Innovative Mackerel Tuna Crackers: Sensory and Nutritional Quality, Digestibility and Shelf-Life Estimation

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Research indicates that fish eating by pregnant women can diminish the likelihood of delivering a stunted infant. Mackerel tuna is a popular and economically priced fish in Indonesia. Mackerel tuna possesses a high protein content and an abundance of minerals. The study aimed to develop mackerel tuna cracker products and assess their sensory quality, nutritional content, digestibility, and shelf life. The findings indicated that the mackerel tuna crackers were well-received. The most favoured product is Formula 3, which contains an additional 25% tapioca flour. The product's nutritious content may enhance nutrient intake in pregnant women. The digestibility of mackerel tuna crackers is 98.14%, and the estimated shelf life of the product is 56 days. Additional research on the efficacy of mackerel tuna crackers as a nutritional intervention for pregnant women is urgently needed.

1. Background

In 2022, almost 148 million children under five years old globally, representing 22.3 percent, suffered from stunting. This nutritional syndrome arises from systemic food failures, marked by limited affordability and access to healthy food (WHO, UNICEF, & The World Bank, 2023). Indonesia is one of the nations confronting the issue of stunting. In 2022, the incidence of stunting in Indonesia diminished to 21%. Nevertheless, in numerous provinces and municipalities, the frequency of stunting continues to be markedly elevated. The 2022 Indonesian Nutritional Status Survey (SSGI) reported a stunting rate of 30.4% in West Aceh Regency, surpassing the WHO's tolerance threshold and failing to meet the RPJMN target of 14% by 2030. The government persists in executing diverse strategies and programs to diminish stunting prevalence, one of which entails addressing the nutritional requirements of pregnant women. Pregnancy elevates the nutritional demands of women due to the development of foetal tissue. This phase of growth and development requires sufficient consumption of high-quality protein. Meat, fish, and dry legumes are regarded as vital protein sources for pregnant women. A balanced diet of energy and protein (with protein comprising a maximum of 20% of total energy) throughout pregnancy facilitates foetal development and enhances birth weight (Liberato, Singh, & Mulholland, 2013). Malnutrition during pregnancy is positively correlated with children's anthropometric measurements (Haque et al., 2022). Gestation is a pivotal period that profoundly affects the nutritional condition of infants. The mother's role during this period is vital in mitigating stunting (Saleh et al., 2021). The dietary intake of mothers during pregnancy considerably influences the occurrence of stunting in offspring (Fitriani, Achmad, & Nurdiana, 2020). The supplementation of macronutrients and micronutrients during gestation significantly influences the nutritional status of neonates (Tyagi, Toteja, & Bhatia, 2017). During pregnancy, protein requirements must increase: 1 g/day in the first trimester, 8 g/day in the second trimester, and 26 g/day in the third trimester, to sustain foetal and placental growth and development.A significant dietary concern during pregnancy is maternal Chronic Energy Deficiency (CED). The 2018 Basic Health Research (Riskesdas) revealed that 17.3% of pregnant women in Indonesia suffered from Chronic Energy Deficiency (CED) (8). This statistic represents a decline from the 2013 rate of 24.2%, however the prevalence remains elevated, much beyond the WHO tolerance threshold of 5%. The elevated prevalence of CED is incongruous given Indonesia's wealth of natural resources, which may be utilised to supply nutrient-dense foods to satisfy familial nutritional requirements, especially for pregnant women. Diverse local food sources, particularly those abundant in protein, can enhance the nutritional quality of pregnant women suffering with CED.Mackerel tuna (Euthynnus affinis) serves as a superior protein source, equivalent to other commercially important tuna species such skipjack, yellowfin, and bigeye tuna. Mackerel tuna is economical, nutritionally dense, and abundant in omega-3 fatty acids. Each 100 grammes of mackerel tuna has 69.40% water, 1.50% fat, 25.00% protein, and 0.03% carbs, in addition to other minerals such as calcium, phosphorus, iron, sodium, and vitamins A (retinol) and B (thiamin, riboflavin, and niacin). Mackerel tuna is a superior supplier of minerals and fatty acids. The nutritional attributes, texture, and quality of its white and dark muscle render this species very ideal as a raw material for the food sector. The dark muscle is notably nutritionally advantageous, mostly due to its fatty acid composition, which is predominantly comprised of polyunsaturated fatty acids (PUFAs). Mackerel tuna, or tiny tuna/kawakawa, is a medium-sized species of the Scombridae family. It is among Indonesia's most commercially significant fish species, inhabiting tropical and temperate seas. Mackerel tuna flourishes in waters with temperatures above 18°C and is found in the warm regions of the Arabian Sea, the Indo-Pacific, and the eastern tropical Pacific.The Ministry of Marine Affairs and Fisheries (2021) reported a substantial growth in mackerel tuna output, rising around 61.27% from 366,900 tonnes in 2010 to 592,056 tonnes in 2019. Mackerel tuna is nutritionally abundant in protein and includes substantial levels of polyunsaturated fatty acids (PUFA). Research on the nutritional composition of mackerel tuna indicates protein concentrations of 23.15% in white muscle and 23.12% in dark muscle, with polyunsaturated fatty acid (PUFA) levels of 51.86% in white muscle and 55.87% in dark muscle. Owing to its abundant nutritional composition, mackerel tuna is frequently utilised as a principal component in numerous processed food items (Kannaiyan et al., 2019). This study created a nutrient-dense, crispy, and savoury food intervention product in the shape of mackerel tuna crackers, mostly composed of mackerel tuna flesh. These mackerel tuna crackers are formulated as extra nutrition for pregnant women and may be enjoyed as an accompaniment to rice or as a regular snack. The study aimed to assess the sensory and proximate composition of mackerel tuna crackers to satisfy the nutritional requirements of mothers and infants during pregnancy. This study's findings aim to advance innovation in supplementary food products for pregnant women, addressing nutritional requirements and mitigating stunting in Indonesia.

2. Method

The study comprised two primary phases: the product development phase and the product quality assessment phase. The product development phase encompassed the production of mackerel tuna crackers. Laboratory analyses were performed in three facilities: the Syiah Kuala University laboratory, the IPB University integrated laboratory, and the Mbrio Food Laboratory. The purpose of the organoleptic test was to evaluate product acceptability through the five senses. Evaluation was conducted by 27 untrained panellists who assessed various aspects, including colour, shape, sound/crispness, scent, and texture of the mackerel tuna cracker product. Panellists assess acceptability by evaluating the value of each parameter, which includes: 1 strongly dislike, 2 dislike, 3 slightly dislike, 4 somewhat like, 5 like, and 6 strongly like. The data was subsequently analysed using one-way ANOVA in SPSS version 27. Proximate analysis seeks to determine the chemical makeup of mackerel tuna cracker products. The analysis included the contents of water, fat, protein, ash, and carbohydrates. Proximate analysis was conducted utilising the Kjeldahl method, Soxhlet extraction, and various other techniques. The atomic absorption spectrophotometer (AAS) method was employed to analyse the mineral content and quantify the levels of iron (Fe), calcium (Ca), and zinc (Zn). Quantification of amino acid concentrations via HPLC (ICI instrument/Shimadzu SCL-10A/Shimadzu CBM 20A). Assessment of product shelf life with the IKK/P-16 Point C (Conventional) approach.

2.1. Development of Prototype

The preparation of the mackerel tuna cracker in this investigation was derived from the methodology of Lobo, Santoso, & Ibrahim (2019), with alterations (Lobo et al., 2019). The used raw materials comprised boneless mackerel tuna meat, chicken eggs, garlic, turmeric, ginger, palm sugar, water, fried shallots, fried garlic, pepper, ground coriander, salt, finely chopped kaffir lime leaves, and tapioca flour, with the proportions of each item specified in Table 1. The processing of mackerel tuna crackers comprised two principal stages: the marination stage and the primary processing stage. The procedure commenced with the evisceration of the fish and the disjunction of the flesh from the skeletal structure. Garlic, crushed coriander, and palm sugar were combined to create a marinade, which was thereafter poured uniformly to the fish and allowed to marinate for 40 minutes. Subsequent to marination, the fish was amalgamated with the remaining components with a chopper until the mixture achieved a smooth and uniform consistency (Lobo et al., 2019). Three distinct formulations of mackerel tuna crackers were devised based on the percentages of raw materials: Formula 1, Formula 2, and Formula 3 (F1, F2, and F3). The principal distinction among these three formulations was the differing amount of tapioca flour, as seen in Table 1. The slurry was subsequently transferred into aluminium trays that had been lightly coated with oil to avert adhesion. The mixture was steamed for 50 minutes, thereafter removed, and permitted to drain. Subsequently, the steaming amalgamation was sliced into slender square segments. The items were subsequently desiccated in a dehydrator at a temperature of 55°C for 10 hours. The dehydrated crackers were subsequently fried in cooking oil at a low temperature.

Table 1: Formulation of Mackerel Tuna Crakers.

Ingredients	Formulation		
	F1 (%)	F2 (%)	F3 (%)
Mackerel tuna meat	59.8	56.5	53.4
Egg	12.0	11.3	10.7
Tapioca flour	3.0	8.5	13.4
Garlic	2.4	2.3	2.1
Turmeric	0.7	0.7	0.6
Ginger	0.6	0.6	0.5
Brown sugar	1.2	1.1	1.1
Water	6.0	5.6	5.3
Fried red onion	7.2	6.8	6.4
Fried garlic	3.6	3.4	3.2
Pepper	0.3	0.3	0.3
Coriander powder	2.4	2.3	2.1
Salt	0.6	0.6	0.5
Chopped lime leaves	0.2	0.2	0.2

Figure 1: Process of Product Development for Mackerel Tuna Crackers.

3. Results and Discussion

3.1. Evaluation of Sensory

Table 2 presents the sensory evaluation of mackerel tuna crackers. The measured parameters included colour, shape, sound, crispness, fragrance, texture, and flavour. The variation in the quantity of tapioca flour incorporated into recipes 1, 2, and 3 significantly influences product colour, with a significance level of 0.001 (P value <0.05). The colour in Formula 1 noticeably differs from that in Formula 2 and Formula 3, although the colour in Formula 2 and Formula 3 is not markedly different. The variation in tapioca flour percentage incorporated into formulas 1, 2, and 3 significantly influences the product's shape, with a significance level of 0.002 (P value < 0.05). The configuration of Formula 1 markedly differs from that of Formula 2 and Formula 3; yet, the product configuration of Formulas 2 and 3 is not substantially distinct. The sound/crispiness evaluation indicated that all product formulations were not statistically different, with a significance level of 0.166 (P value > 0.05). The aroma assessment indicated that there were no significant differences across the product formulations, with a P value of 0.607 (P > 0.05). The product taste assessment indicated that all formulations did not differ substantially, with a p-value of 0.109 (P > 0.05).The hedonic score study indicates that the most favoured product is formula 3, which contains an addition of 25% tapioca flour. Formula 3 appears to be outstanding regarding colour, shape, sharpness, aroma, and texture, achieving the highest standards. An increased proportion of tapioca flour may contribute to an enhanced flavour and mitigate the fishy taste of the fish.

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Table 2: The Result of Organoleptic Tests, Proximate and Minerals of Mackerel Tuna Crackers.

Parameter	Unit	Type of Formulation of the Product		
		F1 (5% tapioca flour)	F2 (15% tapioca flour)	F2 (25% tapioca flour)
Organoleptic				
Color		3.52±0.93a	4.44±1.01b	4.78±0.57b
Shape		3.89±0.97a	4.63±0.83b	4.67±0.78b
Sound/crispness		4.74±0.76a	4.96±0.58a	5.07±0.61a
Aroma		4.85±0.77a	4.96±0.80a	5.04±0.75a
Texture		4.04±1.09a	4.56±0.93a	4.56±1.01a
Taste		4.30±0.99a	4.11±0.97a	4.19±0.83a
Overall		4.30±0.72a	4.52±0.80ab	4.78±0.69b
Proximate Content				
Water	% db	3.24	3.84	4.32
Ash	% db	4.51	3.98	3.79
Protein	% db	41.04	38.39	32.97
Fat	% db	27.53	22.76	19.17
Carbohydrate	% db	20.32	27.64	36.78
Crude fiber	% db	6.60	7.22	7.28
Minerals				
Iron (Fe)	mg/100g	22.70	19.62	17.36
Zink (Zn)	mg/100g	7.73	6.75	6.64
Calcium (Ca)	mg/100g	432.78	295.41	297.26
Note: db: Dry base, F: Formula				

3.2. Evaluation of Proximate Content

Table 2 indicates that formula 3 possesses the highest water content at 4.32%. The protein, fat, and ash content were highest in formula 1, with 41.04%, 27.53%, and 4.51%, respectively. Formula 3 contains the largest carbohydrate and crude fibre levels, at 36.78% and 7.28%, respectively. Protein and fat are essential nutrients that must be adequately supplied throughout pregnancy, as foetal growth and development are entirely reliant on the mother's protein and fat reserves. Inadequate nutritional availability for the foetus due to poor protein and fat intake by pregnant mothers (Mohanty et al., 2014). Conversely, protein and fat exhibit a significant correlation with foetal growth throughout gestation and the nutritional status of birth outcomes (Gala, Godhia, & Nandanwar, 2016). Biochemical studies indicate that maternal blood lipid levels throughout late pregnancy correlate with the newborn's anthropometric measurements. Increased serum lipids during pregnancy are crucial for healthy foetal development.According to Table 3, the nutritional requirements for pregnant women as per IOM (Institute of Medicine/US standardisation) and AKG (Angka Kecukupan Gizi/Indonesia RDA) indicate that the product satisfies only about 25% of the mother's daily nutritional needs. The protein content in the product constitutes fifty percent of the daily protein requirements for pregnant women. Under this premise, the daily protein requirements of pregnant women can be fulfilled by ingesting 200 g of mackerel tuna crackers, excluding other protein sources ingested by moms on that day. This product's nutritional content, specifically protein, is essential for the nutritional health of pregnant women and foetuses. Protein is a crucial nutrient that mothers require during pregnancy for the growth and development of the foetus in utero. This aligns with recent research indicating that protein requirements during pregnancy warrant attention, as protein is crucial for tissue development and foetal growth, particularly in the third trimester. Conversely, fish protein is easily digestible, possesses a high biological value, and is essential for growth and development, the maintenance and repair of damaged tissues, and the synthesis of enzymes and hormones necessary for numerous physiological processes. Seventeen. The heightened protein requirements during pregnancy must be fulfilled to support the development and growth of the foetus and placenta (Marangoni et al., 2016).

Table 3: Requirements of Macro Nutrient and Minerals Per Day During Pregnancy.

Nutrient	IOM 2002/2005		AKG 2019	
	Non Pregnant	Pregnant	Non Pregnant	Pregnant
Macro Nutrient				
Carbohydrate (g)	130	175	360	+40
Protein (g)	46	71	60	+10/+30
Fat (g)	ND	ND	65	+2-3
Mineral				
Calcium	1000	1000	1100	+200
Iron	18	27	26	+9
Zinc	8	11	10	+4
Note: IOM : Institute of Medicine, AKG : Indonesia RDA				

3.3. Evaluation of Mineral Content

The mineral analysis of the three mackerel tuna cracker formulations in Table 2 indicates that Formula 1 possesses the highest iron (Fe) concentration, measuring 22.70 mg/100g of sample. Numerous studies have indicated that iron supplementation influences the growth of children with iron deficient anaemia (Tacon, Lemos, & Metian, 2020). Nonetheless, multiple meta-analyses of randomised controlled trials evaluating the effects of iron therapies on the growth of children under five years did not demonstrate significant outcomes (Phornphutkul et al., 2008). A meta-analysis of 14 research conducted in low- and middle-income countries confirmed this, covering individuals aged between 34 and 167 months (Roberts & Stein, 2017). Zinc is the pivotal element in numerous enzymes that facilitate the differentiation of growth cells. Research indicates that zinc plays a crucial role in growth processes, as evidenced by studies on zinc deficiency in humans, which results in acrodermatitis enteropathica. This condition is linked to growth impairments and heightened vulnerability to infections, and it is a genetically inherited metabolic disorder that results in diminished zinc absorption in the intestines. The maximum zinc mineral concentration is included in formula 1, specifically 7.73 mg/100g of the product. Animal studies have demonstrated the impact of zinc supplementation on growth (Williams & Mills, 1970). Zinc deficiency in rats leads to structural growth alterations and diminishes the length of the tibia and femur bones (Gat-Yablonski, Yackobovitch-Gavan, & Phillip, 2009; Rossi et al., 2001). Zinc may influence development processes by diminishing IGF-I secretion and peripheral IGF-I activity (MacDonald, 2000). The impact of zinc supplementation on human growth has been extensively researched in recent years; nevertheless, the findings have been inconsistent, partially due to significant diversity in inclusion criteria. Zinc supplementation's impact on growth in prepubertal children has not been deemed substantial (Brown et al., 2002), however certain research indicate consistent results for children under 5 years old in underdeveloped nations (Imdad & Bhutta, 2011). The beneficial impacts of zinc on linear growth seem to be substantial post age 2 (Liu et al., 2018). Nevertheless, several research present contradictory findings (Bhandari, Bahl, & Taneja, 2001; Ramakrishnan et al., 2004; Ramakrishnan, Nguyen, & Martorell, 2009). A systematic evaluation of research including over 27,000 children under 5 years of age from low- and middle-income countries revealed that zinc supplementation did not influence anthropometric indicators (Gera, Shah, & Sachdev, 2019). The precise method by which zinc influences linear growth remains ambiguous. Formula 1 contains the highest calcium concentration, with 432.78 mg per 100g of the product. Calcium homeostasis is essential for bone health and development. Calcium shortage in animals leads to diminished bone mineralisation and impaired bone strength (Gera et al., 2019). The injection of vitamin D and calcium reinstates normal bone growth in children with nutritional rickets (Chen et al., 2002). Insufficient milk consumption post-weaning likely results in low calcium and vitamin D intake, contributing to stunting in children in Africa (Munns et al., 2016). Calcium supplementation for 13 months has been linked to increased height in adolescent boys aged 16 to 18.

3.4. Evaluation of Essential Amino Acid Content

Table 4 indicates that leucine possesses the greatest amino acid score at 491.06 mg/g, whereas threonine has the lowest value at 83.94 mg/g. Amino acids are crucial to protein synthesis and energy production. Different amino acids serve distinct functions; for instance, valine has a part in development, digestion, and the neurological system. Lysine participates in the cross-linking of protein production. Histidine serves as a precursor to histamine during the growth process. Isoleucine participates in haemoglobin synthesis and muscle development. Methionine serves as a precursor to cysteine. Phenylalanine serves as a precursor to tyrosine and melanin. Threonine contributes to the maintenance of protein equilibrium and collagen synthesis (Mohanty et al., 2014; Yuliarti, 2009).

Table 4: Evaluation of Essential Amino Acid Content.

Parameters	Unit	Type of Formula			*FAO (2013)	Amino Acid Score (%)
		Formula 1	Formula 2	Formula 3		
Histidine	mg/g	92.17	79.36	86.85	61	151.10
Lysine	mg/g	114.58	91.55	111.25	46	249.09
Leucine	mg/g	78.57	56.61	74.48	16	491.06
Methionine+ Crystine	mg/g	52.38	44.42	50.40	25	209.52
Phenylalanine+ Tyrosine	mg/g	63.46	52.00	60.22	40	158.65
Threonine	mg/g	5.54	7.85	5.07	6.6	83.94
Valine	mg/g	37.77	31.15	37.72	23	164.22
Tryptophane	mg/g	119.37	88.03	103.65	41	291.15

3.5. Evaluation of Non-essential Amino Acid Content

The examination of non-essential amino acid content in Table 5 indicates that Formula 1 contains the greatest total amino acids at 687.21 mg/g, whereas Formula 2 has the lowest at 588.57 mg/g. Non-essential amino acids are crucial for the health of pregnant women and foetal development. The functions of essential amino acids in promoting maternal and foetal health during gestation encompass: 1) Foetal growth and development: Non-essential amino acids, including glutamate, aspartate, and alanine, are requisite for foetal growth and development; 2) Placenta formation: Non-essential amino acids, like glycine and proline, are requisite for the development and optimal functioning of the placenta; 3) Maternal health: Non-essential amino acids, including serine and tyrosine, may contribute to maternal health by mitigating the risk of pregnancy problems. 4) Blood glucose regulation: Non-essential amino acids, including glutamate and aspartate, can assist in regulating blood glucose levels in pregnant women; 5) Malnutrition prevention: Non-essential amino acids, such as alanine and glycine, can aid in preventing malnutrition in pregnant women.

Table 5: Evaluation of Non-essential Amino Acid Content.

Parameter	Unit	Type of Product Formulation		
		Formula 1	Formula 2	Formula 3
Serine	mg/g	47.34	40.09	45.64
Glutamate	mg/g	170.23	149.78	167.04
Proline	mg/g	39.28	33.59	38.67
Glycine	mg/g	53.39	45.50	52.61
Alanine	mg/g	67.99	59.86	65.29
Crystine	mg/g	8.31	6.50	8.24
Ileucine	mg/g	54.39	47.13	51.66
Thyrosine	mg/g	39.28	31.96	34.87
Aspartic Acid	mg/g	108.54	94.26	100.79
Arginine	mg/g	98.46	79.90	111.89
Total Amino Acids		687.21	588.57	676.70

3.6. Evaluation of Protein Digestibility

The analysis of protein digestibility in Table 6 indicates that Formula 1 exhibits the highest protein digestibility at 98.279, whilst Formula 2 demonstrates the lowest at 97.952. The mean protein digestibility of mackerel tuna cracker products is 98.14.

Table 6: Evaluation of protein digestibility.

Sample	w. Sampel	ml Titrasi	%N	Final Protein Content (%)	Protein Digestibility (%)	x̄ Protein Digestibility	SD
Formula 1	0.2001	0.139	0.120	0.747	98.279	98.14	0.17
Fromula 2	0.2004	0.153	0.141	0.880	97.952		
Formula 3	0.2007	0.142	0.124	0.73	98.199		

3.7. Estimation of the Product Shelf-life

Figure 2 indicates that the identification of Salmonella sp. and Escherichia coli in all product formulations exhibited no growth (negative). Shelf life testing of Fish Crackers was performed with conventional procedures at a storage temperature of 25°C. The mean organoleptic quality drop score for the colour criterion on the 56th day was 3.00, indicating a noticeable paleness in colour. The average quality drop value for the fragrance metric was 3.00, characterised by a reduction in the unique fish aroma. The average quality drop value for the texture parameter was 2.13, characterised by a soft texture. The average quality reduction for the taste criterion was 2.00, characterised by the loss of the fish plate's characteristic flavour and the presence of a bitter aftertaste.

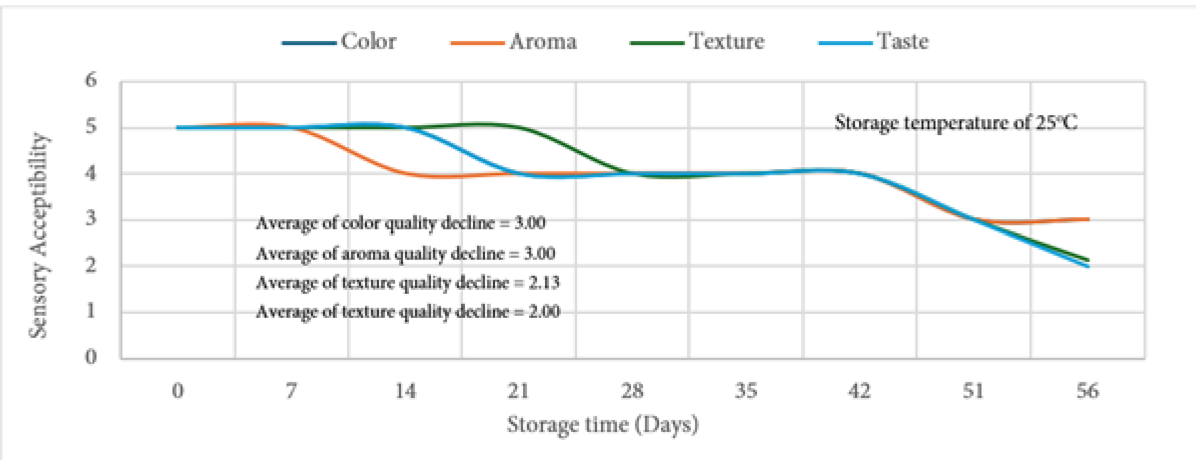

Figure 2: Estimation of the Product Shelf-life

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4. Conclusions

The mackerel tuna crackers exhibit favourable acceptance. Nutritional evaluation, encompassing proximate, mineral, and amino acid composition, could enhance nutrient intake among pregnant women. The protein digestibility of the product indicates that the average protein digestibility of mackerel tuna crackers is 98.14. The outcome of product shelf-life testing estimates that the shelf life of the product is 56 days. Additional research on the efficacy of mackerel tuna crackers as a nutritional intervention for pregnant women is urgently needed.

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Author Contributions

Sukma Elida: writing, editing, review, data analysis; Hardinsyah: review, data validation, supervision, conceptualization; Eny Palupi: review, editing, data validation, supervision, methodology; Ahmad Sulaeman: review, data validation, supervision, methodology

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Institutional Review Board Statement

This research has obtained permission from the Ethics Committee of Poltekkes Jambi with the approval number No. LB.02.06/2/1330/2024

Data Availability Statement

Data will be made available on request.

Conflict of Interest

There is no conflict of interest associated with the material presented in this paper.

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