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Effect of *Sorghum bicolor L.* and *Moringa oleifera* Leaf Flour Substitution on the Nutritional and Organoleptic Quality of Snack Bars for Type 2 Diabetes Mellitus Patients

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Abstract: According to the International Diabetes Federation (IDF), the prevalence of type 2 diabetes mellitus (DM) had increased from 10.5% in 2021 to 11.1% in 2025. The need for the development of functional foods can support dietary management in diabetes sufferers. The purpose of this study was to analyze the effect of substituting sorghum flour and moringa leaf flour on nutritional quality (moisture, ash, protein, fat, carbohydrate content, and energy), organoleptic quality (color, aroma, taste, and texture), and functional quality (fibre and antioxidant activity) of snack bars for type 2 diabetics. This study used a Completely Randomized Design (CRD) using three levels of treatment with the following proportions of sorghum flour to moringa leaf flour: P1 (85:15), P2 (90:10), and P3 (95:5). A total of 25 semi-trained panelists were selected using a purposive sampling technique. Data's were analyzed using One-Way ANOVA for nutritional parameters and functional quality, Kruskal Wallis test for organoleptic data with a 95% confidence level. The results showed that the substitution of sorghum flour and moringa leaf flour had a significant effect on protein, fibre, and snack bar taste ($p<0.05$). However, it had no significant effect on moisture, ash, fat, carbohydrate, color, aroma, texture, or antioxidant activity of snack bars. It was also found that the best treatment level was P3 (95:5). The snack bar formulation based on sorghum and moringa leaves has the potential to be developed as a low glycemic index functional food that supports diet management in type 2 DM patients.

Keywords: moringa leaf flour, sorghum flour, snack bar, type-2 diabetes mellitus, functional food

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INTRODUCTION

Diabetes is one of the diseases whose prevalence is rising each year. The International Diabetes Federation (IDF) estimates that 526.6 million people (10.5%) had type 2 diabetes mellitus in 2021, and 589 million people (11.1%) are projected to have the condition in 2025. The IDF expects that the percentage of people in 2045 with type 2 diabetes mellitus would increase to 12.2%. In Indonesia, according to the Indonesian Health Survey, the prevalence of diabetes mellitus in 2023 was 11.7%. Specifically in East Java province, there is also an increase in people with diabetes mellitus. There were 842,004 people in 2022, and the number rose to 859,187 in 2023 (Dinas Kesehatan Jawa Timur, 2022, 2023).

Type 2 diabetes mellitus accounts for approximately 90% of diabetes types (Milita et al., 2021). The significant number of people with type 2 diabetes mellitus arises due to several factors, such as a change in lifestyle, ignorance to perform early diagnosis of type 2 diabetes mellitus, lack of physical activity, and poor diet planning (Murtiningsih et al., 2021). Methods are utilized in the management of diabetes, including education, Medical Nutrition Therapy (MNT), physical exercise, pharmacological treatment, type 2 diabetes management, and diabetes control. Treatment of diabetes mellitus focuses primarily on medical nutrition therapy, or eating plans, to ensure that blood sugar levels remain within normal limits and are near normal, thereby preventing rapid rises in blood sugar (Perkeni, 2021).

The focus of the eating habits of people with diabetes mellitus is on the right type, amount, and schedule. The appropriate food ingredients for people with diabetes mellitus are those with a low Glycemic Index (GI) and high fibre content. Sorghum is a low glycemic index food ingredient with a glycemic index of 43. Besides having a low glycemic index, sorghum is rich in vitamins, minerals, and food polyphenols, including anthocyanins and tannins (Mukai & Kataoka, 2019). Anthocyanins are antioxidants with antihyperglycemic, antimutagenic, hepatoprotective, and antihypertensive functions. Anthocyanins can also suppress multiple free radicals that lead to oxidative stress (Daeli & Ardiaria, 2018). Diabetic rats treated with sorghum flour exhibit a reduction in fasting blood sugar levels. Low GI makes carbohydrates degrade slowly, thereby reducing insulin requirements and increasing insulin sensitivity (Dewi et al., 2020).

Several related studies have also demonstrated the potential of sorghum as a functional food ingredient for managing metabolic diseases. Sorghum-based diets have been shown to lower fasting blood glucose levels and improve insulin sensitivity in people with diabetes (Mahdi et al., 2024). Sorghum's bioactive compounds, such as phenolic acids, flavonoids, and anthocyanins, have antioxidant and anti-inflammatory activities that help control blood glucose (Li et al., 2022).

High fibre levels also affect blood glucose levels in people with diabetes. Blood glucose levels in hyperglycemic mice. There is also a delay in glucose diffusion and a decrease in amylase activity due to the increased viscosity of intestinal contents and decreased, transit time, resulting in short glucose absorption. Additionally, it affects the increase in insulin secretion and glucose utilization by liver cells (Daeli & Ardiaria, 2018).

One of the food ingredients that has high fibre is moringa leaves. The fibre content in moringa leaves is 0.9 grams, while in moringa leaf flour, it is 19.2 grams (Gopalakrishnan et al., 2016). Decrease in blood glucose levels in diabetic patients after they are given moringa leaf decoction. Moringa leaves contain beta-carotene, a precursor to vitamin A, as well as antioxidants that protect the body from free radical attacks and various diseases (Age, 2021). Additionally, moringa leaves contain vitamin C, which helps normalize insulin levels in diabetics, and vitamin E, which helps prevent the development of diabetes. The levels of beta-carotene, vitamin C, and vitamin E in moringa leaves are reported at 24735 μg/100 g, 220 mg, and 448 mg, respectively (Bidura et al., 2020; Gopalakrishnan et al., 2016).

Moringa oleifera supplementation can improve oxidative balance and glucose metabolism. Research by Rakkini et al. (2024) explains that moringa polyphenols can significantly increase antioxidant enzyme activity, while Paula et al. (2017) found hypoglycemic effects in moringa-based food products.

The complications of diabetes are linked to oxidative stress. Oxidative stress is a state characterized by an elevated level of free radicals, an altered antioxidant defense system, or both (Prawitasari, 2019). Antioxidants, like sorghum and moringa leaves, help prevent free radicals from forming in cells. They also improve the enzymes that protect against these radicals. Sorghum flour has a vigorous antioxidant activity with an IC50 of 88.89 ppm (Antari et al., 2021). Meanwhile, the antioxidant activity of moringa leaves is categorized as quite strong, with the value of 49.30 ppm (Purnama et al., 2021).

In this study, sorghum and moringa leaves were formulated as snack bars for people with diabetes. Snack bars were selected because they were easy to carry and eat. They did not require a specific environment for consumption. Instead, they offered utility, contained full nutrients, and could be incorporated into foods that lasted long when stored.

Although numerous studies have been conducted on sorghum and moringa leaves, they have focused on their single use rather than their combined use. This study addresses this scientific gap by evaluating the synergistic effects of sorghum flour and moringa leaf flour combinations at various ratios to optimize nutritional, sensory, and functional properties simultaneously. Based on this description, this study aims to analyze the effect of sorghum flour and moringa leaf substitution on the nutritional, organoleptic, and functional qualities of snack bars for people with type 2 diabetes mellitus.

METHODS

Design, Time, and Place

The research design of this study was a quasi-experimental study. The snack bar was prepared at the Food Ingredient Science Laboratory of the Malang Ministry of Health Polytechnic. The final test, carried out on the organoleptic test, was performed in the Taste Testing Laboratory of the Health Polytechnic, under the Ministry of Health in Malang. The moisture, ash, and fat content were measured at the Tabling Laboratory of the Research Institute of Various Crops of Nuts and Tubers. Protein level, fibre content, and antioxidant activity were tested at THP-FTP Quality and Food Safety Testing Laboratory, Brawijaya University. The study period spanned from November 2022 to June 2023. This study was designed using a Completely Randomized Design (CRD) with three treatments

(P1, P2, and P3) and three replications. The RAL was chosen because it was considered capable of maintaining homogeneity of experimental conditions.

Experimental Design

This study employed a Completely Randomized Design with three levels of treatment. Each level of treatment was carried out three times, resulting in a total of nine experimental units. The design of the snack bar formulation was based on the dietary guidelines of DM Perkeni (2021) for fat, carbohydrate, and fibre content, as well as those of Perkeni (2015) for protein content, in addition to meeting the nutritional needs of a 10% diet. The snack bar formulation in the study consisted of sorghum flour and moringa leaf flour in proportions of 85:15, 90:10, and 95:5. The organoleptic test included a hedonic test using 25 semi-trained panelists.

Sorghum flour (Sorghum bicolor L.) and Moringa leaf flour (Moringa oleifera) were sieved using a 60-mesh sieve to achieve uniform particle sizes. The snack bar formation process involved mixing the dry ingredients, adding a dark chocolate binder, molding the dough, and baking for 15 minutes. After cooling, the product was stored in a sealed container. Treatment P3 (95:5) served as a baseline control for comparison with the other two substitution ratios.

Subjects and Sampling Technique

Organoleptic testing was conducted on 25 semi-trained panelists selected using a purposive sampling technique. Inclusion criteria for this study were non-smokers, no allergies to plant-based ingredients, and normal taste perception. All participants provided informed consent prior to the test.

Measurement Instruments and Procedures

This study used physical and chemical instruments to measure the nutritional and functional quality of the snack bars, as well as organoleptic instruments to assess quality. Protein content was determined using the semimicro Kjeldahl method (AOAC 981.10), fat content was analyzed using the Soxhlet extraction method (AOAC 920.39), moisture content was measured using the oven method (AOAC 925.10), and ash content was determined using an electric furnace or muffle furnace (AOAC 923.03). Carbohydrate content was calculated using the difference method, and energy value was determined using the Atwater conversion method. Crude fiber content was analyzed using the gravimetric method, while antioxidant activity was measured using the DPPH radical scavenging method using a UV-Vis spectrophotometer at a wavelength of 517 nm to obtain the IC_{50} value. Organoleptic testing was conducted using a hedonic test sheet with a rating scale of 1 to 5, where a score of 1 indicates "very dislike" and a score of 5 indicates "very like."

Data Processing and Analysis

Analysis of the nutritional value of snack bars used various methods, including protein content determined by the semimicro Kjeldahl method, fat content by the direct extraction method with Soxhlet, moisture content through the oven method, ash content using the electric kiln method, carbohydrate content by different methods, energy value with the Atwater method, fibre content with the gravimetric method, antioxidant activity through the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, and organoleptic quality assessed with the hedonic scale test by a panel of 25 moderately trained individuals.

All measurement procedures followed AOAC standards and were repeated three times to ensure reliable results. Prior to analysis, data were tested for normality using the Shapiro-Wilk and Levene homogeneity tests. Data processing of nutritional value (energy, protein, fat, carbohydrate, water, and ash content) and functional quality (fibre content and antioxidant activity) was analyzed using the One-Way ANOVA test at a 95% confidence level. Meanwhile, organoleptic quality data (color, aroma, taste, and texture) were analyzed using the Kruskal-Wallis test at a 95% confidence level. Data were analyzed using IBM SPSS Statistics version 26.

RESULTS AND DISCUSSION

Nutritional Value Analysis

The results of the nutrient content analysis are presented in Table 1. Each sample was analyzed for its energy value, macronutrients (carbohydrates, proteins, and fats), moisture content, and ash content. The results of the nutrient content analysis were based on 100 grams of snack bar products.

Table 1

Nutritional value per 100 grams of product (Mean±SD)

Parameters	P1	P2	P3
Energy (Kcal)	437.7 ± 10.56^a	436.7 ± 5.37^a	444.6 ± 1.05^a
Carbohydrate (%)	70.50 ± 1.69^a	70.51 ± 1.24^a	71.26 ± 0.72^a
Protein (%)	10.56 ± 0.30^a	9.67 ± 0.21^b	9.33 ± 0.13^b
Fat (%)	12.61 ± 1.87^a	12.88 ± 0.91^a	13.58 ± 0.30^a
Fibre (%)	5.63 ± 0.25^a	5.03 ± 0.98^b	4.9 ± 0.10^b
Antioxidant activity (ppm)	37.94 ± 11.94^a	55.98 ± 21.72^a	68.77 ± 12.57^a
Water content (%)	3.54 ± 0.70^a	4.07 ± 0.46^a	3.46 ± 0.40^a
Ash (%)	2.78 ± 0.27^a	2.85 ± 0.77^a	2.36 ± 0.09^a

Remarks: a, b similar letter notation meant that there was no real difference in the level of statistical tests (α=0.05)

Moisture Rate

The water content of snack bars at each treatment ranged from 3.46 to 4.07 g/100 g, as shown in Table 1. All values met the USDA Number 25048 requirement of less than 11.3%. The highest average was at P2 (4.07 g/100 g), and the lowest was at P3 (3.46 g/100 g). A One-Way ANOVA (95% confidence) revealed no significant effect of sorghum and moringa flour proportions on moisture content ($p = 0.378$), indicating similar moisture content across treatments.

The moisture levels of the constituent ingredients also influence the moisture content of the snack bars. It is supported by previous research that Sorghum flour contains 10.29% moisture (Cahyadi et al., 2018), which is higher than the 6.64% moisture content of moringa leaf flour (Kurniawati et al., 2018). Additionally, fibre content affects water adsorption. Materials with higher fibre content can adsorb more water, as noted by (Cahyadi et al., 2018). Moringa leaf flour has a fibre content of 19.2 g/100 g of ingredients (Kumari et al., 2021), while sorghum flour has a fibre content of 4.11 g/100 g.

Ash Rate

Analysis of three treatment levels indicated that the ash content of snack bars ranged from 2.36 to 2.85 grams per 100 grams of product, as shown in Table 1. The highest average ash content was observed in P2 at 2.85 grams per 100 grams, while the lowest was found in P3 at 2.36 grams per 100 grams. One-Way ANOVA at a 95% confidence level demonstrated that the proportion of sorghum flour and moringa leaf flour did not significantly affect the ash content of snack bars ($p = 0.443$). Therefore, the ash content remained statistically consistent across all treatment levels.

The higher ash content of snack bars is due to a higher percentage of moringa leaf flour. It is attributed to the fact that moringa leaf flour contains more ash than sorghum flour. The ash content of moringa leaf flour is 11.67 g /100 g, whereas the sorghum flour is 2.24 g /100 g (Kurniawati et al., 2018; Waqiah et al., 2019).

Protein Levels

Analysis of three treatment levels indicated that the protein content of snack bars ranged from 9.33 to 10.56 grams per 100 grams, as shown in Table 1. The highest protein content was observed in P1 at 10.56 grams per 100 grams, while P3 exhibited the lowest value at 9.33 grams per 100 grams. One-Way ANOVA at a 95% confidence level demonstrated that the proportions of sorghum flour and moringa leaf flour significantly affected protein content ($p=0.002$). The Duncan Multiple Range Test identified significant differences between P1 and P2, and between P1 and P3, but not between P2 and P3.

The amount of protein in snack bars had not met the standards set by Perkeni (2015) . The study had reduced the amount of protein in the snack bars, which was calculated empirically. Lowering the protein level is related to the denaturation of proteins heated above their denaturation temperature. Protein denaturation refers to the transformation of protein molecules without dissociating their covalent bonds. Therefore, heat treatment during the processing can enhance the storage of proteins and their digestibility (Hidayah et al., 2020).

The amount of moringa leaf flour determines the increased protein content. The more moringa leaf flour is used, the richer the snack bar is in protein. Moringa leaf flour contains 27.1 g/100 g, more than sorghum flour, which includes 8.39 g/100 g. Proteins and amino acids are modulators of glucose and can increase gluconeogenesis. In short-term studies, researchers have found that high-protein foods have a favorable impact on glucose homeostasis (Rudijanto et al., 2018).

Fat Levels

Analysis of three treatment levels indicated that the fat content of snack bars ranged from 12.61 to 13.58 grams per 100 grams, as shown in Table 1. The highest average fat content was observed in P3 at 13.58 grams per 100 grams, while the lowest was found in P1 at 12.61 grams per 100 grams. One-Way ANOVA at a 95% confidence level showed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the fat content of snack bars ($p = 0.623$). It indicated that the fat content of snack bars in each treatment was quite similar.

The fat content of the development snack bar per serving in this study exceeded the standard fat content according to Perkeni (2021), which was 5.83 grams (higher than the standard range of 4.6-5.83 grams), as shown in Table 2 below. The fat content in the snack bar remained relatively consistent across all treatments because the fat sources were the same. Fat sources in snack bars included eggs, dark chocolate, and margarine.

Table 2

Nutritional value of P3 snack bars on the snack needs of DM patients (Perkeni, 2021)

Nutritional value	Daily necessities (Perkeni, 2021)	Snack needs 10% of energy	Serving size (43 g)	Percentage of fulfillment (%)	Percentage of fulfillment from energy (%)
Energy	2100 kcal	210 kcal	191.19 kcal	91.04	-
Protein	10-20% of the energy	5.25-10.50 g	4.01 g	-	8.39
Fat	20-25% of energy	4.67-5.83 g	5.83 g	-	27.48
Carbohydrates	45-65% of energy	23.62-34.12 g	30.64 g	-	64.1
Fibre	20-35 g	2-3.5 g	2.10 g	105	-

The fat content in moringa leaves was higher than in sorghum flour. The increased fat content in snack bars correlates with a higher proportion of sorghum flour. Although moringa leaf flour had a higher fat content than sorghum flour, its small proportion in the snack bars minimized its impact on the overall fat content of the product. Moringa leaf flour contained 12.5 g/100 g of fat, while sorghum flour contained 0.81 g/100 g.

Eating high-fat food increases the risk of obesity. Obesity stimulates inflammatory activity and metabolic disorders, which in turn enhance oxidative stress. Long-term oxidative stress leads to cell and tissue damage, manifesting in the onset of degenerative diseases, such as diabetes mellitus (Susantiningsih, 2015).

Carbohydrate Levels

Analysis of three treatment levels indicated that the carbohydrate content of snack bars ranged from 70.50 to 71.26 grams per 100 grams, as shown in Table 1 above. The highest average carbohydrate content was observed in P3 at 71.26 grams per 100 grams, while the lowest was found in P1 at 70.39 grams per 100 grams. One-Way ANOVA at a 95% confidence level revealed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the carbohydrate content of snack bars ($p = 0.723$). It indicated that the carbohydrate content of snack bars at each treatment level was relatively similar.

The higher carbohydrate content in snack bars is attributed to the use of sorghum flour as a substitute for wheat flour. Sorghum flour is a significant carbohydrate source, containing 86.76%, while moringa leaf flour contains 38.2% carbohydrates. Thus, the carbohydrate content of the developed snack bar per serving in this study met the standard carbohydrate content, as per Perkeni (2021), which was 30.64 grams, within the standard range of 23.62-34.12 grams, as presented in Table 2 above.

The relationship between carbohydrate intake and the incidence of type 2 diabetes mellitus. Carbohydrates are broken down and absorbed as monosaccharides, mainly glucose, which raises blood sugar levels and stimulates insulin production. In type 2 diabetes mellitus, the body is unable to store glucose properly and utilizes it in the tissues, leading to impaired glucose absorption and utilization despite adequate carbohydrate intake (Simanjuntak et al., 2022).

Sorghum is a carbohydrate in the form of fibre. Fibre will inhibit glucose absorption in the intestines, resulting in a low glycemic index. The proportions of amylose and amylopectin can influence the value of the glycemic index. High-amylose foods would be difficult to digest because the unbranched nature of amylose makes it too strong to bind, and it becomes harder to gelatinize than amylopectin, which is branched and has a bigger molecular size that is easier to gelatinize. Compared to rice flour, the sorghum flour content of amylose is greater. White sorghum flour also has amylose 19.59 and amylopectin 46.27 (Avif & Oktaviana, 2020).

Meanwhile, the portions of amylose and amylopectin in rice flour are 7.97% and 59.7%, respectively (Imanningsih, 2012). It indicates that it is harder to gelatinize sorghum flour since it contains high levels of amylose, thus making its glycemic index lower than that of sorghum flour. The enzyme α-amylase will digest the amylose compounds in the starch in a shorter time than amylopectin (Ardiansyah et al., 2018).

Energy Value

Analysis of three treatment levels indicated that the energy value of snack bars ranged from 436.7 Kcal to 444.6 Kcal per 100 grams, as shown in Table 1. The highest average fat content was observed in P3 at 444.6 Kcal per 100 grams, while the lowest was found in P2 at 436.7 Kcal per 100 grams. One-Way ANOVA at a 95% confidence level demonstrated that the proportion of sorghum flour and moringa leaf flour did not significantly affect the fat content of snack bars ($p = 0.723$). It showed that the energy value of snack bars in each treatment was quite similar.

Fat, protein, and carbohydrates are the elements that contribute to calculating the total energy. Protein and carbohydrates contribute 4 Kcal/gram of energy, whereas fat contributes 9 Kcal/gram. The total energy content of the snack bar (P3) was the largest, equaling 444.6 kcal/100g. It is because P3 contains the highest average fat content, resulting in a high value of donated energy. As presented in Table 2, the energy content of snack bars per serving met the standard for carbohydrate value, which was 191.19 grams against the standard of 210 grams; this indicated that it met 91.04% of the nutritional needs. Compared to the USDA standard, the energy content of the development snack bar was still higher, at 444.65 grams per 100 grams of product, versus the standard of 403 grams per 100 grams of product, as indicated in Table 4.

The consumption of high-energy foods is linked to blood sugar levels. The energy delivered in high-energy foods that is not utilized in long-term activities can contribute to the development of obesity, insulin resistance, and type 2 diabetes mellitus. Overconsumption of high-energy foods stimulates insulin resistance by increasing blood glucose and blood free fatty acid concentration (Fariqi & Yunika, 2021).

Functional Quality Analysis

The results of functional quality analysis are presented in Table 3. Each sample was analyzed for fibre levels and antioxidant activity. The nutritional content is based on 100 grams of snack bar products.

Table 3

Nutrient content per 100 grams of product (Mean±SD)

Parameters	P1	P2	P3
Fibre content (%)	5.63 ± 0.25[a]	5.03 ± 0.98[b]	4.9 ± 0.10[b]
Antioxidant activity (ppm)	37.94 ± 11.94[a]	55.98 ± 21.72[a]	68.77 ± 12.57[a]

Remarks: a, b similar letter notation meant that there was no real difference in the level of statistical tests (α=0.05)

Fibre Rate

Analysis of three treatment levels indicated that the fibre content of snack bars ranged from 4.9 to 5.63 grams per 100 grams, as shown in Table 1. The highest protein content was observed in P1 at 5.63 grams per 100 grams, while P3 exhibited the lowest value at 4.9 grams per 100 grams. One-way ANOVA at a 95% confidence level demonstrated that the proportions of sorghum flour and moringa leaf flour significantly affected protein content ($p = 0.005$). It indicated that the fibre content varied at each treatment level. Based on the Duncan Multiple Range Test follow-up test results, a significant difference was observed between P1 and P2, as well as between P1 and P3. However, there was no significant difference between P2 and P3.

The increasing substitution of moringa leaf flour causes the higher fibre content in snack bars. Moringa leaf flour's fibre content is higher than that of sorghum flour. Moringa leaf flour has a fibre content of 25 g/100 g of ingredients (Ardiansyah et al., 2018), while sorghum flour has a fibre content of 4.11 g/100 g.

Fibre is a part of plants with properties that are resistant to digestion and absorption in the human small intestine and can undergo partial or complete fermentation in the large intestine. Fibre that is still intact will be fermented by bacteria in the colon forming SCFA (Short-Chain Fatty Acids), a type of short-chain fatty acid. The formation of SCFA induces the secretion of the hormones GLP-1 (Glucagon-Like Peptide-1), GIP (Gastric Inhibitory Polypeptide), and PYY (Peptide YY), which will increase insulin sensitivity and cause a decrease in blood glucose levels (Simanjuntak et al., 2022).

Some foodstuffs that contain insoluble fibre would include sorghum and moringa leaves. The insoluble fibre content in sorghum ranges from 75 to 90 per cent (Khalid et al., 2022), where as in moringa leaves, it is 29.09-41.23 percent (Badejo et al., 2018). Both water-insoluble and soluble fibres are helpful in diabetes mellitus. Gastric emptying may be blocked by water-soluble fibre. Besides a steady reduction of postprandial glucose, the glycemic index can also be reduced. Water-insoluble fibre may prolong intestinal transit time, consistently lower insulin resistance, and minimize the risk factors associated with type 2 diabetes mellitus. Findings from a large-scale prospective cohort study indicate that consuming insoluble fibre-rich foods can reduce insulin resistance by 20-30% (Weickert

& Pfeiffer, 2018), and consuming developed snack bars can also lower insulin resistance. Results from a large-scale prospective cohort study indicate that consuming foods high in insoluble fibre can reduce insulin resistance by 20-30% (Weickert & Pfeiffer, 2018), suggesting that consuming developed snack bars may potentially minimize insulin resistance.

Antioxidant Activity

Analysis of three treatment levels indicated that the antioxidant activity of snack bars ranged from 37.94 to 68.77 ppm, as shown in Table 2 above. The highest average antioxidant activity was observed in P3 at 68.77 ppm, while the lowest was found in P1 at 37.94 ppm. One-Way ANOVA at a 95% confidence level revealed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the fat content of snack bars ($p = 0.139$). It indicated that the energy value of snack bars in each treatment was quite similar.

The antioxidant activity could be enhanced by a higher sorghum flour fraction. Sorghum flour has greater antioxidant activity than moringa leaf flour. Antioxidant activity of sorghum flour has an IC50 of 88.89 ppm (Antari et al., 2021), while moringa leaf flour has an IC50 of 49.30 ppm (Purnama et al., 2021). The antioxidant activity of P2 and P3 in this study could be classified as a compound with a potent antioxidant activity (IC50 value 50-100). Meanwhile, the antioxidant activity of P1 was characterized as very strong (IC50< 50). The antioxidant activity was higher when the IC50 value was lower.

The compounds in moringa leaf flour that contribute to antioxidant activity are vitamin C, beta-carotene, phenols, tannins, steroids, triterpenoids, flavonoids, saponins, interquinones, and alkaloids, while in sorghum flour are carotene, flavonoids, phenols, tannins, protocatechuic acid, and taxifolin. The administration of antioxidants aims to inhibit the production of intracellular free radicals or enhance the ability of defense enzymes to combat free radicals, thereby helping to prevent the development of oxidative stress and diabetes-related vascular complications (Ardianti et al., 2019). According to Mahargyani (2019), the stronger the antioxidant activity, the more effective its inhibition of the enzyme α-glucosidase, which delays the rise in blood glucose and thereby decreases blood glucose levels. The antioxidant activity in P1 was classified as very strong, while P2 and P3 were classified as strong. This classification suggested that it had the potential to inhibit enzyme activity and lower blood sugar levels.

Organoleptic Quality Analysis

The results of the organoleptic quality test, which encompassed color, aroma, taste, and texture, are presented in Table 4. Twenty-five semi-trained panelists conducted the organoleptic quality assessment.

Color

Color is one of the parameters that determines product quality. Visually, color is a key factor in determining the acceptance of a product. The average level of panelists' preference for snack bar colors at each treatment level was at a level of liking of 2.92–3.04 (likes). The results of Kruskal-Wallis' statistical analysis at a 95% confidence level showed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the color of the snack bars (p = 0.846). It indicated that the snack bar's color at each treatment level was relatively the same.

The flakes produced from the baking process using a Semprong cake mold at each level of treatment had an increasingly green color along with the addition of moringa leaf flour. It is because moringa leaf flour has natural chlorophyll pigments derived from moringa leaves. However, the snack bar products produced visually had a similar color, namely dark chocolate, because the flakes were bound with dark chocolate.

Table 4

Average hedonic test results (Mean±SD)

Parameters	P1	P2	P3
Color	2.96±0.72 [a]	3.04±0.77 [a]	2.92±0.74 [a]
Aroma	2.60±0.69 [a]	3.00±0.69 [a]	3.04±0.82 [a]
Taste	2.88±0.71 [a]	2.92±0.74 [a]	3.60±0.63 [b]
Texture	3.08±0.74 [a]	2.76±0.65 [a]	2.88±0.65 [a]

Remarks: a, b similar letter notation meant that there was no real difference in the level of statistical tests (α=0.05)

Aroma

Scent can be defined as something acceptable to the sense of smell. Aroma can serve as an indicator of damage to the product resulting from heating or improper storage methods. The aroma of food can indicate the deliciousness of the food product. The average level of preference for the aroma of snack bars in this study at each treatment level was 2.60–3.04 (likes). The results of Kruskal-Wallis' statistical analysis at a 95% confidence level showed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the aroma of the snack bars (p = 0.076). It indicated that the aroma of snack bars at each level of treatment was relatively the same.

The panelists' preference for the aroma of snack bars increased as the amount of moringa leaf flour decreased. It is because, naturally, moringa leaf flour has a languorous aroma. The higher the addition of moringa leaf flour, the more sluggish the aroma of the snack bar becomes. However, the lingering aroma of moringa leaf flour was minimized with the scent of dark chocolate. This finding aligns with research by Supriyanto et al. (2022), which suggests that the higher the proportion of moringa leaf flour, the more undesirable the aroma of the snack bar becomes and the stronger the lanolin aroma.

Taste

Taste is the most crucial parameter in product acceptance. The average level of preference for the snack bar's taste among panelists at each treatment level was 2.88–3.60 (ranging from 'like' to 'very like'). The results of Kruskal-Wallis' statistics at a 95% confidence level showed that the proportion of sorghum flour and moringa leaf flour significantly influenced the taste of snack bars (p = 0.001). It showed that the taste of snack bars at each level of treatment was authentic. Based on the follow-up test results, the Mann-Whitney test revealed a significant difference between P1 and P3, as well as between P2 and P3, while no significant difference was found between P1 and P2.

The panelists' preference for taste increased as the addition of moringa leaf flour decreased. It is because moringa leaf flour typically contains tannins. Tannins can cause a bitter taste when consumed because they form cross-links with proteins or glycoproteins in the oral cavity, which is consistent with other research findings by Ardianti et al. (2019). It shows that the higher the proportion of moringa leaf flour, the more undesirable the product becomes. Although flake produces a slightly bitter taste, this bitterness can be masked by the sweet flavor of dark chocolate, allowing panelists to accept the product.

Texture

Texture is one of the key parameters that can significantly impact a product's taste. The average level of panelists' preference for the texture of snack bars at each treatment level was 2.76–3.08 (likes). The results of Kruskal-Wallis' statistical analysis at a 95% confidence level showed that the proportion of sorghum flour and moringa leaf flour did not significantly affect the texture of the snack bars ($p = 0.282$). It indicated that the texture of snack bars at each level of treatment was relatively the same.

The snack bar's texture at each treatment level in this study was neither too dense nor too fragile. It was due to the proportion of dry ingredients (flakes) exceeding that of the binding material (dark chocolate). This finding aligns with research by Purnama et al. (2021) which suggests that an unbalanced proportion of dry and binding ingredients can lead to brittle snack bars.

Best Treatment

The effectiveness index method was used to determine the best treatment level in this study. The calculation showed that the optimal treatment level was P3 (95:5 %). P3 had the highest total yield value, which was 0.61. Table 5 below presents the characteristics of snack bars developed by P3, per 100 grams of snack bars, compared to product standards, which are also presented in Table 2 aforementioned.

Table 5

Characteristics of P3 snack bar per 100 grams compared to snack bar product standards

Characteristic	Snack Bar Development	USDA
Energy value (Kcal)	444.65	403
Carbohydrate content (g)	71.26	66.7
Protein content (g)	9.33	9.38
Fat content (g)	13.58	10.9
Moisture content (g)	3.46	11.26
Ash content (g)	2.26	1.72
Fibre content (g)	4.96	7.5
Antioxidant activity (ppm)	68.77	-
Color	2.88 (likes)	-
Aroma	3.04 (likes)	-
Taste	3.60 (very like)	-
Texture	2.92 (likes)	-

Description: USDA number 25048 on Nutri-grain fruit and nut bars

The findings of this study align with previous research, which found that sorghum flour can improve the nutritional quality of food products due to its high vegetable protein and fiber content (Puteri & Nurkhoeriyati, 2025). Moringa leaf flour contains high levels of protein, vitamins, and antioxidants, which can improve the functional properties of food products (Mahargyani, 2019). However, this study also confirmed that adding large amounts of moringa flour can reduce panelists' preference for taste and aroma due to its herbal and slightly bitter taste (Antari et al., 2021).

The organoleptic test results showed that the P3 (95:5) formulation was the most preferred by the panelists, especially in terms of taste and crunchy texture. These results are in line with Zuhra & Junita (2025) study that increasing the proportion of moringa flour in bread products increases nutritional value, but decreases the preference score for taste. This study provides empirical evidence that substitution of 5% moringa leaf flour in sorghum flour-based snack bar products is sufficient to improve nutritional and functional quality without reducing sensory acceptability. These findings strengthen the concept of synergistic functional substitution in food formulation science, where two natural ingredients can complement each other in terms of both nutritional value and characteristics.

The main strength of this study lies in the use of AOAC-standardized analytical methods. However, this study has limitations because it did not measure the glycemic index (GI) and nutrient bioavailability in vivo, which would provide a comprehensive picture of the product's metabolic effects on blood glucose levels.

CONCLUSION

The formula chosen in this study was snack bar P3, which consisted of a 95:5 ratio of sorghum flour and moringa leaf flour. The nutritional content of products related to type 2 diabetes mellitus is energy, carbohydrates, protein, fat, fibre, and antioxidant activity. The serving suggestion for the development snack bar is approximately 43 grams, equivalent to two snack bars, in one meal to meet the needs of 10% interludes. Based on the study's results, it was found that the protein content was lower, and the fat content exceeded the set standard. Therefore, it is necessary to have an advanced formulation so that the protein and fat content of snack bars meet the standard.

The results of this study indicate that the combination of sorghum and moringa leaves has a synergistic effect in improving the nutritional and functional quality of the product, with a 5% proportion of moringa leaves, while maintaining its flavor. Further research is recommended to conduct glycemic response and shelf-life tests to expand the functional validation of the snack bar.

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Author Contribution Statement

Fawwiz Aulya Amin: Conceptualization; Methodology; Experimenter; Data Analysis; Writing Original Draft. **Theresia Puspita:** Supervisor; Validation; Review & Editing. **Komang Suwita:** Supervisor; Validation; Review & Editing.

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