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Development of Instant Complementary Feeding (MP-ASI) Product Based on Smoked Mackerel Flour and Moringa Leaf Flour as a Stunting Prevention Strategy Using the Foam-Mat Drying Method

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ABSTRACT

Stunting is a chronic nutritional problem in Indonesia that adversely affects children's physical growth and cognitive development. According to data from the Ministry of Health of the Republic of Indonesia (2025), the 2024 Indonesian Nutritional Status Survey (SSGI) found that the national prevalence of stunting declined from 21.5% in 2023 to 19.8% in 2024. Although this figure was 0.3 percentage points below the 2024 national target of 20.1%, it remained higher than the target set for 2025, which is 18.8%. One of the major contributing factors is inadequate protein and calcium intake among children aged 6–24 months, highlighting the need for nutritionally adequate complementary foods. Mackerel fish (*Rastrelliger spp.*) has considerable potential as a source of animal protein and calcium, whilst moringa leaves (*Moringa oleifera*) are rich in vitamins and minerals. This study aimed to develop an instant complementary feeding (MP-ASI) porridge based on smoked mackerel flour and moringa leaf flour using the foam-mat drying method with egg white as a foaming agent. The analyzed parameters included physicochemical characteristics, nutritional value, and organoleptic properties. The results demonstrated a significant interaction between ingredient proportion and foaming agent concentration on most parameters, except carbohydrate content and aroma. The optimum formulation consisted of 90% smoked mackerel flour, 10% moringa leaf flour, and 6% foaming agent. This formulation produced a high protein content and a calcium content of 1.176.45 mg/100 g; however, its protein digestibility (65%) remained lower than that of the commercial product comparator (74%).

Contribution to Sustainable Development Goals (SDGs):

SDG 2: Zero Hunger

SDG 3: Good Health and Well-being

1. INTRODUCTION

1.1. Research Background

Stunting remains a major chronic nutritional problem and a significant challenge in child health development in Indonesia. This condition is characterised by impaired growth in children, particularly indicated by height-for-age measurements below the standard for their age group. The consequences of stunting extend beyond physical growth impairment, affecting cognitive

development, future productivity, and overall human resource quality. According to data from the Ministry of Health of the Republic of Indonesia (2025), the 2024 Indonesian Nutritional Status Survey (SSGI) found that the national prevalence of stunting declined from 21.5% in 2023 to 19.8% in 2024. Although this figure was 0.3 percentage points below the 2024 national target of 20.1%, it remained higher than the target set for 2025, which is 18.8% [1]. One of the principal causes of stunting is inadequate intake of protein and essential micronutrients, particularly calcium, during early childhood, especially among



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children aged 6–24 months. At this stage, children require complementary feeding (MP-ASI) that is adequate not only in quantity but also in nutritional quality [2].

Mackerel fish (*Rastrelliger spp.*) is a local food resource with considerable potential for development as a raw material for complementary feeding products. This fish contains high levels of animal protein, calcium, and iron [3]. The utilisation of both fish flesh and bones in flour form can enhance mineral content, particularly calcium, which plays an essential role in bone formation and child growth. However, the strong fishy odour presents a challenge in mackerel processing. Traditional smoking methods involving direct combustion have several limitations, particularly the accumulation of hazardous compounds such as tar and benzopyrene. The use of liquid smoke offers an alternative approach, as it can reduce the formation of carcinogenic polycyclic aromatic hydrocarbons (PAHs) [4].

Moringa leaves (*Moringa oleifera*), as a nutrient-dense plant-based food source, also possess substantial potential for preventing stunting. Moringa leaves are rich in plant protein, vitamins A and C, calcium, zinc, iron, and folic acid, all of which are essential for bone growth, nervous system development, and haemopoiesis. Previous research reported that supplementation with moringa leaf powder in malnourished children improved haemoglobin levels and reduced the prevalence of anaemia, a recognised risk factor for stunting [5].

Previous studies have demonstrated that incorporating 10–20% moringa leaf powder into instant complementary porridge increased protein digestibility by up to 18% compared with control formulations [5]. Another study involving instant porridge fortified with 20–30% mackerel flour showed improvements in protein content, healthy lipids (EPA and DHA), and micronutrient composition, meeting the nutritional needs of infants aged 6–24 months [6]. Although mackerel bones contain substantial amounts of calcium, the utilisation of mackerel remains largely limited to its flesh. Therefore, this study proposes an innovative approach by utilising smoked mackerel flesh-and-bone flour combined with moringa leaf flour to enhance the protein and calcium content of instant complementary feeding porridge produced using the foam-mat drying method.

1.2. Literature Review

1.2.1. Stunting

Stunting is a chronic nutritional disorder that commonly occurs during the first 1,000 days of life and is characterised by height-for-age measurements below –2 standard deviations according to UNICEF standards. This condition is primarily caused by prolonged inadequate nutrient intake, particularly deficiencies in animal protein and essential micronutrients such as calcium, iron, and zinc, which are critical for bone growth and child development [6].

Stunting prevention requires early intervention through optimal nutritional intake, particularly among infants and young children. Animal protein functions as an essential building component for tissue formation, metabolism, and immune function, whilst calcium plays a vital role in the formation and maintenance of bone structure [7][8]. Previous research demonstrated that children who did not consume animal protein had a ninefold higher risk of developing stunting compared with children receiving adequate animal protein intake [9].

Adequate protein and calcium intake in children should be fulfilled through complementary feeding (MP-ASI) with balanced nutritional composition according to the Recommended Dietary Allowance (RDA). Therefore, the development of complementary foods enriched with protein and calcium is important for supporting optimal growth and preventing stunting in children.

1.2.2. Complementary Feeding (MP-ASI)

High-quality Complementary Feeding (MP-ASI) should fulfil four principal criteria, namely timely introduction, nutritional adequacy, safety and hygiene, and responsive feeding practices. As infants reach ages 8–11 months, their oromotor abilities and acceptance of diverse foods progressively develop. At this stage, caregivers are encouraged to introduce a wider variety of foods to accommodate increasingly complex nutritional needs. Previous research by Krebs *et al.* (2011) demonstrated a significant association between animal protein consumption in complementary feeding and a reduced risk of linear growth retardation (stunting), leading the World Health Organization (WHO) to recommend animal-source foods as an essential component of complementary feeding [7].

These criteria are consistent with the Regulation of the Indonesian Ministry of Health No. 41 of 2014 concerning Balanced Nutrition Guidelines, which has subsequently been updated through technical guidance issued after 2019 [6]. According to these guidelines, complementary foods should possess organoleptic characteristics appropriate to the infant's motor and oral developmental stages. Texture modification should be introduced progressively, beginning with pureed foods for infants aged 6–8 months, finely chopped foods for those aged 9–11 months, and small food pieces for children aged 12 months and above. Therefore, the provision of complementary foods that meet nutritional, safety, and texture-suitability requirements is essential to support optimal infant growth and development [8].

1.2.3. Nutritional Composition of Indian Mackerel (*Rastrelliger spp.*)

Indian mackerel (*Rastrelliger spp.*) is a small pelagic fish with high nutritional value and strong potential as a nutrient-rich food source in Indonesia. It contains high levels of protein, lipids, minerals, and vitamins essential for growth and development, particularly in early childhood. Mackerel flour contains approximately 65.37% protein, 14.85% fat, 5% carbohydrate, omega-3 fatty acids, phosphorus, and calcium [9]. Its protein is considered high-quality animal protein due to its complete essential amino acid profile, with protein digestibility reported at 18–22%, making it a more affordable alternative to beef or poultry [9].

Traditional fish smoking methods commonly used in Indonesia present food safety and environmental concerns due to the formation of Polycyclic Aromatic Hydrocarbons (PAHs), including carcinogenic benzo(a)pyrene [3]. Liquid smoke offers a safer alternative by producing smoking effects with lower PAH contamination. Derived from the condensation of biomass combustion smoke, liquid smoke contains bioactive compounds such as phenols, carbonyls, and organic acids with antimicrobial, antibacterial, and antioxidant activities [10].

The advantages of liquid smoke make it a relevant smoking technology for food products, particularly fisheries products, and

a more adaptable approach compared with conventional smoking methods. Liquid smoke may be produced from various wood sources, including coconut shell, acacia, bamboo, and eucalyptus, each contributing distinct aroma profiles. This technology has been widely applied in meat and seafood products and has demonstrated effectiveness in inhibiting pathogenic bacteria such as *Salmonella* and *Escherichia coli* in processed fish products [10].

1.2.4. Nutritional Composition of *Moringa oleifera* Leaves

Moringa oleifera leaves are widely recognised as a tropical plant utilised as a functional food source due to their high nutritional content. In the context of nutrient-dense foods, moringa leaves are often referred to as a “superfood” because they are rich in protein, vitamins, minerals, and bioactive compounds. Their abundant nutritional composition makes moringa leaves a promising alternative food ingredient for addressing nutritional deficiencies, particularly stunting. Moringa leaf flour contains approximately 23.78% protein, 2.74% fat, 51.66% carbohydrate, 2003 mg of calcium, 18.9 mg of vitamin A, 17.3 mg of vitamin C, 20.5 mg of vitamin B₂, and 2.64 mg of vitamin B₁. In addition, moringa leaves contain substantial amounts of calcium, iron, magnesium, and potassium, exceeding the levels found in several other leafy vegetables [11]. These nutritional components play an important role in preventing stunting, as the vitamins and minerals in moringa leaves contribute significantly to children's growth and development.

1.2.5. Nutritional Composition of Rice Flour

Rice (*Oryza sativa* L.) is a primary carbohydrate source with considerable potential as a base ingredient for complementary foods (MP-ASI) due to its wide availability, affordability, and high consumer acceptance. Rice flour possesses favourable characteristics, including high digestibility, a fine texture, good solubility in hot water, and the ability to produce a soft porridge consistency suitable for infants aged 6–24 months. In addition, rice has a relatively low allergenic potential compared with other cereals and a neutral flavour that facilitates fortification with protein- and micronutrient-rich ingredients without compromising the sensory quality of the final product [12]. From a nutritional perspective, rice flour serves as an excellent source of energy due to its high carbohydrate content. According to data from the Directorate of Nutrition, Ministry of Health of the Republic of Indonesia, every 100 g of rice flour contains approximately 12 g of moisture, 145.8 mg of ash, 0.3 g of fat, 7 g of protein, and 80 g of carbohydrates. This composition highlights the suitability of rice flour as a base ingredient for MP-ASI, particularly as an energy source that can be combined with protein- and micronutrient-rich ingredients to produce a more nutritionally balanced complementary food product [12].

2. MATERIALS AND METHODS

2.1. Material

The primary materials used in this study were fresh Indian mackerel subjected to liquid smoking and moringa leaf flour. Supporting ingredients used in the formulation of complementary food (MP-ASI) included rice, skimmed milk powder, foaming agent, and vegetable oil. Protein digestibility analysis was

conducted using the multi-enzyme method involving proteolytic enzymes, namely trypsin, α -chymotrypsin, and peptidase, in a buffer solution. Additional chemical reagents used in the analyses included distilled water (H₂O), potassium sulphate (K₂SO₄), mercuric oxide (HgO), boric acid (H₃BO₃), hydrochloric acid (HCl), nitric acid (HNO₃), sodium hydroxide (NaOH), and methyl blue indicator. A commercial instant complementary food product, *Promina* “Salmon Pumpkin” variant, was used as the comparison sample.

2.2. Experimental Design

The experimental design in this study consisted of two main treatment factors, namely the proportion of smoked mackerel fish flour to moringa leaf flour and the concentration of egg white used as a foaming agent. A factorial Completely Randomised Design (CRD) involving two factors was employed. Factor I comprised the proportion of smoked mackerel fish flour and moringa leaf flour at three levels: 90%:10%, 80%:20%, and 70%:30%. Factor II consisted of egg white concentration as the foaming agent at three levels: 2%, 4%, and 6%. Each treatment combination was conducted in duplicate, resulting in a total of 18 experimental units.

2.3. Research Procedure

The research procedure involved preparing smoked mackerel flour, moringa leaf flour, and rice flour, and formulating instant complementary food (MP-ASI) using the foam-mat drying method. The preparation of smoked mackerel fish flour was adapted from the modified method of [13], including fish cleaning, immersion in a liquid smoke solution, draining, drying using a cabinet dryer at 60°C, pressure cooking, secondary drying, milling, and sieving through an 80-mesh sieve to obtain a fine and homogeneous flour.

The preparation of moringa leaf flour was carried out according to the modified method of [14], involving the sorting of young leaves, washing, blanching at 80°C for 1–2 minutes, rapid cooling using ice water, drying in a cabinet dryer at 60°C for 3 hours, milling, and sieving through an 80-mesh sieve.

The preparation of rice flour followed the modified method of [15], comprising rice sorting, soaking for 3 hours, draining, milling, drying using a cabinet dryer at 60°C for 1 hour, and sieving through an 80-mesh sieve to obtain a uniform rice flour.

The preparation of instant MP-ASI porridge was conducted according to the modified method of [16] using the foam-mat drying technique. The process began with mixing smoked mackerel fish flour, moringa leaf flour, and rice flour according to the treatment formulations, followed by dilution and mixing using a mixer until a homogeneous consistency was achieved. Egg white was added as a foaming agent at concentrations of 2%, 4%, and 6%, followed by the incorporation of maltodextrin into the mixture. The formulation was subsequently dried in a cabinet dryer at 60°C for 3 hours until a dried layer formed, then sequentially milled and sieved through an 80-mesh sieve to obtain a fine, homogeneous instant MP-ASI powder.

2.4. Physicochemical and Sensory Analysis

Each experimental unit underwent physical and chemical analyses. Physical analysis included determining water absorption capacity, while chemical analyses included evaluating moisture, ash, protein, fat, and carbohydrate content.

Subsequently, the best-performing formulation selected from the 18 experimental units was further analysed for calcium content and in vitro protein digestibility.

3. RESULT AND DISCUSSION

3.1. Proximate Composition Analysis

3.1.1. Moisture Content

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel fish flour and moringa leaf flour and the concentration of foaming agent, with each treatment factor also exerting a significant effect ($p \leq 0.05$) on the moisture content of the instant MP-ASI porridge produced. The mean moisture content values of instant MP-ASI porridge formulated with varying proportions of smoked mackerel fish flour and moringa leaf flour, combined with different foaming agent concentrations, are presented in Figure 1.

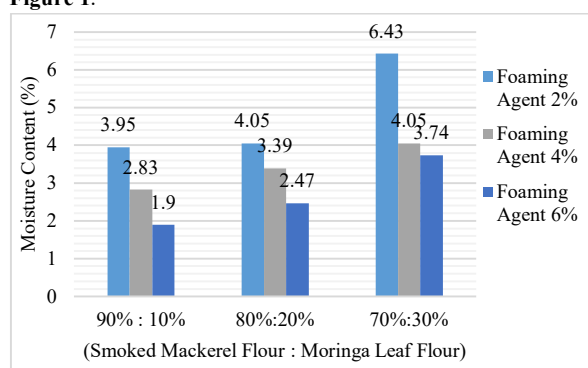


Figure 1. Moisture Content of Instant MP-ASI Porridge Formulated with Different Proportions of Smoked Mackerel Fish Flour and Moringa Leaf Flour with the Addition of Foaming Agent.

Figure 1. shows that increasing the proportion of moringa leaf flour and decreasing the proportion of smoked mackerel fish flour resulted in higher moisture content in the instant MP-ASI porridge, whereas increasing the foaming agent concentration reduced the product's moisture content [17]. The high fibre and polar compound contents of moringa leaves contribute to a greater water-binding capacity, thereby increasing product moisture. Conversely, the addition of egg white as a foaming agent promotes the formation of a porous foam structure, thereby increasing the evaporation surface area and accelerating water removal during drying. Accordingly, higher foaming agent concentrations resulted in lower moisture content [18].

Most formulations complied with the Indonesian National Standard (SNI 01-7111.1-2005), which specifies a maximum moisture content of 4%, except for the formulation containing smoked mackerel fish flour and moringa leaf flour at a ratio of 70%:30% with 2% foaming agent, which produced a moisture content of 6.43%, potentially reducing product shelf life.

3.1.2. Ash Content

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel fish flour and moringa leaf flour and the concentration of foaming agent, with each treatment factor also showing a

significant effect ($p \leq 0.05$) on the ash content of the instant MP-ASI porridge produced. The mean ash content values of instant MP-ASI porridge formulated with varying proportions of smoked mackerel fish flour and moringa leaf flour and different concentrations of foaming agent are presented in Figure 2.

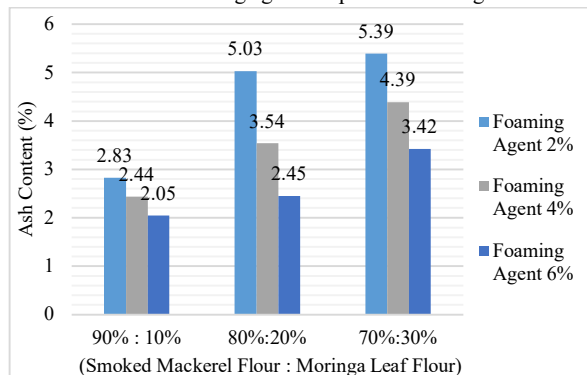


Figure 2. Ash Content of Instant MP-ASI Porridge Formulated with Different Proportions of Smoked Mackerel Fish Flour and

Moringa Leaf Flour with the Addition of Foaming Agent.

Figure 2. shows that increasing the proportion of moringa leaf flour and decreasing smoked mackerel fish flour increased the ash content of the instant MP-ASI, whereas higher concentrations of foaming agent reduced ash content. The elevated mineral content of moringa leaves, particularly calcium, iron, magnesium, and potassium, was identified as the primary factor contributing to the product's increased ash content [14]. In contrast, the egg white-based foaming agent reduced ash content due to its high moisture content and low mineral content, and the formation of a porous structure during the foam-mat drying process generated a mineral dilution effect [17].

Most formulations complied with the Indonesian National Standard (SNI 8133:2015), which specifies a maximum ash content of 5%, except for the formulation containing smoked mackerel fish flour and moringa leaf flour at a 70%:30% ratio with 2% foaming agent, which had an ash content of 5.39%.

3.1.3. Carbohydrate Content

Based on the analysis of variance (ANOVA), the proportion of smoked mackerel fish flour and moringa leaf flour, as well as the addition of foaming agent, had a significant effect ($p \leq 0.05$) on the carbohydrate content of the instant MP-ASI porridge. However, no significant interaction was observed between the two factors. The results of Duncan's Multiple Range Test (DMRT) at the 5% significance level showed identical letter designations among the foaming agent treatments, indicating that variations in foaming agent concentration did not result in significant differences in the product's carbohydrate content. The mean carbohydrate content of instant MP-ASI porridge formulated with different proportions of smoked mackerel fish flour and moringa leaf flour is presented in Table 1.

Table 1. Mean Carbohydrate Content of Instant MP-ASI Porridge Formulated with Different Proportions of Smoked Mackerel Fish Flour and Moringa Leaf Flour.

Treatment Proportion of Smoked Mackerel Flour: Moringa Leaf Flour	Carbohydrate Content	DMRT 5%
	Mean±SD	
90% : 10%	61.31 ^a ±2.58	-
80% : 20%	64.16 ^b ±5.38	2.44
70% : 30%	64.06 ^b ±4.79	2.54

Table 1. shows that the proportion of smoked mackerel fish flour and moringa leaf flour significantly affected the carbohydrate content of instant *MP-ASI*, with values ranging from 61.31% to 64.16%. The increase in carbohydrate content was primarily attributed to the higher concentration of carbohydrates in moringa leaf flour compared with smoked mackerel fish flour. Raw material analysis indicated that moringa leaf flour contained 52.33% carbohydrate, whereas smoked mackerel fish flour contained only 13.70%. The high dietary fibre content of moringa leaves, primarily in the form of polysaccharides, contributed to the product's increased carbohydrate content. In contrast, smoked mackerel fish flour, as an animal-derived ingredient, is predominantly composed of protein and lipids with relatively low carbohydrate content; therefore, increasing its proportion had a limited effect on the product's overall carbohydrate content [18]. The mean carbohydrate content values of instant *MP-ASI* porridge with different foaming agent concentrations are presented in **Table 2**.

Table 2. Mean Carbohydrate Content of Instant *MP-ASI* Porridge with Different Foaming Agent Concentrations.

Treatment foaming agent concentration	Carbohydrate content	DMRT 5%
	Mean±SD	
2%	60.89 ^a ±1.84	2.44
4%	63.68 ^b ±2.66	-
6%	64.97 ^c ±5.22	2.54

Table 2. shows that the addition of a foaming agent significantly affected ($p \leq 0.05$) the carbohydrate content of instant *MP-ASI* porridge, which ranged from 60.89% to 64.97%. The lowest carbohydrate content was observed at a foaming agent concentration of 2% (60.89%), while the highest value was obtained at 6% (64.97%). This increase may be attributed to improved efficiency of the foam-mat drying process, in which egg white proteins form a stable porous structure that enhances moisture removal and promotes the concentration of solid components, including carbohydrates [16]. However, the effect of the foaming agent was less pronounced than that of the smoked mackerel fish flour and moringa leaf flour proportions, as moringa leaf flour contains considerably higher carbohydrate levels than smoked mackerel fish flour [17].

3.1.4. Protein Content

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel fish flour and moringa leaf flour and the concentration of foaming agent, with each treatment factor also exerting a significant effect ($p \leq 0.05$) on the protein content of the instant

MP-ASI porridge produced. The mean protein content values of instant *MP-ASI* porridge formulated with different proportions of smoked mackerel fish flour and moringa leaf flour and varying concentrations of foaming agent are presented in **Figure 3**.

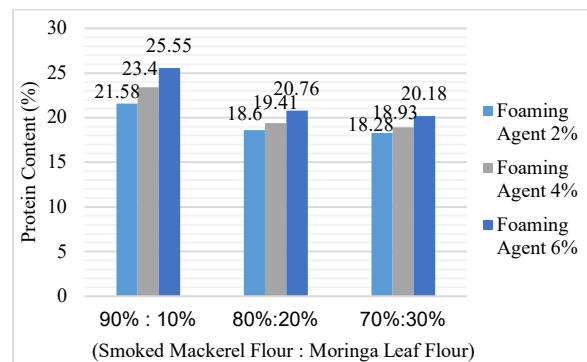
**Figure 3.** Protein content of instant *MP-ASI* porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour, and with different concentrations of a foaming agent.

Figure 3. shows that increasing the proportion of moringa leaf flour and decreasing the proportion of smoked mackerel flour reduced the protein content of instant complementary feeding porridge (*MP-ASI*), whereas increasing the concentration of the foaming agent enhanced the protein content. The higher protein content of smoked mackerel flour than that of moringa leaf flour was identified as the main factor contributing to the increase in product protein content [20]. Furthermore, the use of egg white as a foaming agent also contributed to the increase in protein content due to its high concentration of functional proteins, including ovalbumin and ovomucin [21]. All formulations complied with the requirements of SNI 8133:2015, which specifies a minimum protein content of 8%, indicating their nutritional suitability as complementary foods for infants and young children.

3.1.5. Fat Content

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel flour and moringa leaf flour and the concentration of foaming agent, while each treatment factor also exerted a significant effect ($p \leq 0.05$) on the fat content of the resulting instant *MP-ASI* porridge. The mean fat content values of instant *MP-ASI* porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour, along with different foaming agent concentrations, are presented in **Figure 4**.

Figure 4. shows that increasing the proportion of moringa leaf flour and decreasing the proportion of smoked mackerel flour reduced the fat content of instant *MP-ASI*, whilst increasing the concentration of the foaming agent also contributed to a reduction in product fat content. The high lipid content of smoked mackerel flour was identified as the primary factor contributing to increased fat levels, whereas moringa leaf flour, characterised by low fat and high fibre contents, reduced fat content through a dilution effect on lipid components [18]. Furthermore, the egg white-based foaming agent contributed to lower fat levels due to its inherently low lipid content.

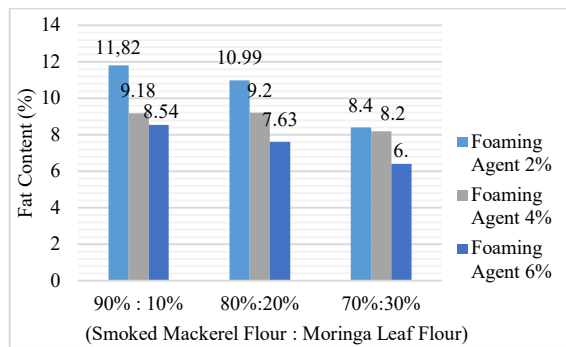


Figure 4. Fat content of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different concentrations of *foaming agent*.

All formulations complied with SNI 8133:2015, which specifies a minimum fat content of 4%, indicating that the products met the quality requirements for instant complementary foods for infants and young children.

3.2. Physical Analysis

3.2.1. Water Absorption Capacity

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel flour and moringa leaf flour and the concentration of foaming agent, whilst each treatment factor also had a significant effect ($p \leq 0.05$) on the water absorption capacity of the resulting instant MP-ASI porridge. The mean values of the water absorption capacity of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour, and with different foaming agent concentrations, are presented in **Figure 5**.

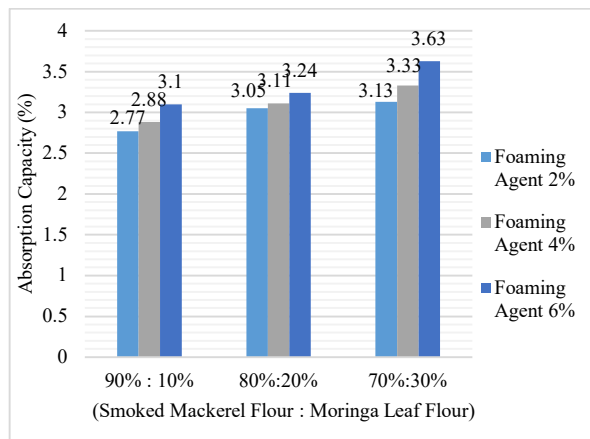


Figure 5. Water absorption capacity of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different concentrations of *foaming agent*.

Figure 5. shows that increasing the proportion of moringa leaf flour and decreasing the proportion of smoked mackerel flour enhanced the water absorption capacity of instant MP-ASI, whilst increasing the concentration of the *foaming agent* also increased water absorption. The high fibre content of moringa leaf flour improved water-binding capacity through the presence of hydrophilic functional groups [22], whereas the protein and lipid contents of smoked mackerel flour reduced water absorption due

to their hydrophobic properties. In addition, the egg white-based *foaming agent* increased product porosity during foam-mat drying, thereby enlarging the surface area and accelerating rehydration. A high water absorption capacity indicates favourable rehydration properties; however, it may also cause the porridge to thicken more rapidly, potentially affecting the adequacy of nutrient intake in infants [16].

3.2.2. Solubility

Based on the analysis of variance, a significant interaction ($p \leq 0.05$) was observed between the proportion of smoked mackerel flour and moringa leaf flour and the concentration of *foaming agent*, whilst each treatment factor also exerted a significant effect ($p \leq 0.05$) on the solubility of the resulting instant MP-ASI porridge. The mean solubility values of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different *foaming agent* concentrations are presented in **Figure 6**.

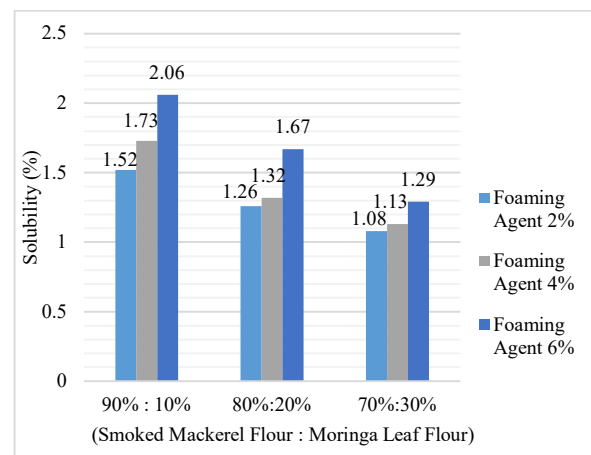


Figure 6. Solubility of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different concentrations of *foaming agent*.

Figure 6. shows that increasing the proportion of moringa leaf flour and decreasing the proportion of smoked mackerel flour reduced the solubility of instant MP-ASI, whereas increasing the concentration of the *foaming agent* enhanced product solubility. The reduction in solubility was attributed to the high fibre content of moringa leaf flour, which increased the proportion of water-insoluble components, thereby hindering product dispersion and dissolution. The improvement in solubility observed in formulations containing smoked mackerel flour was attributed to the presence of proteins with polar functional groups that interact readily with water and enhance the product's hydration capacity [22]. Furthermore, the increase in solubility resulting from the addition of a *foaming agent* was attributed to the formation of lighter, more porous particle structures during the foam-mat drying process, thereby increasing the surface area available for water contact and accelerating dissolution [16]. The enhancement of functional properties was also influenced by physical modifications of particle structure induced by the foaming process, which contributed to improved solubility of the instant MP-ASI product [23].

3.3. Organoleptic Analysis

3.3.1. Color

Based on the analysis of variance, the formulation comprising different proportions of smoked mackerel flour and moringa leaf flour with the addition of foaming agent showed a significant effect ($p \leq 0.05$) on the color parameter of MP-ASI porridge. The mean values of the color parameter obtained from the organoleptic evaluation of MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different foaming agent concentrations are presented in **Table 3**.

Table 3. Mean color parameter values of MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different concentrations of foaming agent.

Treatment	Color	DMRT
Proportion of Smoked Mackerel Flour: Moringa Leaf Flour	Mean $\pm$ SD	5%
90% : 10%	2% 4.04 ^{ab} $\pm$ 1.14	0.81
	4% 4.48 ^b $\pm$ 1.00	0.85
	6% 3.44 ^a $\pm$ 1.12	-
80% : 20%	2% 4.60 ^b $\pm$ 1.38	0.88
	4% 5.44 ^c $\pm$ 1.50	0.90
	6% 4.52 ^b $\pm$ 1.45	0.87
70% : 30%	2% 5.44 ^c $\pm$ 1.12	0.90
	4% 6.28 ^d $\pm$ 1.40	0.90
	6% 4.60 ^b $\pm$ 1.22	0.89

The organoleptic evaluation of the colour parameter presented in **Table 3**, demonstrated that the colour scores of instant MP-ASI porridge ranged from 3.44 to 6.28, indicating variations in colour acceptance among the formulations. The most favourable score was obtained from the formulation containing 90% smoked mackerel flour, 10% moringa leaf flour, and 6% foaming agent, suggesting that the colour characteristics of this formulation were closest to those of the control sample ("R"). In contrast, the lowest score was recorded for the formulation containing 70% smoked mackerel flour, 30% moringa leaf flour, and 4% foaming agent, indicating lower colour acceptability than the control.

The variation in colour acceptance was primarily influenced by differences in the proportion of smoked mackerel flour and moringa leaf flour used in the formulations. An increase in the proportion of moringa leaf flour and a corresponding decrease in smoked mackerel flour produced a progressively greener product colour due to the high chlorophyll content naturally present in moringa leaves. This greener appearance differed markedly from the yellowish-white colour of the control sample, thereby reducing panelist preference and overall acceptance [5]. Conversely, formulations containing a higher proportion of smoked mackerel flour and a lower proportion of moringa leaf flour exhibited a lighter and more neutral colour profile that more closely resembled the control product.

3.3.2. Aroma

Based on the analysis of variance, the formulation consisting of varying proportions of smoked mackerel flour and moringa leaf flour, with the addition of different concentrations of a foaming agent, showed no significant effect ($p > 0.05$) on the aroma parameter of MP-ASI porridge. The mean aroma scores of MP-ASI porridge formulated with different proportions of smoked mackerel flour and moringa leaf flour and supplemented with varying foaming agent concentrations are presented in **Table 4**.

Table 4. Mean aroma scores of MP-ASI porridge formulated with different proportions of smoked mackerel flour and moringa leaf flour and varying concentrations of foaming agent.

Treatment	Aroma
Proportion of Smoked Mackerel Flour: Moringa Leaf Flour	Mean $\pm$ SD
90% : 10%	2% 4.16 $\pm$ 1.40
	4% 4.16 $\pm$ 1.55
	6% 4.12 $\pm$ 1.56
80% : 20%	2% 4.60 $\pm$ 1.22
	4% 4.40 $\pm$ 1.22
	6% 4.04 $\pm$ 1.27
70% : 30%	2% 4.32 $\pm$ 1.31
	4% 4.32 $\pm$ 1.55
	6% 4.00 $\pm$ 1.00

The organoleptic evaluation of the aroma parameter presented in **Table 4**, demonstrated that the aroma scores of MP-ASI porridge ranged from 4.00 to 4.60, indicating that the products were generally perceived as having an aroma comparable to the control sample ("R"). ANOVA results demonstrated that the proportions of smoked mackerel flour and moringa leaf flour, as well as the concentration of *foaming agent*, did not significantly affect the aroma of the product. The most favourable score was obtained from the formulation containing smoked mackerel flour and moringa leaf flour at a 70%:30% ratio with a 6% foaming agent (4.00), whereas the lowest score was observed in the 80%:20% formulation with a 2% *foaming agent* (4.60).

3.3.3. Taste

Based on the analysis of variance, the formulation consisting of varying proportions of smoked mackerel flour and moringa leaf flour, with the addition of different concentrations of a foaming agent, had a significant effect ($p \leq 0.05$) on the taste parameter of MP-ASI porridge. The mean taste scores of instant MP-ASI porridge formulated with different proportions of smoked mackerel flour and moringa leaf flour and varying foaming agent concentrations are presented in **Table 5**.

The organoleptic evaluation of the taste attribute presented in **Table 5**, demonstrated that the mean taste scores of instant MP-ASI porridge ranged from 4.36 to 5.44. The highest level of acceptance was observed for the formulation containing 90% smoked mackerel flour, 10% moringa leaf flour, and 4% *foaming agent*, with a score of 4.36, indicating that the product's taste remained similar to that of the control sample ("R"). In contrast, the lowest score was recorded for the 70%:30% formulation with

a 6% foaming agent, at 5.44. indicating lower taste acceptability compared with the control sample.

Table 5. Mean taste parameter scores of MP-ASI porridge formulated with different proportions of smoked mackerel flour and moringa leaf flour and varying concentrations of foaming agent.

Treatment		Taste	DMRT
Proportion of Smoked Mackerel Flour:	Foaming Agent Concentration	Mean±SD	5%
90% : 10%	2%	4.52 ^{ab} ±1.00	0.79
	4%	4.36 ^a ±0.99	-
	6%	4.64 ^{ab} ±1.15	0.82
80% : 20%	2%	4.80 ^{abc} ±1.26	0.86
	4%	4.72 ^{abc} ±1.17	0.86
	6%	4.92 ^{abc} ±1.22	0.84
70% : 30%	2%	5.24 ^{bc} ±1.23	0.87
	4%	5.16 ^{bc} ±1.70	0.87
	6%	5.44 ^c ±1.23	0.87

3.3.4. Texture

Based on the analysis of variance, the proportion of smoked mackerel flour and moringa leaf flour combined with the addition of foaming agent had a significant effect ($p \leq 0.05$) on the texture parameter of MP-ASI porridge. The mean scores for the texture parameter of instant MP-ASI porridge formulated with different proportions of smoked mackerel flour and moringa leaf flour and varying foaming agent concentrations are presented in **Table 6**.

Table 6. Mean texture scores of instant MP-ASI porridge formulated with varying proportions of smoked mackerel flour and moringa leaf flour and different concentrations of foaming agent.

Treatment		Texture	DMRT
Proportion of Smoked Mackerel Flour:	Foaming Agent Concentration	Mean±SD	5%
90% : 10%	2%	5.04 ^c ±1.46	0.90
	4%	4.88 ^{bc} ±0.93	0.88
	6%	5.28 ^c ±1.62	0.90
80% : 20%	2%	4.08 ^a ±1.00	0.81
	4%	4.04 ^a ±1.10	-
	6%	4.16 ^{ab} ±0.69	0.85
70% : 30%	2%	4.92 ^{bc} ±1.35	0.89
	4%	4.96 ^c ±1.46	0.90
	6%	4.68 ^{abc} ±1.52	0.87

The organoleptic evaluation of the texture attribute presented in **Table 6**. demonstrated that the mean texture scores of instant MP-ASI porridge ranged from 4.04 to 5.28. The most favourable score was obtained from the formulation containing smoked mackerel flour and moringa leaf flour at a ratio of 80%:20% with 4% foaming agent (4.04), indicating that the product texture remained comparable to the control sample ("R"). In contrast, the lowest

score was observed in the 90%:10% formulation with a 4% foaming agent, indicating lower texture acceptability than the control.

3.4. Determination of the Optimum Treatment

The optimum treatment for instant MP-ASI was determined using the De Garmo method, which comprehensively considered chemical, physical, and organoleptic parameters. The analysis identified formulation A1B3, consisting of a 90:10 ratio of smoked mackerel flour to moringa leaf flour with 6% foaming agent, as the best treatment due to its highest effectiveness value among all formulations. This formulation complied with SNI 8133:2015 requirements, including maximum moisture content (5%), maximum ash content (5%), minimum protein content (8%), and minimum fat content (4%), indicating its nutritional suitability as an instant complementary food.

In addition, formulation A1B3 exhibited favourable physical characteristics, particularly in water absorption capacity and solubility, attributed to the formation of a more porous powder structure during the foam-mat drying process [26]. The formulation also demonstrated good organoleptic acceptance, with colour, taste, aroma, and texture scores comparable to the control sample. The lower proportion of moringa leaf flour helped maintain an acceptable colour and reduce bitterness, whilst the higher proportion of smoked mackerel flour provided a savoury flavour preferred by the panellists [7][23]. Based on the selection of the optimum formulation, further analyses of protein digestibility and calcium content were conducted. The results of these analyses are presented in the following **Table 7**.

Table 7. Protein Digestibility and Calcium Content of the Optimum Treatment of Instant MP-ASI Porridge

Sample	Analytical Parameters		
	Protein Digestibility (%)	Calcium Content (mg/100g)	Viscosity (cP)
Optimum Treatment (A1B3)	65%	1,176.45	780
Commercially Available Product (R)	74%	580.50	1200

Table 7. shows that the optimum formulation, A1B3, contained 1.176.45 mg/100 g of calcium, which was substantially higher than the commercial product *Promina "Salmon Pumpkin Honey"* containing 580.50 mg/100 g. The elevated calcium content in formulation A1B3 was attributed to the use of whole smoked mackerel flour, including calcium-rich bones, which enhanced the mineral contribution to the final product [3][25]. This high calcium content may help meet the daily mineral requirements of infants and young children and support bone development and prevent stunting [8].

Protein digestibility analysis revealed that formulation A1B3 had a digestibility of 65%, lower than the commercial product (74%). The reduced protein digestibility was associated with the presence of dietary fibre and antinutritional compounds in moringa leaf flour, including tannins, phytates, and oxalates, which can form complexes with proteins, inhibit proteolytic enzyme activity, and reduce protein bioavailability [19][22]. In

contrast, the higher protein digestibility of the commercial product was likely influenced by the use of more digestible protein sources and advanced processing technologies, such as protein hydrolysates and controlled heat treatment.

The viscosity of the optimum MP-ASI formulation A1B3 was 780 cP, which was lower than that of the commercial MP-ASI product 1,200 cP. This difference may be attributed to the higher proportions of smoked mackerel flour and moringa leaf flour, which contain protein and dietary fibre that do not contribute to viscosity development as effectively as starch. In addition, the fibre present in moringa leaf flour tends to absorb water without forming a viscous gel matrix. The use of 6% egg white as a foaming agent and the application of foam mat drying produced a more porous powder structure, resulting in improved rehydration properties but lower viscosity. In contrast, commercial MP-ASI products generally contain a higher proportion of pregelatinised cereal starch, which enhances water absorption and gel formation, thereby increasing viscosity [27].

4. CONCLUSION

- 1) A significant interaction was observed between the proportions of smoked mackerel flour, moringa leaf flour, and foaming agent concentration on most physicochemical characteristics and organoleptic properties of instant MP-ASI porridge, with the exception of carbohydrate content and aroma.
- 2) The optimum formulation consisted of 90% smoked mackerel flour and 10% moringa leaf flour with 6% foaming agent, producing high protein and calcium contents (1.176.45 mg/100 g), although its protein digestibility was lower than that of the control (65%).

5. RECOMMENDATIONS

The relatively low protein digestibility observed in the optimum formulation may be attributed to antinutritional compounds in moringa leaf flour, including tannins, phytates, and oxalates. Future studies should therefore investigate processing techniques to reduce these compounds, such as fermentation, germination, and blanching prior to drying. The application of these treatments may improve protein bioavailability and digestibility, thereby enhancing the nutritional quality of the developed complementary food product.

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