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Formulation of Sorghum-Based High-Protein Crackers Enriched with Wheat and Soybean Flours for Toddlers

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ABSTRACT*: Various complementary food menus have been developed to support parents in selecting nutritious first foods for toddlers. These foods are commonly based on rice flour as a carbohydrate source. However, the high reliance on rice has driven diversification efforts toward alternative staples. This study explores high-protein biscuits formulated from sorghum flour and soybean flour as potential complementary foods for stunted toddlers. Sorghum provides complex carbohydrates and fiber, while soybean flour contributes high-quality plant-based protein. Five different formulations (F0–F4) were tested using a Completely Randomized Design (CRD) with two replications per treatment, each involving three sample units. The chemical properties analyzed included moisture, ash, fat, protein, and carbohydrate content. One-way ANOVA followed by Duncan's multiple range test (α = 0.05) was applied to assess significant differences. The results showed statistically significant differences ($p < 0.05$) among the formulas in terms of protein and fat content. Protein content ranged from 5.21% to 7.66%, and fat ranged from 7.8% to 9.55%. F3 was selected as the best formulation due to its optimal balance of nutrients, highest protein content (7.66%), and compliance with Indonesian National Standard (SNI) for biscuits. Its full nutritional profile includes 3.7% moisture, 1.52% ash, 9.55% fat, 7.66% protein, and 77.7% carbohydrates. Given that toddlers aged 1–3 years require approximately 20 g/day of protein and 1,125 kcal/day, this product can contribute meaningfully to their daily intake. Thus, sorghum–soybean biscuits demonstrate potential as nutritious complementary foods to help address protein-energy malnutrition and reduce the prevalence of stunting in toddlers. Thus, biscuits made from sorghum and soybean flour can be an alternative nutritious food supplement for toddlers. It is recommended that these crackers be further fortified with other important nutrients such as iron, zinc, and vitamin A, which also play a role in preventing stunting.*

Keywords: *Crackers, Nutrition, Sorghum Flour, Soybean Flour*

1. INTRODUCTION

Toddlerhood is an important period in the human growth and development process. The growth and development period at this age is a period that occurs rapidly and will never happen again, therefore it is often called the golden age (Satria, et al., 2022). Toddler age is 0-59 months at this age toddlers need good nutritional intake because a fulfilled nutritional status will make the nutrients needed by the body/tissues function, grow, and develop properly. Nutrition is a very important part of the growth and development of toddlers. If it is not met properly, one of the problems that often occurs in toddlers is stunting (Aini and Yekti, 2013).

Ensuring adequate food intake is a key nutritional intervention closely linked to the nutritional well-being of toddlers. Supplying appropriate food to toddlers is crucial in preventing malnutrition during early childhood. Complementary foods must be given in appropriate portions, frequencies, and nutrition (Herman et al., 2023). The primary approach to stunting prevention focuses on meeting maternal nutritional needs during pregnancy and ensuring adequate nutrition for toddlers throughout the First 1,000 Days of Life by supplementing their diet with both plant-based and animal-based protein sources (Ramadhani & Adi, 2023; Mulyani et al., 2022; Billah, 2023).

One of the well-known breast milk supplement ingredients (MP-ASI) is instant porridge. Commercial instant porridge is usually made from rice flour which is a source of carbohydrates. Consuming good food with important nutrients such as lots of protein in it will improve body quality (Prayitno, et al., 2024). The high consumption of rice today is the basis for efforts to consume diverse foods from similar sources to avoid dependence on one commodity (Faridi et al., 2023). The most commonly recognized complementary food to breast milk (MP-ASI) is instant porridge, typically made from rice flour and primarily composed of carbohydrates. The high consumption of rice today encourages efforts to diversify food sources so that there is no dependence on commodities, especially rice (Rahmad, 2018; Klerks et al., 2019).

Sorghum, as an alternative to rice, is an excellent source of carbohydrates. Due to its wide adaptability to the environment, sorghum is one of the types of cereals cultivated in Indonesia (Setyowati et al., 2023). According to research conducted (Wibowo, 2015), sorghum increases energy content by up to 29%, protein content by up to 33%, and iron by up to 53% of daily consumption. In addition, sorghum contains the most iron (Fe) and fiber compared to rice, wheat, and corn. After removing large amounts of seeds and embryos, sorghum can be made into flour. After that, the endosperm is ground to the desired fineness (Rosniar, 2016). Sorghum is usually used as a food crop in poor countries with dry climates, while in developed countries with sufficient availability, it is used as feed (Cholilie, et al., 2020).

Stunting results from inadequate intake of energy and nutrients. Adequate and high-quality protein intake is essential for optimal bone development and growth. The quality of protein-rich foods is determined by the type and quantity of essential amino acids they contain (Puspita et al., 2023; Maigoda et al., 2023). Efforts to prevent stunting, intake of macronutrients and micronutrients can affect toddler growth. Protein is a macronutrient that is beneficial for growth. The study found that the intake of protein, calcium, and phosphorus was notably lower among children experiencing stunting compared to those who were not stunted (Wiyono et al., 2023).

Enhancing crackers with plant-based protein sources, such as a combination of sorghum flour and legumes, can improve the protein content of sorghum, thereby supporting children's growth and development. Nuts contain lysine, leucine, and isoleucine, but little methionine and cystine. Therefore, nuts are often combined with cereals because cereals have a lot of methionine and cystine but little lysine (Nudianti, 2019). Sorghum serves as a valuable source of dietary fiber, protein, iron, phosphorus, and B vitamins (Wulandari, 2017). Its nutritional content makes it a potential choice to increase the nutritional value of food.Amorta (2020) stated that soyb

eans are among the top five high-protein foods due to their considerable protein content. Soybeans consist of approximately 9% water, 40% protein, 18% fat, 3.5% fiber, 7% sugar, and around 18% other components. To enhance the protein content of sorghum flour, the addition of soybean flour is necessary. This study aims to improve the protein value of sorghum flour by incorporating soy flour at varying percentages. Among all types of beans, soybeans are the type of beans that contain the highest protein, followed by cowpeas (Agus and Yuli, 2023).

Thus, sorghum and soybeans can be used for MP-ASI. This can function as a food diversification to support the growth and development of infants and meet their nutritional needs at the age of six months. Based on these problems, researchers are motivated to explore the development of an innovative toddler cracker made from sorghum flour enriched with soybean flour, aiming to create a high-protein food product that fulfills protein requirements using local ingredients.

2. MATERIALS AND METHODS

This experimental study used a Completely Randomized Design (CRD) Factorial, which used sorghum flour and added soybean flour to the formulation. The making of the cracker formulation was carried out at the Agro-Industrial Processing Technology Laboratory, Agricultural Industrial Technology Study Program, Faculty of Agriculture, Muhammadiyah University of Jember, while the analysis of water content, ash content, fat content, protein content and carbohydrate content was carried out at the Food and Agricultural Product Chemistry Laboratory, Faculty of Agricultural Technology, University of Jember. The samples used in this study were five samples with two repetitions so that the total sample was 10 samples taken using the random sampling technique. The determination of the cracker formulation can be seen in Table 1.

2.1 Tools and Materials

The tools needed are an oven, aluminum pan, a basin to make sorghum flour and red bean flour. In addition to distilled water, other chemicals used include $CuSO_4$, H_2SO_4, K_2SO_4, NaOH, 0.1 N HCl (merck), 1% phenolphthalein (milipore, germany) and 0.1 N NaOH (merck). In conducting protein analysis using a Kjeldahl flask, condenser, distillation apparatus series, spatula, beaker glass, mortar and pestle, watch glass, analytical balance, measuring cup, dropper pipette, fume hood (Pyrex, Germany), Erlenmeyer flask (Iwaki, Germany), funnel and burette (Pyrex, Germany).

Table 1. Cracker Material Formulation

Ingredients (g)	F0	F1	F2	F3	F4
Wheat Flour	80	50	50	50	80
Sorghum Flour	0	30	30	30	30
Soybean Flour	0	10	15	20	0
Cornstarch	10	10	10	10	10
Egg Yolk	30	30	30	30	30
Margarine	60	60	60	60	60
Refined Sugar	40	40	40	40	40
Milk Powder	54	54	54	54	54

*F0 is Control
F1 is Soybean Flour 10 g
F2 is Soybean Flour 15 g
F3 is Soybean Flour 20 g
F4 is Without Soybeans with 30 g Sorghum Flour

This study used sorghum from the Indonesian Sorghum Farmers Union (SEPASI) with the inclusion criteria for sorghum, namely the condition of whole, smooth seeds, not broken or cut with a full size, not empty on the inside, and not rancid. Soybeans were obtained from markets in Jember Regency with the inclusion criteria of soybeans that are still in good condition, the surface of the beans is smooth and shiny, not wrinkled, sprouted, and there are no black spots. The exclusion criteria for sorghum and soybeans are the condition of intact seeds, not broken and not cut, wrinkled surface and no rancid odor. The first stage of the research was to make Sorghum flour and Soybean flour.

2.2 Making Sorghum Flour and Soybean Flour

After the Sorghum seeds are collected, they are sorted to remove dirt or dust. Then, the skin is removed from the whole Sorghum seeds and processed to produce Sorghum rice. After that, the Sorghum rice is soaked for 24 hours with a water ratio of 1:1. Then the soaked Sorghum rice is drained with a drying machine until the water content drops by 12-14%. In the flouring process, the dried Sorghum rice is ground with a smooth iron cylinder to produce fine flour according to standards (Tionusa & Soeprapto, 2023). The making of soybean flour begins with soybeans that meet the specifications being soaked in water for 24 hours, then washed with running water and drained for ±15 minutes. Furthermore, the soybeans are dried in an oven for ±12 hours, at a temperature of 60°C. Then it is ground using a blender and sieved with a flour sieve (60-80 mesh) to obtain soybean flour (Mulyani Asfi et al., 2017). There were 5 samples in this study with 2 treatments.

3. RESULTS AND DISCUSSION

The food products developed in this study are intended to support the fulfillment of nutritional needs of toddlers, especially those experiencing stunting. Stunting is a condition of failure to thrive due to chronic malnutrition, and is greatly influenced by the intake of protein, energy, and important micronutrients such as iron, calcium, and zinc. Therefore, analysis of the nutritional content of sorghum-based crackers enriched with soy flour is crucial to assess the product's contribution to the daily needs of toddlers. Toddlers aged 1–3 years need around 20 grams of protein, 1,125 kcal of energy, 7 mg of iron, 650 mg of calcium, and 5 mg of zinc per day. By knowing the nutritional composition of the product, it can be evaluated whether this cracker formulation is able to be an alternative functional food that supports efforts to prevent and overcome stunting by increasing affordable and easily consumed nutritional intake by toddlers.

3.1. Interpretation of Result

Analysis of water content, ash content, fat content, protein content, and carbohydrate content was conducted at the Food Analysis Laboratory, Jember State Polytechnic. The average results of water content, fat content, protein content, and carbohydrate content showed a significant difference if the superscript letters were different and the results showed no significant difference if the superscript letters were the same in the nutrients of each formulation presented in Table 2 as follows:

Table 2. Results of Nutritional Value of Crackers

Component	Sample Results					
	F0	F1	F2	F3	F4	Significance
Water content (%)	3,66±0,07^a	3.67±0.2^a	3.69±0.35^a	3.70±0.84^a	3.73±0.63^a	0.88
Ash Content(%)	1,44±0,04^a	1.46±0.35^a	1.49±0.70^a	1.52±0.11^a	1.54±0.14^a	0.87
Fat Content(%)	9,31±0,06^a	9.37±0.84^a	9.46±0.21^a	9.55±0.20^a	9.51±0.28^a	0.92
ProteinContent(%)	7,52±0,06^a	7.55±0.49^a	7.62±0.04^a	7.66±0.19^a	7.64±0.21^a	0.89
Carbohydrate(%)	78,08±0,23^a	77.98±0.14^a	77.82±0.36^a	77.77±0.43^a	77.80±0.33^a	0.90

3.2 Water Content

The results of the water content test indicate that the control formula (F0) had a water content of 3.66%. A higher addition of sorghum flour was associated with an increase in the moisture content of the crackers (F1 to F5).

This is because the water absorption capacity of sorghum flour is low, which is 1.51%. The absorption capacity is influenced by the starch composition in sorghum flour, particularly the proportions of amylose and amylopectin.

The mechanism of interaction between amylose or amylopectin and water occurs through the gelatinization process, where when heated in water, starch granules absorb water and begin to swell. The hydrogen bonds between starch molecules weaken, allowing water molecules to enter and form new hydrogen bonds with amylose and amylopectin. The crystalline structure of starch granules, especially those containing amylose, begins to break down, and some of the amylose dissolves out to form a thick solution. Meanwhile, the more branched amylopectin remains in the granules and helps maintain viscosity. When the mixture is cooled, the amylose molecules re-form the bonds between the chains that form the gel structure, a process called retrogradation, while amylopectin experiences it more slowly.

Sorghum flour contains approximately 23–28% amylose, with the remainder being amylopectin. The low amylose content of sorghum flour causes the volume expansion value to be lower. This is because with a high amylose content, it absorbs more water so that the volume is also greater, and vice versa (Yuli, 2009). Based on SNI No. 01-2973 (2011), the maximum water content for crackers is 5%. Thus, crackers with the addition of sorghum flour meet the SNI cracker standards. The water content of a substance indicates the proportion of water it contains by weight, measured either on a wet or dry basis. Excessive moisture can lead to microbial growth, which negatively impacts the shelf life and safety of the product. Therefore, this water content is very important for product quality. Since water can affect physical properties or chemical changes, the water content in food affects the acceptability, freshness, and shelf life of food. The texture, presentation, and taste of food can be affected by the amount of water in it (Eden & Rumambarsari, 2020).

3.3 Ash Content

Ash content reflects the level of purity and quality of food ingredients, and can be used to detect the presence of contamination or unwanted mixtures, such as soil or other inorganic materials. In addition, the comparison of ash content between the two types of flour can provide an overview of the nutritional value of each, especially related to the contribution of minerals to nutritional needs. Therefore, this analysis is an important step in quality control and assessment of the nutritional value of sorghum and soybean-based food products.

Based on the Anova test with a significance of 5%, it is known that there is an effect of cracker formulation treatment on the ash content of the crackers produced. Ash content across different cracker formulations ranges from 1.44% to 1.54%. Variations in ash content are affected by the composition of the raw materials. Since sorghum flour has a higher ash content than wheat flour, increasing its proportion in the formulation leads to higher ash levels in the final product (Syifahaque et al., 2023).

According to Wulandari (2017), ash content is influenced by the amount of minerals in the ingredients. Sorghum flour has a high mineral content such as Mg, Ca, Zn, Cu, Mn, Mo, and Cr. The average ash content of formulations F1 through F4 does not exceed 2%, thereby meeting the quality standards for crackers as specified in SNI No. 01-2973 (2011), which sets the maximum permissible ash content at 2%. Ash content serves as an indicator of the mineral levels present in food products. The ash content in the cracker samples rose as the proportion of sorghum and soybean flour substitutions increased. Legumes, including soybeans, are known to be rich in mineral content, which contributes to higher ash levels. The fortification of sorghum flour with soybean flour resulted in greater ash content due to the higher mineral concentration in soybean flour compared to sorghum flour (Folashade Bolarinwa et al., 2016).

3.4 Fat Content

According to the biscuit quality requirements based on SNI 01-2973-2011, the minimum fat content in crackers is 9.5% and all formulations have exceeded the minimum fat content requirements. The highest fat content is found in F3 with a fat content of 9.55% with a soybean flour formulation of 20 grams which is more than other formulations. Sorghum flour is rich in fiber and antioxidants and is gluten-free, but tends to produce a crumblier texture when used alone. The addition of soy flour increases the protein and healthy fat content and imparts a distinctive savory flavor, but can also make the texture denser or chewier if not balanced properly. Wheat flour, which contains gluten, acts as a natural binder and helps form a firm, crunchy structure in crackers. The combination of the three allows for the development of high-protein crackers with a texture that remains crunchy and stable, while enhancing the overall nutritional profile. However, proper formulation is essential to balance the functional and sensory characteristics of the three ingredients.

According to Khumaini (2022), the fat content of mung beans (1.5%) is greater than wheat (1%), so the more mung bean substitutions, the more fat is contained in it. In addition to F3, the highest fat content was observed in formulation F4, which contained 30 grams more sorghum flour compared to the other formulations. This finding aligns with studies by Akajiaku et al. (2017) and Pasune et al. (2019), which reported that increasing the amount of sorghum flour in food products, such as noodles, leads to a rise in fat content. From the results obtained, it is known that only F3 and F4 meet the quality requirements of crackers crackers based on SNI. Factors that affect the fat content in biscuits come from raw materials such as the use of margarine in their manufacture. According to Milkesa (2020), biscuits made from a composite of sorghum and soybean flour contain approximately 3.6% fat. The study further demonstrated that incorporating higher amounts of red bean or soybean flour into rice-based mixtures led to an increase in fat content.

3.5 Protein Content

The protein levels in the biscuit formulations are directly influenced by the amounts of sorghum and soybean flour incorporated. In addition, wheat flour also plays an important role in making high-protein crackers because it contains gluten, a protein that provides structure and elasticity to the dough. In high-protein products, wheat flour helps maintain the density and stability of the structure when adding other protein ingredients such as soy flour, bean flour, or vegetable animal protein. Gluten from wheat flour forms an elastic network that traps gas during baking, resulting in a crispy and non-crumbling cracker texture. However, the proportion of wheat flour needs to be adjusted in a balanced manner so as not to reduce the total protein content, while maintaining the taste, crispiness, and final characteristics of the product.

An increase in sorghum flour content generally corresponds to a rise in protein levels. The highest protein content, 7.66%, was observed in F3, while a decrease was noted in F4 as soybean flour was excluded. The observed rise in protein content across the cracker samples indicates that all formulations qualify as a good protein source. This is supported by analytical results showing that each formulation meets the minimum protein requirement of 5% as stated in the SNI 01-2973-2011 standard.

Protein ranks as the second major constituent in sorghum grains, accounting for approximately 15% of the seed content. However, its concentration is influenced by both genetic factors and environmental conditions. Protein in sorghum can be separated into albumin, kafirin, globulin, prolamin and glutelin fractions. In the germination process, starch and proteins undergo hydrolysis, resulting in the formation of soluble sugars and free amino acids. These transformations are facilitated by the enzymatic actions of amylase and protease. Sorghum seeds are known to contain key amino acids such as threonine, methionine, phenylalanine, lysine, and tryptophan (Majzoub et al., 2023).

The inclusion of soybean flour, which has a protein content of 15.30%, contributed to the higher protein levels in formulations F3, F2, and F1, surpassing the protein contribution from sorghum flour, which contains 11.38% protein (Nour et al. 2015). Improved nutritional value in legume crackers is also evidenced by the enrichment of key essential amino acids such as lysine, threonine, and tryptophan, due to legume flour addition, while maintaining adequate levels of sulfur amino acids. The results of the study by Sparvoli et al., (2015) it was also found that the inclusion of cereals in the composite flour led to a decrease in the protein content of the crackers. This shows that legumes have a higher average protein content than cereals such as sorghum.

Sorghum is a promising food crop with strong potential for development in Indonesia. It serves as a viable alternative to wheat flour in supporting local food diversification initiatives. Nutritionally, sorghum comprises approximately 70% carbohydrates, 8–12% protein, and 2–6% fat (Kurniasari et al., 2023). This influences the protein levels in formulations containing a combination of wheat and sorghum flour, as seen in F1, F2, and F3, which exhibit relatively high protein content. Several studies have indicated that the incorporation of processed soybean flour alongside wheat flour and other ingredients contributes to increased protein content, with higher amounts of soybean flour resulting in greater protein levels. Soybean flour contains a significantly higher amount of protein compared to wheat flour, with approximately 23.1 grams of protein (Salsabila et al., 2023).

3.6 Carbohydrate Content

The addition of sorghum flour and wheat flour in food processing, such as baking or heating, significantly affects carbohydrate reactions, especially in terms of starch gelatinization, browning (Maillard reaction and caramelization), and glucose availability. Sorghum flour contains starch that tends to have a higher gelatinization temperature and is more resistant to heat damage than wheat flour, because its structure is denser and does not contain gluten. In contrast, wheat flour which is rich in gluten produces a more elastic dough structure, allowing the starch to gelatinize more evenly during heating. In the Maillard reaction, the reducing sugar and protein content of the two flours will interact, especially at high temperatures, producing a brownish color and distinctive aroma. Sorghum also has phenolic compounds that can affect Maillard reactivity and inhibit starch-degrading enzymes, thereby reducing the glycemic index of the final product. Thus, the combination of these two flours in processing will determine the texture, color, taste, and nutritional value of the product through the chemical reactions of carbohydrates that occur during the thermal process. The carbohydrate content test showed that the carbohydrate content of F4 was 77.8%, F3 was 77.7%, F2 was 77.82%, F1 was 77.98%, and F0 was 78.08%. An increased proportion of sorghum and soybean flour in the crackers led to a reduction in the average carbohydrate content of the biscuits. This is attributed to the lower carbohydrate content in sorghum flour compared to wheat flour (77.3 g per 100 g of edible part) (Ministry of Health of the Republic of Indonesia, 2018).

A one-cup serving of sorghum provides approximately 143 grams of carbohydrates. The majority of these carbohydrates are stored as starch, accounting for about 70% of the grain, primarily located in the endosperm. Sorghum starch is composed of 40–50% amylose and 45–54% amylopectin. The content of starch components in sorghum affects its use in various types of food products. For example, to produce thick dough, high amylose levels are required. Conversely, to make complementary foods for children with low viscosity, low amylose levels and high amylase activity are required. According to SNI 01-2973-2011, the quality requirements for carbohydrate content in crackers are at least 70% so that the quality requirements for all cracker formulas have met the SNI standard for cracker quality.

4. CONCLUSIONS AND RECOMMENDATIONS

The incorporation of sorghum and soybean flours enhances the quality of the resulting crackers, and produces new products with high-quality nutritional content.

The optimal combination variation that produces crackers with good quality is F3 (sample with the most soybean flour) crackers, because this formulation provides an increase in protein content compared to crackers that do not or only add one of sorghum flour and soybean flour so that it can be an alternative for additional food for toddlers in Indonesia. It is recommended that these crackers be further fortified with other important nutrients such as iron, zinc, and vitamin A, which also play a role in preventing stunting.

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