatives have served about 30% of global meat consumers and continue to grow annually (Sendhil *et al.*, 2024), positioning this product as a potential contributor to healthier diets, local resource utilization, and environmental sustainability.

Material and Method

Materials

The main ingredients used in making vegetable jerky are cassava leaves (*Manihot esculenta*), okra (*Abelmoschus esculentus*), and sago flour. The ratio of the main ingredients to a total basic dough of 100 g per formulation is cassava leaves : okra : sago flour = 2 : 2 : 1 (w/w). The marination seasoning ingredients included garlic (15 g), shallots (25 g), white pepper powder (4 g), salt (10 g), coriander powder (4 g), palm sugar (160 g), and soy sauce (60 mL). All ingredients were obtained from local markets and used in fresh condition.

Sample Preparation

Cassava leaves were washed, steamed for 15 minutes, and then blended until smooth. Okra is washed, sliced, and blended until homogeneous. The marinade is made by grinding garlic and shallots, then mixed with the other seasonings until well combined. The treated cassava leaves and okra are then mixed with sago flour (2:2:1) and stirred until homogeneous. The dough is then shaped to a uniform thickness and steamed for 15 minutes. The steamed product is cut uniformly, marinated for 15 minutes, and then dried using a cabinet dryer at 50°C for 5 hours (Mishal *et al.*, 2022; Wijono & Estiasih, 2021).

Instrumentation and Measurements

Texture measurement was conducted using a Texture Profile Analyzer (TPA) (LLYOD Instruments, TA plus Ametek, UK 2007) to compare the textural properties of plant-based jerky and commercial beef jerky. Samples were cut into uniform dimensions prior to analysis, and parameters including hardness, cohesiveness, springiness, gumminess, and chewiness were recorded. Color measurement was performed using a handled colorimeter (NR60CP, 3nh, China) based on the CIE L*, a*, and b* color system. Color values were measured at three different points on each sample, and the mean values were calculated. Sensory evaluation was carried out using a Focus Group Discussion (FGD) to assess perceived similarities in texture and taste between plant-based jerky and commercial beef jerky.

Data Analysis

Texture and color data were expressed as mean ± standard deviation (SD) based on triplicate measurements. The results were compared descriptively between plant-based jerky and commercial beef jerky. Chemical analysis was performed using proximate analysis according to the AOAC method (Latimer & Horwitz, 2012 in Mishal *et al.*, 2022). Sensory evaluation results obtained from the Focus Group Discussion (FGD) were analysed descriptively and summarized qualitatively to assess perceived similarity in texture and taste between plant-based jerky and commercial beef jerky.

Results and Discussion

Based on Figure 1., plant-based jerky has a thin sheet shape similar to commercial meat jerky with a relatively dense surface and compact structure. Visually, the color of the product does not show a dark brown color like beef jerky because plant-based raw materials do not contain myoglobin pigments, but still display brownish hues formed from the marinating and heating of spices. This brown color is likely influenced by non-enzymatic browning reactions between sugar and protein components during the drying process (Yoganarasimhaswamy et al., 2025). To objectively evaluate the product quality, physical properties were analysed through texture analysis, color analysis, and Focus Group Discussion (FGD) to assess panellist taste perceptions and acceptance levels of the product.

Figure 1. Plant-Based Jerky.

Texture Analysis

Table 1. Texture profile analysis results.

Sample	Hardness (gf)	Cohesiveness	Springiness (mm)	Gumminess (mm)	Chewiness (N)
Plant-Based Jerky	2281.3 ± 0.800	0.085 ± 0.002	2.910 ± 0.001	192.71 ± 0.35	5.501 ± 0.018
Commercial Beef Jerky	2200.3 ± 0.379	0.108 ± 0.049	3.442 ± 0.172	238.01 ± 0.38	8.038 ± 0.242

*measured using Texture Profile Analyzer (TPA)

Based on the texture analysis result (Table 1.), plant-based jerky showed a hardness value of 2281.3±0.800 gf, which is very close to and even slightly higher than commercial beef jerky (2200.3±0.379 gf). This relatively small difference indicates that in terms of hardness, which is a key parameter in initial bite force perception, plant-based products have been able to rival the mechanical characteristics of commercial beef jerky. Although the cohesiveness, springiness, gumminess, and chewiness values of plant-based products tend to be lower, the similarity in hardness values indicates that plant-based formulations have succeeded in forming a structure that is strong and compact enough to be texturally competitive with meat-based jerky.

The main contribution comes from cassava leaves, which have a coarse fiber structure such as cellulose, hemicellulose, and lignin. This forms a fibrous network similar to muscle fibers and increases the hardness of the product (Edhirej *et al.*, 2017). In addition, sago flour, which is rich in starch, especially amylopectin, undergoes gelatinization when heated and then undergoes slight retrogradation during drying, thereby forming a solid matrix that strengthens the internal structure (Abduh *et al.*, 2024). Meanwhile, okra acts as a natural binder due to its mucilage content such soluble pectin and hydrophilic polysaccharides which is capable of forming a viscoelastic gel, increasing cohesion between particles, although the data shows that the cohesiveness value of plant-based jerky is slightly lower than commercial beef jerky. This may be due to the absence of myofibrillar proteins, such as those found in beef, which naturally form an elastic and compact tissue after heating (Fatima *et al.*, 2025).

In terms of elasticity parameters, the springiness and chewiness values of plant-based jerky are lower than those of commercial beef products, indicating that plant-based structures tend to be more fragile and less elastic. Animal proteins in beef are capable of forming elastic three-dimensional networks after heat denaturation, thereby increasing springiness and chewiness (Beniwal *et al.*, 2021). In contrast, the structure of plant-based jerky is mostly supported by starch-fiber-pectin interactions. Although okra mucilage helps retain moisture and provides some elasticity, the dominance of stiff cassava leaf fibers and the relatively brittle sago starch matrix after drying result in lower gumminess and chewiness values (Bagul *et al.*, 2026). Thus, functionally, it can be concluded that cassava leaves play a role in increasing hardness and fibrous character, okra functions as a binding agent and gel former that affects cohesiveness, while sago flour contributes to the formation of a solid matrix through starch gelatinization that affects the hardness and overall structure of the product.

Color Analysis

Table 2. Sensory analysis results.

Sample	Mean Hedonic Score of Samples		
	L	a	b
Plant-Based Jerky	27.85 ± 0.229	1.07 ± 0.126	5.12 ± 0.126
Commercial Beef Jerky	23.00 ± 0.395	8.10 ± 0.272	5.78 ± 0.272

*measured using chromameter

Based on the color analysis results (Table 2.), plant-based jerky has an L* value of 27.85±0.229 which is higher than commercial beef jerky (23.00±0.395), indicating that plant-based products tend to be brighter. However, the a* value of plant-based jerky (1.07±0.126) is much lower than beef jerky (8.10±0.272), indicating that the red color intensity of plant-based products is still not as strong as commercial beef jerky. The red color of meat is generally influenced by myoglobin pigments and browning reactions during heating. Meanwhile, the b* values of both products are relatively close, indicating that the level of yellowness is not much different. Overall, plant-based jerky has produced the characteristic brown color of jerky, but with a brighter character and less redness compared to meat-based products.

Based on the color parameters, higher L* value of plant-based jerky can be associated with the absence of myoglobin and the different browning mechanisms occurring in plant matrices. In meat systems, redness (a*) is primarily attributed to myoglobin and its heat-induced derivatives such as metmyoglobin and denatured globin hemochromes, which contribute to the characteristic red-brown color of jerky after drying and heating. Recent reviews explain that thermal processing of meat promotes myoglobin oxidation and Maillard reactions between reducing sugars and amino groups, intensifying red-brown hues (Provost, 2019). In contrast, plant-based jerky formulated from cassava leaves, okra, and sago flour lacks heme pigments, resulting in a significantly lower a* value. Cassava leaves naturally contain chlorophylls and carotenoids, but these pigments are unstable during heating and drying, undergoing degradation and pheophytin formation that shift the color toward olive-brown rather than red (Chaiareekitwat *et al*., 2022).

Furthermore, the browning in plant-based jerky is mainly driven by non-enzymatic Maillard reactions and possible caramelization of carbohydrates from sago starch during drying. Sago flour, rich in starch (amylopectin-dominant), provides reducing sugars upon partial hydrolysis, which participate in Maillard reactions with amino acids from cassava leaves, forming brown melanoidin pigments (Hawa *et al*., 2024). Meanwhile, okra contributes phenolic compounds and mucilage polysaccharides, which can influence color stability and light scattering, slightly increasing brightness (L*) while maintaining similar b* (yellowness) values due to natural carotenoid content (Kang *et al*., 2020). Therefore, the combined effects of chlorophyll degradation from cassava leaves, starch-derived Maillard browning from sago, and phenolic interactions from okra result in the typical brown jerky color, albeit brighter and with significantly lower redness compared to meat-based products.

Chemical Analysis

Table 3. Chemical composition of plant-based meat analogue.

Components	Value (%)
Water	17,25 ± 2,45
Carbohydrate	59,53 ± 5,77
Fiber	13,45 ± 2,50
Protein	5,32 ± 0,00
Fat	4,45 ± 0,17

Based on Table 3., the proximate analysis showed that the plant-based meat analogue contained 17.25% moisture, 59.53% carbohydrate, 13.45% crude fiber, 5.32% protein, and 4.45% fat. The relatively low moisture content indicates that the drying process effectively reduced water availability, which may contribute to improved shelf life stability and reduced microbial growth. Moisture content below 20% is generally desirable for dried plant-based products because it enhances storage stability and decreases deterioration during distribution (Zahari *et al*., 2022). Carbohydrates were the predominant component (59.53%), mainly derived from cassava leaves, okra, and the addition of sago flour as a binder. The high carbohydrate level is expected because starch-rich ingredients are commonly used in meat analogues to provide structure, improve texture, and facilitate water binding. The chemical analysis showed this product also exhibited a high crude fiber content (13.45%), reflecting the contribution of cassava leaves and okra, both of which are recognized as rich sources of dietary fiber. High fiber content is advantageous from a nutritional perspective because dietary fiber has been associated with improved digestive health and enhanced satiety (Ishaq *et al*., 2022).

The protein content was 5.32%, reflecting the natural protein contribution of cassava leaves and okra. Plant leaves are recognized as valuable sources of plant-derived protein and bioactive compounds, contributing to the nutritional quality of the product. Meanwhile, the fat content was 4.45%, indicating a relatively low lipid level that aligns with the composition of the raw materials used. Low-fat plant based products are increasingly preferred by consumers seeking healthier dietary options and may contribute to lower caloric value (Ahmad *et al.*, 2022; McClements *et al.*, 2021).

When compared with the requirements of SNI 01-2908-2013 for meat jerky, the proximate composition of the plant-based meat analogue showed differences in several parameters. The SNI standards set a maximum moisture content of 12%, a maximum fat content of 3%, and a minimum protein content of 18%, whereas the analysis results show the product has a moisture content of 17,25%, a fat content of 4,45%, and a protein content of 5,32%, thus failing to meet these requirements. These differences are expected because the product is formulated entirely from plant-based ingredients which possess a nutritional profile distinct from animal-derived products. The relatively high carbohydrate and fiber contents reflect the contribution of plant materials and starch-based binders, while the protein and fat contents are influenced by the absence of animal tissues. Therefore, comparison with SNI 2908:2013 is used as a general quality reference, given that to date there is no specific national standard for meat analogue or plant-based meat products in Indonesia. These proximate compositions represent the unique characteristics of a plant-based meat analogue rather than a deviation in product quality, highlighting its potential as fiber-rich alternative food product (Badan Standarisasi Nasional, 2013).

Focus Group Discussion

Figure 2. Focus Group Discussion (FGD) to determine taste of plant-based jerky.

Focus Group Discussion (Figure 2.) results indicate that the plant-based jerky was generally perceived positively by the panelists aged 17-60 years in terms of taste, texture, and aroma. Several panellists noted that the savory flavor profile and spice intensity were reminiscent of commercial jerky products, suggesting that the seasoning formulation contributed effectively to the overall sensory character. Furthermore, the texture was described as sufficiently firm and chewy, aligning with the expected characteristics of jerky-type products. Participants also mentioned that the product was versatile in consumption, as it could be suitable both as a side dish accompanying rice and as a ready-to-eat snack, similar to conventional jerky products. Although minor differences compared to commercial beef jerky were still perceptible, the overall acceptance level reflects that the product was considered acceptable and comparable within the context of plant-based alternatives.

Economic Aspect

Table 4. Calculation of Raw Material Costs for Producing 100 grams of Plant-Based Jerky.

Material	Price	
Sago Flour	Rp	2,500
Cassava Leaves	Rp	3,000

Okra	Rp	5,000
Garlic	Rp	500
Shallot	Rp	500
White Pepper	Rp	1,800
Brown Sugar	Rp	3,500
Coriander Powder	Rp	1,000
Soy Sauce	Rp	500
Total	**Rp**	**18,300**

Based on Table 3., the total raw material price of plant-based jerky is Rp 18,300 per 100 g, which is lower than the market price of commercial beef jerky at Rp 78,930 per 100 g. Although the table primarily presents raw material costs rather than a full production cost comparison, the data suggest that the plant-based jerky formulation has a more economical input structure. This is largely supported by the use of locally sourced and abundant plant ingredients in Indonesia, which tend to be more affordable and less price-sensitive than beef. Therefore, the relatively lower raw material cost implies a competitive pricing potential, allowing the product to reach broader consumer segments. Additionally, practical packaging design may further enhance consumer accessibility and convenience in adopting healthier food alternatives.

Socioeconomic and Environmental Implications

Low production costs, supported by the availability of adequate local raw materials, enable consistent processing and support the sustainability of plant-based jerky production as formulated in this study. As a healthier food alternative, the plant-based jerky produced can contribute to improving community welfare and aligns with the United Nations Sustainable Development Goal (SDG) 3 (Good Health and Well-being). Additionally, the plant-based jerky produced in this study has the potential to benefit various stakeholders by providing more stable market access for farmers and added value for agricultural by-products, providing diversification opportunities for MSMEs and traders, and increasing consumer access to affordable and nutritious food. From an environmental perspective, the production of plant-based jerky can contribute to waste reduction, decreased pressure on natural resources, and reduced dependence on imports, thereby strengthening regional economic resilience. These potential impacts are in line with the SDG 12 (Responsible Consumption and Production) (United Nations, 2020).

Conclusion

Plant-based jerky formulated from cassava leaves, okra, and sago flour (2:2:1) demonstrated physical, structural, chemical, and sensory properties comparable to commercial beef jerky, confirming the effectiveness of fiber, starch, and hydrocolloid interactions in forming a compact and stable jerky-like matrix. Cassava leaf fiber and gelatinized sago starch played a critical role in developing structural strength, while okra mucilage functioned effectively as a natural binder to maintain cohesiveness and product integrity resulting in acceptable firmness and chewiness despite the absence of animal protein. Color evaluation showed the typical brown jerky appearance, although with higher brightness and lower redness due to the absence of myoglobin, while sensory assessment confirmed favorable panelist acceptance in terms of taste, texture, and overall quality.

Proximate analysis indicates that the product has relatively high carbohydrate and fiber content, with lower protein and fat levels compared to conventional beef jerky. These characteristics reflect the use of plant-based raw materials and provide added value in the form of potential as a high-fiber alternative food. Although some proximate parameters do not yet meet the requirements of SNI 2908:2013 for beef jerky, this comparison is used only as a general quality reference because of no specific national standard for meat analogue products. Substantially lower raw material costs compared to beef jerky further highlight strong economic feasibility, and utilization of abundant local crops reinforces its relevance for food diversification and sustainable protein development. Overall, findings confirm that cassava leaves, okra, and sago flour represent a scientifically viable and economically competitive formulation for plant-based jerky production, offering a promising approach to expand affordable, sustainable, and locally sourced meat analogue products.

Supporting Information

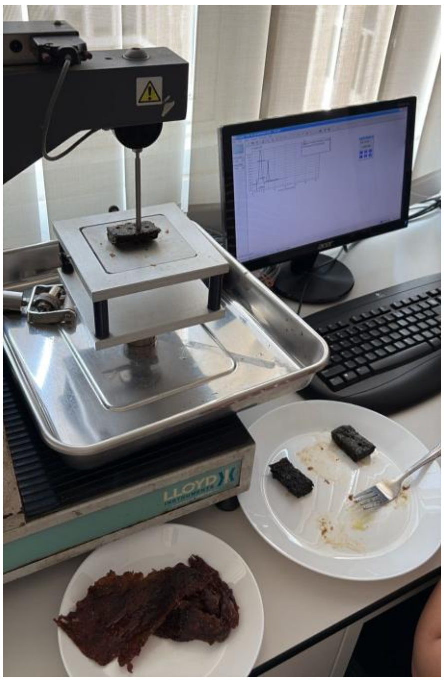

Figure 3. Texture analysis of plant-based jerky.

Acknowledgements

We would like to thank Soegijapranata Catholic University for supporting and facilitating this research. We also extend our gratitude to our lecturer for guiding us through this scientific work, and to our parents for their continuous support.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Anita Carolina L. S., Gabriella Charleen, and Nicholas Ethan Sunjaya equally contributed to the conceptualization, initial idea development, brainstorming, experimental design, plant-based jerky production, physicochemical analyses (including texture and color evaluation), data interpretation, and manuscript writing. All authors were involved in supervision, discussion, and preparation of the article for publication.

Ethical Statement

This study involved human participants in the form of focus group discussions and sensory evaluations conducted with lecturers and students. All procedures involving human participants were carried out in accordance with institutional ethical guidelines and informed consent was obtained prior to participation. This study did not involve animal experimentation or clinical trials. All other experimental procedures were conducted in accordance with standard laboratory practices and institutional research guidelines.

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Cite this article: Sidarta, A.C.L., Charleen, G., & Sunjaya, N.E. (2026). Development and Characterization of A Plant-Based Jerky from Indonesian Local Crops as A Sustainable Meat Analogue. *Journal of Food, Culinary, and Nutrition*, 2(2), 106-116. https://doi.org/10.24167/jfcn.v2i2.15056