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Sorghum-Soybean Flour Enteral Formula Reduces Blood Glucose, Cholesterol, Triglycerides, LDL, and Increases HDL and Albumin in Hyperglycemic Rats

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Background: Diabetes mellitus prevalence is rising. Liquid feeding in the form of enteral formulas is needed to meet the nutritional needs of patients who cannot consume orally. The development of enteral formulas based on sorghum-soybean flour for diabetes mellitus patients, which has been nutritionally analyzed and adjusted to the requirements of enteral manufacturing, was selected for further *in vivo* research. This study evaluated the effect of the sorghum-soybean flour formula on fasting blood glucose (FBG), lipid profile levels, and albumin in hyperglycemic rats.

Materials and methods: This was a true experimental study with pre–post-test randomized control design. Wistar rats were divided into four groups: negative control group was normal rats and given standard feed only; positive control group was hyperglycemic rats and given standard feed only; treatment (T)1 and T2 groups were hyperglycemic rats given standard feed along with enteral formula at a dose of 4,41 g/day and 5,51 g/day for 28 days. Blood samples were collected to analyze FBG, albumin, low-density lipoprotein (LDL), high-density lipoprotein (HDL), triglycerides, and total cholesterol.

Results: There were differences in the levels of FBG, albumin, LDL, HDL, triglycerides, and total cholesterol before and after the intervention in groups T1 and T2. Group T1 showed an 8.12% decrease in FBG, while T2 showed a 29.89% decrease. Triglycerides decreased by 29.22% in T1 and 31.85% in T2; cholesterol decreased by 11.41% in T1 and 13.94% in T2. LDL levels decreased by 29.97% in T1 and 38.44% in T2. Albumin levels increased by 47.90% in T1 and 56.67% in T2. HDL levels increased by 23.94% in T1 and in 35.04% in T2.

Conclusion: Administration of an enteral formula based on sorghum-soybean flour can reduce FBG, triglycerides, total cholesterol, and LDL levels, and increase albumin and HDL levels in hyperglycemic rats.

Keywords: *hyperglycemia, enteral formula, albumin levels, fasting blood glucose, HDL, LDL, total cholesterol, triglycerides*

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Introduction

Diabetes mellitus (DM) is a metabolic disease whose cases are increasing both globally and in Indonesia. Based on global data from the International Diabetes Federation, the estimated number of DM cases in the world is expected to continue to increase, from 463 million in 2019 to 700 million in 2045. Based on data from the 2018 Basic Health Research in Indonesia, the prevalence of DM patients in Indonesia is 2%. This is higher than the 1.5% reported in 2013.[1]

Hyperglycemia is the main characteristic of DM. This condition occurs when blood glucose levels in the body exceed normal limits due to resistance to the insulin hormone.[2] Insulin dysfunction affects the metabolism of macronutrients in the body, one of which is protein. Insulin will prevent the breakdown of protein amino acids into glucose, which will be used to form adenosine triphosphate (ATP) energy, so that amino acids will directly produce ATP, which will cause inhibition of albumin synthesis.[3] Apart from albumin, insulin resistance in DM sufferers causes increased lipolysis in fat tissue, which causes low-density lipoprotein (LDL) cholesterol and total cholesterol levels to increase.[4] Another influence also occurs in the increased production of very low-density lipoprotein (VLDL) and free fatty acids (FFA), which are released into the blood vessels, which can trigger an increase in triglyceride production. As a result, HDL particles are susceptible to being broken down, causing HDL levels to decrease.[5]

DM patients with certain conditions, such as swallowing disorders or critical patients, are vulnerable to the risk of malnutrition. Fulfillment of nutrition is necessary to prevent malnutrition and complications of DM.[6] One attempt to achieve the nutritional needs of DM patients is the administration of enteral formula. Enteral formula is nutritional therapy given to patients orally or using a feeding tube. Enteral formula administration aims to achieve nutritional needs and act as a supplement.[7]

Many enteral formula product developments have been carried out. This is done as an alternative effort to fulfill enteral nutrition when compared to commercial formulas, which are less economical. In previous research, an enteral formula was developed for DM patients based on sorghum flour and soybean flour. Based on previous research results, the enteral formula with 120 grams of sorghum flour and 30 grams of soybean flour contains 1024.5 kcal of energy with an energy density of 1,024 kcal/mL, 65.37% carbohydrates, 11.09% protein, 23.53% fat, dietary fiber 18.83%, and glucose 4.13%.[8] Sorghum flour contains phenolic compounds, antioxidants, fiber and has a low glycemic index so it is good for consumption by DM patients.[9] Soybean flour contains a lot of nutritional value, such as a source of protein, essential amino acids that are low in saturated fat and cholesterol. Soybeans also contain fiber which can control cholesterol in the blood.[10]

Based on the description above, enteral formula products based on sorghum-soybean flour have the potential to provide hypolipidemia and hypoglycemia effects. In addition, research combining these two ingredients is still limited. Therefore, this study aims to determine the effect of administering an enteral formula based on sorghum-soybean flour on blood glucose levels, albumin, and lipid profiles (HDL, LDL, total cholesterol, and triglycerides) in Wistar rats with hyperglycemia.

Materials and methods

Study and Experimental Design

The research was a true experimental pre-clinical study utilizing a randomized pre-posttest with control group design. It was conducted under ethical approval from the Faculty of Medicine, Universitas Diponegoro (Ethics Committee No. 87/EC-H/KEPK/FK-UNDIP/VII/2023). The study commenced in June 2023 at two laboratories: Food Technology Laboratory of the Nutrition Study Program, Faculty of Medicine, Universitas Diponegoro and Research and Experimental Animal Laboratory of Universitas Muhammadiyah Semarang.

A total of 28 male Wistar rats aged 6-8 weeks with a body weight of 170-200 g were used in this study. The research included four groups: a negative control group (C-), a positive control group (C+) induced with streptozotocin (STZ)-nicotinamide (NA) to induce hyperglycemia where fasting blood glucose (FBG) ≥126 mg/dl without further treatment, and two treatment groups (T1 and T2), which were given STZ-NA induction, followed by treatment with enteral formulas containing sorghum-soybean flour.[11]

Hyperglycemic Induction

The study began with an adaptation phase for 7 days with subjects given standard food and drinking distilled water ad libitum during the adaptation phase. After adaptation, 45 mg/kgBB STZ and 110 mg/kgBB NA were induced intraperitoneally. Blood collection to determine the levels of fasting blood glucose (FBG), triglycerides, low-

density lipoprotein (LDL), total cholesterol, high density lipoprotein (HDL), and subject albumin was carried out after 5 days. If the glucose disposal rate (GDR) was ≥126 mg/dL (Hyperglycemic condition) then the rats could be given the intervention by adding the enteral formula.[11]

Preparation and Administration of Enteral Formula

This study used an enteral formula consisting of sorghum flour (Timurasa, Depok, Indonesia), soy flour, and mung bean flour (Gasol, Cianjur, Indonesia) along with extra virgin olive oil (Tropicana Slim, Jakarta, Indonesia), skim milk (Prolac, Deli Serdang, Indonesia), maltodextrin (Lihua Starch, Qinhuangdao, China), and sugar (Gulaku, Lampung Tengah, Indonesia), as well as a commercial enteral formula (Diabetasol, Jakarta, Indonesia). To prepare the formulas, the sorghum, soybean, and mung bean flours were first sieved using an 80-mesh sieve and then baked at 120°C to remove any unpleasant odors. The formulation process involved manually weighing and mixing dry ingredients such as sorghum flour, soybean flour, mung bean flour, skim milk, maltodextrin, and powdered sugar for 3 minutes, followed by the addition of extra virgin olive oil and further stirring for 2 minutes. The mixture was then homogenized using a mixer for 8 minutes to ensure uniformity. The nutritional content per 245 g of enteral formula consisted of 65.37 g carbohydrate, 11.09 g protein, 23.53 g fat, 18.83 g dietary fiber, and 4.13 g sugar.[8]

Group T1 was given with 4.41 g enteral formula and T2 was given with 5.51 g enteral formula. These two doses were diluted to 6 ml which was given 2 times a day (3 ml in the morning and 3 ml in the afternoon). This intervention was carried out for 28 days on the subjects. The research was carried out by observed to data on the body weight of rats which were weighed once a week, standard feed intake which was weighed every day, and the levels of FBG, triglycerides, LDL, HDL, cholesterol, albumin of rats before induction, after induction, and after intervention.

Measurement of Blood Glucose, Lipid Profile, and Albumin

FBG levels are measured using the glucose oxidase para-amino phenazone method. Cholesterol, HDL and LDL levels were measured using the cholesterol oxidase phenol amino phenazone method. Triglyceride levels were measured using the glycerol peroxidase phosphate acid method, and albumin levels were measure using the bromocresol green (BCG) method. Rats were first fasted for 12 hours before blood was taken from the retro-orbital plexus of their eyes by laboratory assistant of Research and Experimental Animal Laboratory, Universitas Muhammadiyah Semarang. The blood obtained was then centrifuged to obtain blood serum and examined at the Regional Health Laboratory, Semarang, Indonesia.

Statistical Analysis

The normality data was tested by Shapiro-Wilk because the data was normally distributed. The effect of intervention on FBG levels, HDL, LDL, total cholesterol, triglycerides and albumin lipid profiles was tested using the paired t-test to determine the effectiveness of administering enteral formulas based on sorghum flour and soy flour on FBG levels, HDL, LDL, total cholesterol, triglycerides, and albumin among groups using the ANOVA parametric test on normally distributed data and the non-parametric test Kruskall Wallis on data that was not normally distributed. On FBG level data, a further post hoc test was carried out using the Gabriel's post hoc test, while albumin, HDL, LDL, triglyceride, and cholesterol levels were used using the Duncan's post hoc test.

Results

Body Weight of Rats During Study

Based on the results, it was found that at the time of acclimatization, the body weight of rats (Table 1) was not significantly different between groups. However, before and after induction, the C+, T1, and T2 groups experienced a slight decrease in body weight, with an average decrease of 3 g across these 3 groups. Following the intervention, the group C+ experienced a decrease of 7 g, while groups T1 and T2 showed an increase in body weight, with an average of 14 g across these 2 groups.

Rat Feed Consumption

Rat feed consumption showed significant differences between groups during the intervention phase. During the intervention phase, the C- and C+ groups were fed solely with Comfeed AD II standard feed, with intake calculated as 10% (C- was 18.88±0.99 g and C+ was 16.24±0.98 g) of body weight. The T1 and T2 group were given standard feed *ad libitum* along with an enteral formula via probe. Feeding in the T2 (12.23±0.80 g) group had a lower rate compared to the T1 (18.88±0.99 g) group, as the dose of enteral formula administered was higher.

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Table 1. Rats' body weight of all groups during acclimatization, before and after STZ-NA induction, and after sorghum-soybean flour intervention.

Group	During Acclimatization (g)	Before STZ-NA Induction (g)	After STZ-NA Induction (g)	After Sorghum-Soybean Flour Intervention (g)
C-	195.29±5.38[a]	221.40±8.24[b]	237.01±9.75[b]	266.35±15.66[c]
C+	187.15±10.99[a]	202.38±13.26[a]	197.10±12.12[a]	190.23±16.65[a]
T1	183.60±8.08[a]	202.34±3.76[a]	201.40±10.67[a]	214.42±7.50[b]
T2	184.03±9.72[a]	205.32±9.49[a]	203.87±9.43[a]	218.23±16.65[b]
p -value	0.089[1]	0.004[1]	0.000[1]	0.000[1]

C-: Negative control; C+: Positive control; T1: Treatment 1; T2: Treatment 2; [1]One Way Anova test; [a.b.c]Different notations indicate significant differences in Duncan's test.

Sorghum-Soybean Flour Enteral Formula Reduced FBG

The FBG levels in C- group did not show a significant difference between C- in pre-intervention and post-intervention (Table 2, Table 3). However, FBG levels in C+ group showed a significant difference between C+ in pre-intervention and C+ in post-intervention. Before and after the intervention showed a significant difference in FBG levels in both the T1 group and T2 group. Before the intervention, the FBG levels in the C+, T1, and T2 groups indicated hyperglycemia (FBG levels: ≥126 mg/dL). T1 and T2 showed a decrease in FBG levels (Figure 1).

Sorghum-Soybean Flour Enteral Formula Reduced Cholesterol, Triglycerides, LDL and Increased HDL

Before the intervention, there were no differences in total cholesterol levels between groups. However, significant differences were observed in FBG, LDL, HDL, and albumin. Post-intervention, both groups T1 and T2 experienced a decrease in total cholesterol, with a significant reduction noted only in group T2. Both groups saw significant decreases in triglyceride levels and increases in HDL levels. LDL levels decreased significantly in both groups.

Sorghum-Soybean Flour Enteral Formula Increased Albumin Level

Albumin levels in the C group before and after the intervention did not show a significant difference (Table 3, Table 4). In contrast, albumin levels in the treatment group before and after the intervention showed a significant difference The albumin levels in the treatment group increased significantly after the intervention. There was no significant difference in the Delta (Δ) increase in albumin levels between T1 and T2 (Figure 1).

Discussion

In this study, the results showed that the enteral formula based on sorghum-soybean flour, which contains high fiber, improved the levels of FBG, total cholesterol, triglycerides, HDL, LDL, and albumin in the STZ-NA-induced rat model. Before STZ-NA-induction, the body weight of the rats in all groups was consistent and matched the research inclusion criteria (170-200 g). The results showed that the weight of the C- group increased from before to after induction because the rat's metabolism functioned normally, with energy primarily derived from glucose digestion. Fats that are not used as a source of energy are stored in fat tissue so that weight can increase.[12] In contrast, the weight of the T1, T2, and C+ groups tended to decrease after STZ-NA induction. This results in accordance with a previous study where the body weight of rats injected with 50 mg/kg STZ decreased by 7.89%.[13] When STZ is induced, it binds to glucose transporter, facilitating its entry into the cytoplasm of pancreatic cells. This causes depolarization in the mitochondria due to the influx of Ca^{2+} ions, followed by excessive energy usage resulting in a shortage of energy inside the cells. This mechanism causes insulin production to be disrupted, resulting in insulin deficiency, which causes all glucose consumed not to be processed perfectly, as a result of which FBG levels in the body can rise.[14]

Table 2. FBG, lipid profile and albumin levels of all groups pre- and post-intervention.

Biomarker	Group	Pre-intervention	Post-intervention	*p*-value
FBG (mg/dL)	C-	90.94 ± 9.57 [a]	99.22 ± 15.38 [a]	0.164 [#]
	C+	144.05 ± 14.74 [b]	118.41 ± 14.93 [ab]	0.019 [#]
	T1	142.62 ± 11.07 [b]	131.89 ± 8.70 [b]	0.007 [#]
	T2	149.48 ± 18.36 [b]	115.08 ± 14.34 [ab]	0.006 [#]
	p-value	0.000*	0.006*	
Total cholesterol (mg/dL)	C-	72.5±6.37	67.66±10 [1]	0.054 [#]
	C+	81.9±4.91	83.62±2.59 [1]	0.408 [#]
	T1	83.38±2.11	73.86±6.61 [1]	0.08 [#]
	T2	82.78±2.79	71.24±5.27 [1]	0.043 [#]
	p-value	0.106*	0.044*	
Triglycerides (mg/dL)	C-	50.37±12.15 [1]	52.98±8.71 [1]	0.698 [#]
	C+	79.53±19.4 [2]	88.58±16.2 [2]	0.007 [#]
	T1	87.54±20.68 [2]	61.96±30.03 [1]	0.003 [#]
	T2	89.56±14.14 [2]	61.03±21.22 [1]	0.00 [#]
	p-value	0.001*	0.028 [1]*	
HDL (mg/dL)	C-	44.14±4.45 [2]	42.71±4.96 [3]	0.082 [#]
	C+	26.83± 3.25 [1]	25.50±3.08 [1]	0.043 [#]
	T1	28.40±2.41 [1]	35.20±6.87 [2]	0.045 [#]
	T2	27.00± 5.10 [1]	35.83±3.66 [2]	0.010 [#]
	p-value	0.000*	0.000*	
LDL (mg/dL)	C-	15.300±6.154 [1]	14.304±8.161 [1]	0.664 [#]
	C+	31.652±3.338 [2]	30.884±3.790 [3]	0.770 [#]
	T1	31.072±4.778 [2]	21.760±4.270 [2]	0.001 [#]
	T2	30.880±6.253 [2]	19.008±2.635 [12]	0.017 [#]
	p-value	0.000*	0.001*	
Albumin (g/dL)	C-	3.16±0.12 [a]	3.18±0.16 [a]	0.826 [#]
	C+	2.07±0.09 [c]	2.37±0.38 [b]	0.105 [#]
	T1	2.28±0.05 [b]	3.38±0.40 [a]	0.000 [#]
	T2	2.20±0.13 [bc]	3.44±0.05 [a]	0.000 [#]
	p-value	0.000*	0.000*	

C-: Negative control; C+: Positive control; T1: Treatment 1; T2: Treatment 2; *One Way Anova test. [#]Paired t-test. [a.b.c]Different notations indicate significant differences in post hoc Gabriel's test. [1.2.3]Different notations indicate significant differences in Duncan's test.

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Table 3. Difference between pre- and post-intervention levels of FBG, lipid profile, and albumin levels of all groups.

Group	Δ FBG (mg/dL)	Δ Total cholestrol (mg/dL)	Δ Triglycerides (mg/dL)	Δ HDL (mg/dL)	Δ LDL (mg/dL)	Δ Albumin (g/dL)
C-	8.28 ± 13.82 [b]	-4.84±3.99[a]	2.61±3.1[a]	-1.43±1.81[a]	-0.99±4.76[a]	0.02±0.21[a]
C+	25.63 ± 18.41 [a]	1.72±4.16[b]	9.05±5.07[a]	-2.50±4.42[a]	1.23±5.17[a]	0.31±0.38[a]
T1	10.72 ± 4.78 [ab]	-9.52±6.8[a]	-25.58±11.54 [b]	6.80±5.26[b]	-9.31±2.21[b]	1.09±0.15[b]
T2	34.40 ± 18.09 [a]	-11.54±6.04[a]	-28.53±9.46[b]	8.83±5.31[b]	-11.87±6.78[b]	1.25±0.11[b]
p-value	0.000[*]	0.006[#]	0.00[1*]	0.001[#]	0.002[1*]	0.000[*]

Δ: Difference between pre- and post-intervention level; C-: Negative control; C+: Positive control; T1: Treatment 1; T2: Treatment 2; FBG: Fasting blood glucose; *One Way Anova Test, [#]Kruskal-Wallis test. [a.b.c]Different notations indicate significant differences in post hoc gabriel's test (FBG and albumin levels) and in Duncan test (Lipid profile).

Interventions are also being made to lower the FBG rate. The significant difference in the decrease of FBG rates among the rats can be attributed to the food fiber content: 18.83% in T1 group and 23.53% in T2 group. The amount of fiber consumed in T2 group is larger and differs significantly from T1 group, which could be a major cause of FBG decline in the subjects as well. Researchers have extensively studied the influence of food fiber supply on FBG rates. One study showed that high-fiber sorghum flour can significantly lower FBG levels in diabetic rats. Another study also showed the administration of 5 g of sorghum flour in hyperglycemic wistar rats reduced FBG from 267.06 mg/dL to 116.43 mg/dL in a 28-day in-vivo trial.[12] Meanwhile, the decrease in blood glucose levels in the positive control group after several days of research until entering the intervention period, could be due variations in beta cell damage and the regeneration process over time. Since the beta cells in this study were not designed to experience total damage, there could be a reduction in fasting blood glucose levels in the Wistar rats.[15] Significant differences in decreases FBG can also occur as a result of the DM severity experienced by the subject. After a blood test, in addition to FBG increases, the rats also showed increases in triglycerides, cholesterol, LDL, along with a decrease in HDL. This can refer to the criteria of metabolic syndrome occurrence, which can lead to metabolic inflammation in the subject. This inflammation includes insulin resistance, high fat levels, and the formation of pro-inflammatory compounds that cause inflammation and oxidative stress due to elevated high FBG levels.[16]

Testing lipid profiles also showed a decrease in triglycerides, total cholesterol, and LDL, and increase in HDL levels. This study was in line with previous study, effect of sorghum flour improved the plasma lipid profile and the atherogenic index in diabetic rats.[17] Consumption of fiber can enhance the feeling of fullness by delaying the emptying of the stomach and slowing down the digestive process in the small intestine. This is due to the modulation of the secretion of incretin, which stimulates the release of insulin, thereby reducing appetite and the synthesis of short-chain fatty acids (SCFAs), especially propionate, is stimulated, which inhibits the production of fatty acid.[18] This condition can reduce the intake of cholesterol-containing foods, resulting in lower levels of total cholesterol.[19] Furthermore, fiber in the body binds to lipids along with bile salts in the intestines and increases cholesterol excretion through the faeces. This inhibition leads to a decrease in the synthesis of cholesterol in the body.[19] Fiber can reduce cholesterol levels by more than 5% in the blood.[20]

Increased levels of HDL in the T1 and T2 groups can be caused by a decrease in total cholesterol levels, as HDL transports cholesterol to the liver for excretion. High fiber intake can also reduce the cholesterol ester transfer protein (CETP) activity, which functions to transfer ester cholesterol from HDL to triglyceride particles. CETP inhibition will change the reverse cholesterol transport route, favoring transport through HDL than VLDL. Therefore, the amount of HDL cholesterol will increase.[18] Generally, a reduction in LDL is correlated with an increase in HDL, which may be due to the liver lipase enzymes activity. Liver lipase enzymes are involved in the catabolism or HDL reorganization process. HDL levels increase when LDL levels decrease because a reduction in lipase enzyme activity

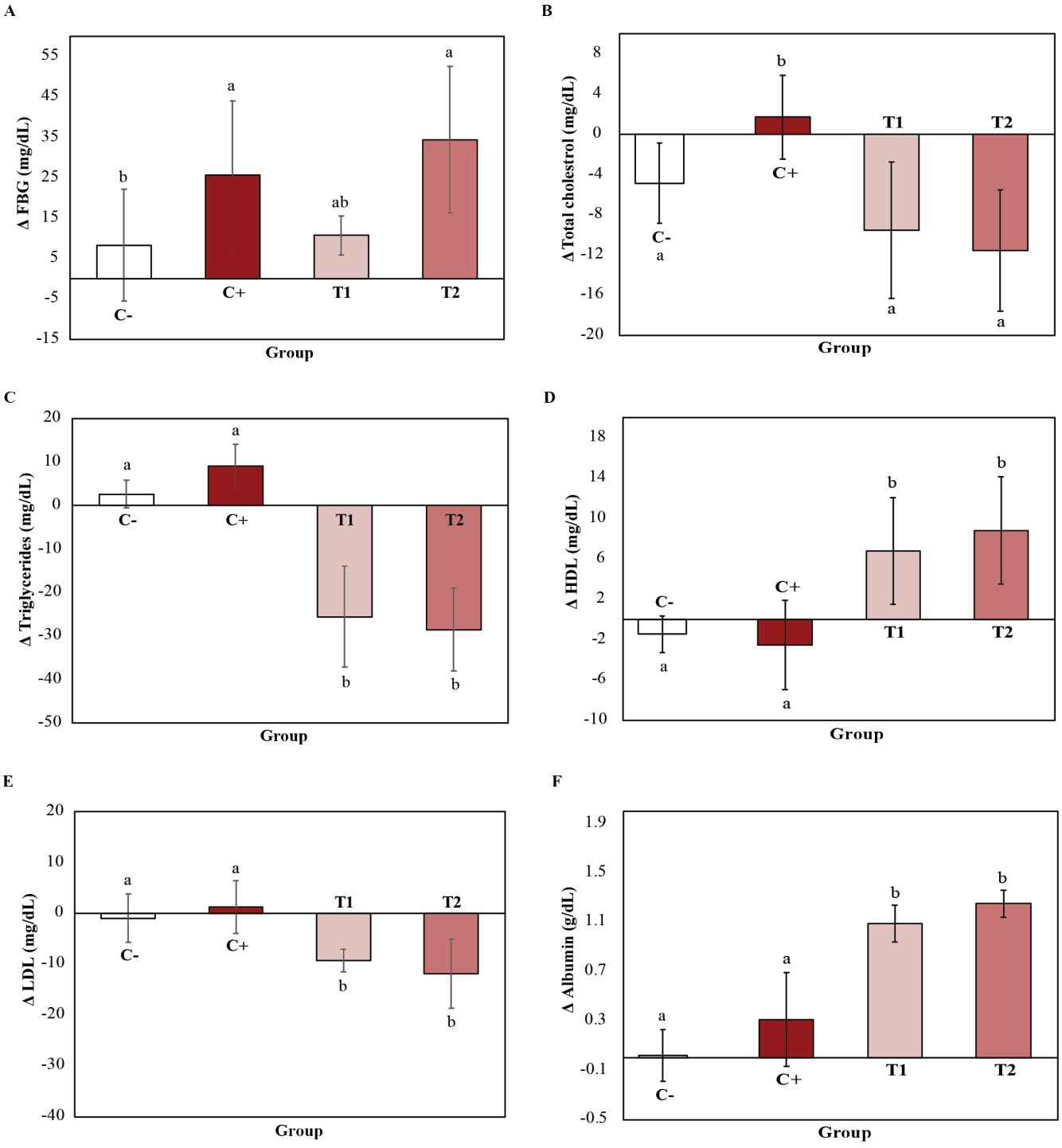

Figure 1. Difference between pre-intervention and post-intervention levels of (A) FBG, (B) total cholesterol, (C) triglycerides, (D) HDL, (E) LDL, and (F) albumin of all groups. C-: Negative control, C+: Positive control, T1: Treatment 1, T2: Treatment 2.

slows down the catabolism process.[17] Several studies have shown that fiber can significantly lower triglycerides.[14,21] Fibers can affect the absorption of fat by adsorbing fatty acids. Triglycerides that are bound to fibers cannot form a mycelium, so they cannot be absorbed in the small intestine and instead enter the colon to be excreted through the stool

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or degraded by intestinal bacteria. In addition, fibers are also able to absorbs bile acid to prevent the use of bile acid in the formation of mycels so that they cannot be re-absorbed and removed through stools.[22]

The significant increase in albumin levels in the T1 group and in the T2 group is due to the intake of protein and fiber from both the enteral formula and the standard feed given. The proteins in sorghum are divided into prolamin (cafirin) and non-prolamin (globulin and albumin) proteins, which can increase albumin levels. In addition, soybeans are also a food source of protein that has been shown to reduce levels of glycated albumin and advanced glycation end-products.[23] The amino acids arginine, phenylalanine, lysine, and proline in soybeans can also help stimulate the process of albumin synthesis.[24] Addition of green peanut flour to meet protein and flavor enhancer requirements. Green beans are a source of vegetable protein with a fairly high protein content of 24%.[25] It has been shown in a study in Wistar rats that given 0.3 g of protein per day increased albumin significantly by 91%.[26] Amino acids are one of the factors needed in albumin synthesis. Adequate protein intake can increase the protein digestive capacity, so the amount of amino acids that the body absorbs will also increase.[27]

In addition to protein intake, the increased levels of albumin in the T1 and T2 groups are due to the dietary fiber content in the enteral formula. Sorghum flour contains 8.83% food fiber, consisting of 2.39% water-soluble fiber and 6.44% insoluble fiber. Consumption of dietary fiber can give a hypoglycemic effect in the body and increase insulin sensitivity. According to previous study, albumin levels will increase along with increased insulin sensitivity because there is stimulation of albumin production by the hormone insulin.[28] Increasing albumin levels can also help improve immune function in DM. In type 2 DM, it is known that their immunity decreases because there is a disruption in the function of regulatory T cells that work in the specific immune system.[29] The results of this study demonstrate that enteral formulas from sorghum-soybean flour can improve the lipid profile so that it can prevent heart disease. Activity of soybeans in preventing heart disease could be related with an increase the estrogen levels. Previous results have shown that soymilk was able to increase estrogen levels and reduce testosterone levels in male infant white Wistar rats.[30]

Although the formula used in this research is a formula that is in accordance with the formula of the Indonesian Endocrinology Association, but the food fiber content is still high, so it requires a longer heating process compared to commercial formulas. A long heating process can affect the quality or nutrient content in enteral formula. This issue is not addressed in this study, as no nutritional analysis was carried out. Further research is needed to test the complete nutritional content and safety of the formula so that it can be consumed by hyperglycemia sufferers.

Conclusion

Administration of enteral formulas based on sorghum flour and soybean flour can reduce FBG, total cholesterol, triglycerides, and LDL, as well as increase HDL and albumin in hyperglycemic Wistar rats. A combination of sorghum flour and soybean flour at a dose of 4.41 g per rat can be used as a healthy alternative food ingredient in hyperglycemic conditions.

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Authors' Contributions

AC, EP, NP, EAM, MA, ENH, SND, TIA, and MSR conceived the presented idea, developed the theory, and performed the computations. All authors discussed the results and contributed to the final manuscript. ENH, SND, TIA, and MSR determined the analytical methods. AC, EP, NP, EAM, MA, ENH, SND, TIA, and MSR verified the analytical methods. EN, ENH, SND, TIF, and MSR conceived and planned the experiments. ENH, SND, TIF, and MSR carried out the experiments. AC, EP, NP, and EAM supervised the project. ENH, SND, TIF, and MSR performed data acquisition and collection, calculated the experimental data, and conducted the analysis. AC, EP, ENH, SND, TIF, and MSR participated in providing critical revisions of the manuscript.

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