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Impact of Steviol Glycosides, Moderate Intensity Swimming, and Intermittent Fasting on the Profile of Fasting Blood Glucose Levels, Malondialdehyde, and Lipidemia in Dmt2-Induced Rats

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ABSTRACT: Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by impaired glucose regulation, lipid abnormalities, and increased oxidative stress. This study aimed to evaluate the effects of steviol glycosides, moderate-intensity swimming, and intermittent fasting on fasting blood glucose, malondialdehyde (MDA), and lipid profiles in a rat model of T2DM. A laboratory-based quasi-experimental study with a pretest–posttest group design was conducted using 30 male Wistar rats allocated to five groups: untreated control, metformin, steviol glycosides, moderate-intensity swimming, and intermittent fasting. Each group received its assigned intervention during the study period. Fasting blood glucose levels were monitored on days 4, 7, 10, 13, 16, and 19, while MDA and lipid profiles were assessed as indicators of oxidative stress and lipid metabolism, respectively. The data were analyzed using the Wilcoxon test. The reported statistical analysis indicated significant differences at the specified measurement time points; however, the available results did not provide sufficient information to establish the magnitude of the changes or determine which intervention produced the most favorable outcomes. Therefore, the findings should be interpreted cautiously until the group-specific results and corresponding statistical values are reported. This study provides a framework for investigating the potential metabolic effects of steviol glycosides, moderate-intensity swimming, and intermittent fasting in experimental T2DM. Further studies should report quantitative changes in glucose, MDA, and lipid parameters, clarify the effects of each intervention, and evaluate the reproducibility of the findings before concluding their therapeutic potential.

1. INTRODUCTION

Diabetes mellitus (DM) is a metabolic disease characterized by absolute or relative insulin deficiency or impaired insulin action (insulin resistance), resulting in hyperglycemia (Davis G., 2018; Bernadetha et al., 2024). Insulin is a hormone produced by the pancreas that regulates blood glucose levels by facilitating glucose uptake and utilization. Consequently, impaired insulin function or insufficient insulin production can lead to elevated blood glucose levels (hyperglycemia). Diabetes mellitus can cause complications, including microangiopathy and macroangiopathy, which may be preceded by disturbances in lipid metabolism, such as dyslipidemia (Stephen J., 2015).

Diabetes mellitus is a group of metabolic disorders characterized by blood glucose levels exceeding the normal range (hyperglycemia) due to an absolute or relative deficiency of insulin (Smeltzer & Bare, 2007). According to Aini and Ardiana, diabetes mellitus occurs when the body is unable to produce or use insulin effectively. This hormone facilitates the transport of glucose from the bloodstream into cells, where it can be used or stored as glycogen. This condition results in hyperglycemia accompanied by various metabolic abnormalities caused by hormonal disturbances. These abnormalities involve carbohydrate, protein, and lipid metabolism and can lead to chronic complications affecting multiple organs (Aini, 2016).

Diabetes mellitus is a chronic degenerative disease that requires long-term treatment and continuous self-management to prevent acute and long-term complications. It is often referred to as a "silent killer" because vascular damage may develop before the disease is diagnosed. Diabetes can reduce life expectancy by approximately five to ten years, partly because the disease may remain undetected until complications have developed (Ministry of Health of the Republic of Indonesia, 2018).

Diabetes not only contributes to premature mortality worldwide but is also a major cause of blindness, cardiovascular disease, and kidney failure. The International Diabetes Federation (IDF) estimated that approximately 463 million people aged 20–79 years worldwide were living with diabetes in 2019, representing 9.3% of the global population in this age group. The prevalence was projected to increase with age, reaching approximately 19.9% (111.2 million people) among those aged 65–79 years. The number of people with diabetes was projected to rise to 578 million by 2030 and 700 million by 2045 (InfoDATIN).

In Indonesia, diabetes is recognized as one of the leading causes of death, ranking third after stroke and cardiovascular disease, according to the cited source. Diabetes has long been perceived as a disease that cannot be completely cured, prompting the use of various treatment approaches, ranging from conventional medical therapies to traditional remedies, all of which aim to manage the disease and improve patients' health. The longer a person lives with diabetes, the greater the potential risk of developing complications. These complications may affect multiple organs and include cardiovascular disease, stroke, liver disorders, gallstones, kidney failure, erectile dysfunction, lower-limb amputation, blindness, various infections, and certain types of cancer (Hans Tandra, 2020).

The management of diabetes mellitus is essential because it is a lifelong condition. Appropriate preventive and therapeutic strategies are therefore required to delay the onset and progression of complications as early as possible (PERKENI, 2015). Diabetes management is commonly based on five key pillars: education, medical nutrition therapy (meal planning), physical activity or exercise, pharmacological treatment, and blood glucose monitoring (PERKENI, 2015).

Given the substantial number of people affected by diabetes and the potentially serious complications associated with the disease, numerous studies have investigated pharmacological agents for its treatment (Sudoyono, 2016). In addition to conventional pharmaceutical agents, traditional approaches involving medicinal plants have also attracted attention as potential complementary strategies for diabetes management. One such plant is stevia (Ningsih, 2015).

Stevia leaves (Stevia rebaudiana) are naturally sweet and are commonly used as an alternative to conventional sugar and artificial sweeteners. Stevia is cultivated in various countries, including Indonesia. Its leaves contain compounds that have attracted research interest for their potential therapeutic applications, particularly in the management of dyslipidemia and diabetes (Bhutia, 2016). Stevia is considered a zero-calorie sweetener and, when used as a sugar substitute, generally has a minimal effect on blood glucose levels (Ahmad U., 2018). The leaves contain bioactive compounds, including steviol glycosides such as stevioside, which have been investigated for their potential effects on blood glucose, cholesterol, high-density lipoprotein (HDL), and triglyceride levels.

In addition to traditional and pharmacological approaches, physical activity is an important strategy for regulating blood glucose levels in individuals with type 2 diabetes mellitus (T2DM). Physical activity refers to any bodily movement produced by skeletal muscles that requires energy expenditure. Regular, structured physical activity undertaken to improve physical fitness is generally

referred to as exercise. Conversely, physical inactivity, including insufficient exercise, is a recognized risk factor for diabetes and contributes to the global burden of mortality (WHO, 2013).

Physical activity is one of the fundamental pillars of diabetes management. Regular exercise, generally recommended for at least 150 minutes per week as part of an appropriate intervention, can help reduce the risk of developing type 2 diabetes mellitus (Gordon, 2016). Exercise should be tailored to an individual's age, physical fitness, and health status. The importance of physical activity and adequate nutritional intake in maintaining health is also discussed by Utamayasa (2021). Blood glucose levels should be assessed when clinically appropriate, particularly in individuals at risk of exercise-related glycemic disturbances. Moderate-intensity exercise is widely used in diabetes-related interventions, and swimming is one physical activity that can be incorporated into an exercise program.

Swimming involves moving the body through water while maintaining buoyancy and coordinating limb movements. It is a widely practiced recreational and competitive sport that can be adapted for individuals of all ages and fitness levels. Swimming can be taught to both children and adults, and aquatic activities may also be introduced to infants under appropriate supervision (Kasiyo Dwijowinoto, 1979, p. 1). Swimming generally requires coordinated arm and leg movements to propel the body through the water or to maintain buoyancy, although equipment may be used when necessary.

Swimming is a low-impact form of exercise that places relatively little stress on the joints, making it a potentially suitable activity for individuals with diabetes. It may also contribute to improved lipid profiles, stress reduction, calorie expenditure, and whole-body muscle conditioning. Because swimming engages multiple muscle groups while minimizing joint loading, it may be a useful exercise option for people with diabetes. Regular physical activity may also support overall physical function and help manage certain symptoms associated with diabetes. However, its effects on symptoms such as tingling or numbness depend on the underlying cause and should not be assumed.

Another important component of diabetes management is medical nutrition therapy, particularly dietary planning. Over recent decades, advances in scientific knowledge have clarified the role of diet in preventing and managing disease-related morbidity and mortality. Dietary patterns influence not only current health status but may also affect the future risk of developing chronic conditions, including cancer, cardiovascular disease, and diabetes. Dietary management is particularly important for individuals with chronic diseases such as type 2 diabetes mellitus. One dietary approach that has attracted increasing research interest is intermittent fasting (IF).

Intermittent fasting is a dietary pattern involving alternating periods of fasting and eating. It is a dietary restriction that has attracted attention because it may be relatively inexpensive to implement and has been investigated for its potential to prevent or manage chronic diseases, including cardiovascular and neurodegenerative disorders, as well as certain cancers. Caloric restriction that reduces energy intake without causing malnutrition may offer health benefits and potentially reduce the risk of some chronic diseases. Intermittent fasting protocols vary in the duration and frequency of fasting periods, which may range from several hours to longer intervals, depending on the specific regimen. These alternating periods of fasting and eating have been investigated for their potential effects on metabolic regulation, cellular maintenance, and physiological adaptation. However, the outcomes depend on the fasting protocol, nutritional adequacy, and individual health status.

Considering the aforementioned background and the potential roles of steviol glycosides, moderate-intensity swimming, and intermittent fasting in metabolic regulation, this study investigated the effects of these interventions on fasting blood glucose, malondialdehyde, and lipid profiles in rats with experimentally induced type 2 diabetes mellitus. Specifically, the study aimed to evaluate the effects of steviol glycosides, moderate-intensity swimming, and intermittent fasting, individually and/or in combination according to the experimental design, on these metabolic

2. MATERIALS AND METHODS

2.1 Study Materials

This study employed a laboratory experimental method to investigate the effects of steviol glycosides, moderate-intensity swimming, and intermittent fasting on fasting blood glucose, plasma malondialdehyde (MDA), and lipid profiles in rats with experimentally induced type 2 diabetes mellitus (T2DM). Metformin was included as a pharmacological comparator, and an untreated control group was used to assess changes in the absence of a designated intervention.

2.2 Experimental Design and Animal Grouping

The study used a pretest–posttest control group design involving five experimental groups: an untreated control group (TP), a steviol glycoside treatment group (SG), a moderate-intensity swimming group (R), an intermittent fasting group (PI), and a metformin treatment group (M). The experimental subjects were rats with experimentally induced T2DM. The animals were assigned to the respective groups to evaluate the effects of the different interventions. The experimental period lasted three weeks (21 days).

2.3 Experimental Procedures

The interventions were conducted in accordance with the designated treatment for each group over the three-week experimental period. The TP group received no designated intervention; the SG group received steviol glycosides; the R group underwent moderate-intensity swimming; the PI group followed an intermittent fasting regimen; and the M group received metformin.

Fasting blood glucose levels were recorded on days 1, 4, 7, 10, 13, 16, and 19. Lipid profiles and plasma MDA levels were assessed before and after the intervention. These measurements were used to evaluate changes in glycemic status, lipid metabolism, and oxidative stress across the experimental groups.

2.4 Biochemical Measurements

The study evaluated three main outcomes: fasting blood glucose, lipid profiles, and plasma MDA levels. Fasting blood glucose was monitored at the designated observation points throughout the experimental period. Lipid profiles and plasma MDA levels were evaluated using pre-intervention and post-intervention measurements. The resulting data were used to describe changes in metabolic parameters in the untreated control and intervention groups.

2.5 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 23. Descriptive statistics were used to summarize the research data. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was evaluated using Levene's test. The reported normality results indicated that only the swimming group met the normality criterion ($p > 0.05$), whereas the other four groups did not ($p < 0.05$). The homogeneity test indicated unequal variances among the groups ($p < 0.05$).

Given these findings, nonparametric methods were used for relevant group comparisons. The reported analyses included comparisons between the untreated control group and the intervention groups. Changes in lipid profiles and plasma MDA levels were also evaluated using the available pre-intervention and post-intervention data. Statistical significance was assessed using the reported p-values, with $p < 0.05$ considered statistically significant.

3. RESULTS AND DISCUSSION

This chapter presents the findings of a laboratory-based experimental study, beginning with descriptive statistics of the research data, followed by the results of hypothesis testing, and concluding with a discussion of the hypotheses evaluated statistically using IBM SPSS Statistics version 23.

3.1 Fasting Blood Glucose

The study, titled "The Effects of Steviol Glycosides, Moderate-Intensity Swimming, and Intermittent Fasting on Fasting Blood Glucose, Malondialdehyde, and Lipid Profiles in Rats with Experimentally Induced Type 2 Diabetes Mellitus," was conducted over 21 days in November 2023.

The blood glucose data were obtained from the mean glucose levels recorded for each group on day 1, when the rats were classified as diabetic or normal, and on days 4, 7, 10, 13, 16, and 19. The TP group consisted of rats that received no intervention. The SG group consisted of diabetic rats treated with steviol glycosides, the R group comprised diabetic rats subjected to swimming exercise, and the PI group consisted of diabetic rats subjected to intermittent fasting. The M group comprised rats treated with metformin. The assigned interventions were administered over a 21-day experimental period. The data obtained during the study are presented in the following table.

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Table 1. Mean and Standard Deviation of Random Blood Glucose Levels in the Untreated Rat Group (TP)

Group 1 - Type 2 Diabetes (Negative Control)							
Subject	Fasting Blood Glucose (mg/dL)						
	Day-1	Day-4	Day-7	Day-10	Day-13	Day-16	Day-19
1	79	350	553	683	675	688	688
2	105	353	241	311	242	250	250
3	100	220	459	647	693	508	508
4	139	438	462	684	492	708	708
5	99	579	662	424	262		
Mean	104.40a	388.00a	475.40	549.80	472.80	430.80	430.80
SD	21.74	132.17	155.11	171.79	216.48	303.00	303.00
Note: Superscripts with the same letter indicate a significant difference between treatments ($p \leq 0.05$)							

Based on Table 1, the mean fasting blood glucose levels in the untreated group increased at several time points during the study period. The most pronounced increase occurred between day 1 and day 4, indicating a substantial rise in fasting blood glucose levels following streptozotocin (STZ) induction.

Table 2. Mean and Standard Deviation of Fasting Blood Glucose Levels in the Steviol Glycoside (SG) Group

Group 2 - Type 2 Diabetes + Steviol Glycosides (Treatment 1)							
Subject	Fasting Blood Glucose (mg/dL)						
	Day-1	Day-4	Day-7	Day-10	Day-13	Day-16	Day-19
1	119	187	224	200	101	85	101
2	109	215	197	104	100	105	87
3	100	416	687	112	87	107	
4	124	397	437	347	313	256	313
5	120	242	426	422	475	375	475
Average	114.40a	291.40a	394.20b	237.00b	215.20	185.60	195.20
SD	9.76	107.07	197.76	142.31	173.07	126.12	194.20
Note: Superscript with the same letter indicates a significant difference between the 2 treatments ($p \leq 0.05$)							

Table 2 shows that the mean fasting blood glucose levels in the steviol glycoside-treated group increased from day 1 to day 4, then increased further through day 7. A significant increase was observed between days 1 and 4, whereas a significant decrease occurred between days 7 and 10. Thereafter, the mean glucose levels generally declined through day 16, followed by a slight increase on day 19.

Table 3. Mean and Standard Deviation of Fasting Blood Glucose Levels in the Swimming Group

Group 3 - Type 2 Diabetes + Swimming (Treatment 2)							
Subject	Fasting Blood Glucose (mg/dL)						
	Day-1	Day-4	Day-7	Day-10	Day-13	Day-16	Day-19
1	101	187	393	240	200		
2	128	195	182	240	164	150	
3	95	160	624	240	172	209	200

4	90	170	243	198	164	122	164
5	120	233	402	272	162	151	162
Average	106.80a	189.00a	368.80	238.00b	172.40b	126.40	105.20
SD	16.42	28.19	171.42	26.31	15.90	77.43	97.22
Note: Superscripts with the same letter indicate a significant difference between the 2 treatments ($p \leq 0.05$)							

Table 3 shows that the mean fasting blood glucose levels in the moderate-intensity swimming group increased during the initial phase of the study. A significant increase in fasting blood glucose levels was observed between days 1 and 4, whereas a significant decrease occurred between days 10 and 13.

Table 4. Mean and Standard Deviation of Fasting Blood Glucose Levels in the Intermittent Fasting (IF) Group

Group 4 - Type 2 Diabetes + Intermittent Fasting (Treatment 3)							
Subject	Fasting Blood Glucose (mg/dL)						
	Day-1	Day-4	Day-7	Day-10	Day-13	Day-16	Day-19
1	102	456	166	288	188	180	188
2	105	460	682	431	422	400	422
3	85	492	467	384	573	501	
4	100	526	637	622	441	428	
5	115	250	323	456	487	449	487
Average	101,40[a]	436,80[a]	455,00	436,20	422,20[b]	391,60[b]	219,40
SD	10,83	108,17	215,49	122,10	143,30	123,93	229,08
Note: Superscripts with the same letter indicate a significant difference between the 2 treatments ($p \leq 0.05$)							

Table 4 shows that mean fasting blood glucose levels in the intermittent fasting group increased at several time points during the intervention period. A significant increase was observed between days 1 and 4, followed by a significant decrease between days 13 and 16.

Table 5. Mean and Standard Deviation of Fasting Blood Glucose Levels in the Metformin (M) Group

Group 5 - Type 2 Diabetes + Metformin (Treatment 4)							
Subject	Fasting Blood Glucose (mg/dL)						
	Day-1	Day-4	Day-7	Day-10	Day-13	Day-16	Day-19
1	112	424	394	283	352	234	308
2	120	171	274	287	456	107	456
3	102	240	190	121	89	99	
4	98	290	337	400	308	216	
5	106	370	436	330	369	210	369
Average	107.60[a]	299.00[a]	326.20	284.20	314.80	173.20	226.60
SD	8,65	100.76	97.53	102.65	137.20	64.75	213.44
Note: Superscripts with the same letter indicate a significant difference between 2 treatments ($p \leq 0.05$)							

Based on Table 5, the mean fasting blood glucose levels in the metformin-treated rat group increased. A significant increase was observed between days 1 and 4 of treatment.

Table 6. Mean blood glucose levels on days 1, 4, 7, 10, 13, 16, and 19 across all study groups.

		Day 1		Day 4		Day 7		Day 10		Day 13		Day 16		Day 19	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	NT	104.40[a]	21.74	388.00[a]	132.16	475.40	155.10	549.80	171.79	472.80	216.47	430.80	302.99	430.80	302.99
2	M	107.60[a]	8.64	299.00[a]	100.76	326.20	97.52	284.20	102.65	314.80	137.19	173.20	64.75	226.60	213.43
3	SGE	114.40[a]	9.76	291.4[a]	107.06	394.20[b]	197.76	237.00[b]	142.31	215.20	173.06	185.60	126.11	195.20	194.19
4	Sw	106.80[a]	16.42	189.00[a]	28.18	368.80	171.41	238.00[b]	26.30	172.40[b]	15.90	126.40	77.42	105.20	97.21
5	IF	101.40[a]	10.83	436.80[a]	108.17	455.00	215.48	436.20	122.09	422.20[b]	143.30	391.60[b]	123.92	219.40	229.08

Key: SD = Standard Deviation, NT = No Treatment, M = Metformin, SGE = Steviol Glycoside Extract, Sw = Swimming, IF = Intermittent Fasting, *p < 0.05

Based on the data in Table 6, the mean fasting blood glucose profiles of rats with type 2 diabetes mellitus (T2DM) across treatment groups at multiple time points are shown in the following figure.

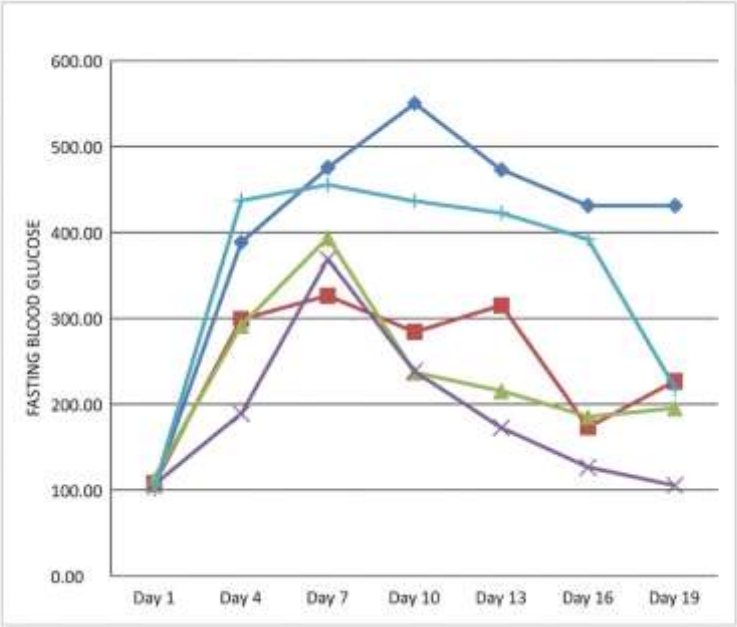


Figure 4.1. Mean Fasting Blood Glucose Profile (mg/dL) of T2DM Rats Under Various Treatments Over 19 Days

Based on Table 6 and Figure 4.1 above, the mean fasting blood glucose (FBG) levels varied among the experimental rat groups. The untreated group showed an increase in FBG from 104.40 to 430.80. These data indicate that blood glucose levels in the untreated rats increased compared with the initial measurements. The metformin-treated group showed an increase in FBG from 107.60 to 226.60. Similarly, the steviol glycoside-treated group showed an increase in FBG from 114.40 to 195.20. The

swimming group showed a decrease in FBG from 106.80 to 105.20, whereas the intermittent fasting group showed an increase from 101.40 to 219.40.

In this study, the Shapiro–Wilk test was used to assess normality, and Levene's test was used to assess homogeneity of variance. The normality test results showed that only one of the five groups had a p-value greater than 0.05, indicating that the swimming group had a normal distribution. The other four groups—the untreated, metformin, steviol glycoside extract, and intermittent fasting groups—had p-values below 0.05, indicating that their data were not normally distributed. The homogeneity test yielded a p-value below 0.05, indicating that the data did not meet the assumption of homogeneous variances.

Because the data did not satisfy the assumptions of normality and homogeneity, a nonparametric test was required. The following presents the results of the nonparametric analyses for the individual experimental rat groups.

The reported pairwise comparison results showed p-values below 0.05 for comparisons between the untreated group and the metformin-treated group, the untreated group and the swimming group, and the untreated group and the steviol glycoside extract group. In contrast, the comparison between the untreated group and the intermittent fasting group yielded a p-value greater than 0.05.

3.2 Lipid Profile

The lipid profile data in this study were obtained from pretest and posttest measurements conducted in each of the treated and untreated rat groups. The data collected during the study were as follows:

Table 7. Mean Pretest and Posttest Lipid Profiles Across All Study Groups

Subject	TP		EGS		R		PI		M	
	Plasma Lipid (mg/dL)		Plasma Lipid (mg/dL)		Plasma Lipid (mg/dL)		Plasma Lipid (mg/dL)		Plasma Lipid (mg/dL)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	105	121	110	118	101		106	126	104	110
2	103	179	114	189	117		116	118	101	118
3	102		102		104	152	102		110	
4	108	132	106	174	100	118	106		100	
5	109		101	156	112	156	110	138	117	101
Average	105.40	144,00	106,60	159,25	106.80	142.00	108.00	127.33	106.40	109,67
SD	3,05	30,81	5,46	30,63	7,40	20,88	5,29	10,07	7,09	8,50

Legend: TP = Untreated, M = Metformin, EGS = Steviol Glycoside Extract, R = Swimming, PI = Intermittent Fasting, Pre = Before Treatment, Post = After Treatment.

Table 7 shows changes in the mean lipid profiles at each measurement point across all treatment groups. However, the changes were not statistically significant in any treatment group ($p \geq 0.05$).

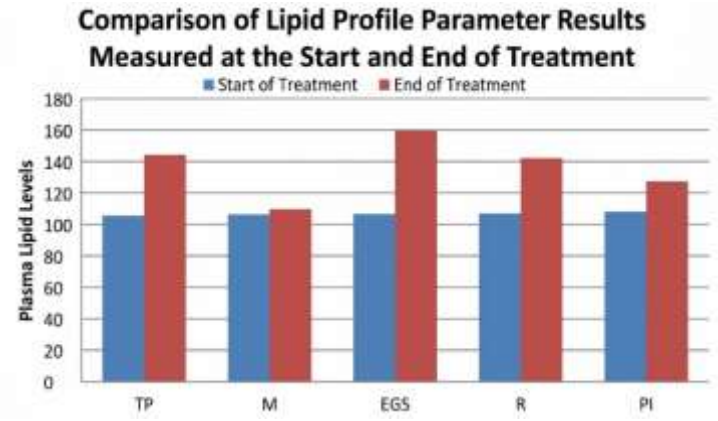


Figure 4.2. Mean Plasma Lipid Profile (mg/dL) in T2DM Rats

Table 8. Blood Plasma MDA Profile in T2DM Rats Before and After Research Treatment

Subject	TP		EGS		R		PI		M	
	Blood Plasma MDA (mg/dL)		Blood Plasma MDA (mg/dL)		Blood Plasma MDA (mg/dL)		Blood Plasma MDA (mg/dL)		Blood Plasma MDA (mg/dL)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	2,12	3,03	2,18	2,76	2,39		1,55	1,98	2,07	1,89
2	1,74	2,76	1,5	2,23	1,82		1,89	3,06	1,16	2,62
3	2,02		2,27		1,69	2,71	2,43		2,5	
4	2,68	2,36	1,43	2,8	1,54	3,09	2,27		2,21	
5	2,18		1,9	2,22	2,52	2,62	2,23	2,47	2,04	2,06
Average	2,15	2,72	1,86	2,50	1,99	2,81	2,07	2,50	2,00	2,19
SD	0,34	0,34	0,38	0,32	0,44	0,25	0,35	0,54	0,50	0,38
Notes: TP = Untreated, M = Metformin, EGS = Steviol Glycoside Extract, R = Swimming, PI = Intermittent Fasting, Pre = Before Treatment, Post = After Treatment.										

Based on Table 8 above, the mean plasma malondialdehyde (MDA) levels in rats with type 2 diabetes mellitus (T2DM) before and after the study interventions across the different treatment groups can be illustrated in the following graph:

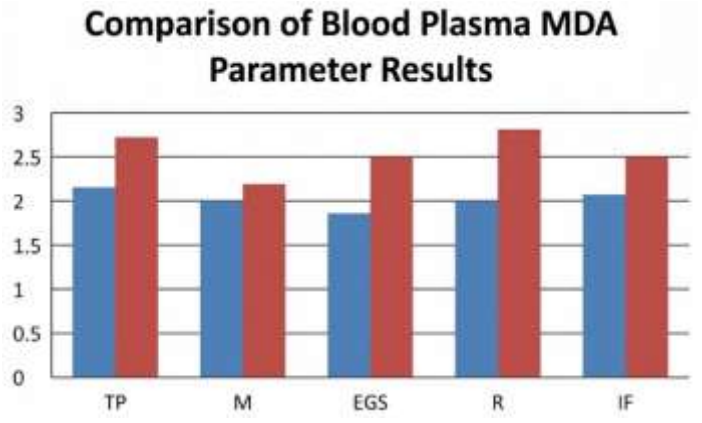


Figure 4.3. Blood Plasma MDA Profile in T2DM Rats

Based on Table 8 and Figure 4.3 above, it can be concluded that mean plasma malondialdehyde (MDA) levels increased across all rat groups. The data indicate that plasma MDA levels increased in the untreated group compared with the initial measurements. The metformin-treated group also showed an increase in plasma MDA levels. Similarly, increases in plasma MDA levels were observed in the steviol glycoside-treated, swimming, and intermittent fasting groups. However, the changes in mean plasma MDA levels at each measurement point were not statistically significant in any treatment group ($p \geq 0.05$).

3.3 Discussion

The fasting blood glucose levels in the untreated group increased from 104.40 to 430.80 mg/dL, indicating that hyperglycemia persisted throughout the observation period. This pattern provides context for comparing the treatment groups; however, changes in mean values alone are insufficient to establish an intervention's effectiveness. The swimming group showed the most distinct pattern, with a final mean of 105.20 mg/dL compared with an initial mean of 106.80 mg/dL. In contrast, the steviol glycoside, intermittent fasting, and metformin groups showed higher final mean values than their initial values. These findings should be interpreted cautiously because the assumption tests indicated non-normal distributions in four of the five groups and unequal variances. Therefore, the nonparametric test results and relevant between-group comparisons are more informative than comparisons of mean values alone. Experimental studies in diabetic rat models have reported that steviol glycoside supplementation may affect glucose metabolism, although the magnitude and direction of the effect depend on the model conditions and treatment composition (Kurek et al., 2022a; Kurek et al., 2022b).

The distinction between descriptive trends and statistical findings is also relevant when interpreting the swimming and intermittent fasting groups. In the swimming group, the final value was close to the initial value, which is consistent with the possibility that physical activity may help regulate glucose. However, a decrease between time points should not be considered statistically significant unless supported by the relevant overall or pairwise statistical test. Experimental literature on exercise in diabetic animals indicates that metabolic responses may vary according to exercise duration, intensity, and protocol. Accordingly, the swimming pattern observed in the present study should be regarded as a trend rather than conclusive evidence of effectiveness. In the intermittent fasting group, the final mean was higher than the initial mean, and the comparison with the untreated group was not statistically significant. Thus, this study does not provide strong evidence of a difference between intermittent fasting and no intervention. Studies of time-restricted feeding in rats suggest that responses to fasting patterns may be associated with redox balance, making the duration and schedule of fasting relevant to interpreting the findings (Akram et al., 2020; Bhoumik et al., 2020).

For the lipid profile, the absence of statistically significant changes across the study groups means that these data do not support the conclusion that the treatments altered lipid levels during the observation period. Mean values may indicate trends, but without test statistics, effect sizes, and confidence intervals, those trends cannot be reliably distinguished from sample variability. This result differs from some studies of steviol glycosides in diabetic rats that examined changes in lipid metabolism. Direct comparison is, however, limited by differences in study design, dosage, treatment duration, and diabetes-induction models (Kurek et al., 2020; Ahmad et al., 2023). The findings should therefore be described as showing no statistically significant changes in the lipid profile, rather than as demonstrating that none of the interventions has any biological effect.

Mean MDA levels were reported to increase in all groups, but these changes were not statistically significant. MDA is an indicator of lipid peroxidation, so an increase in its mean level may indicate a change in oxidative status. It does not, by itself, establish an increase in oxidative stress without statistical support and complementary biomarkers, such as antioxidant capacity or antioxidant enzyme activity. The findings also indicate that changes in glucose were not accompanied by a reduction in MDA during the 21-day treatment period. Studies in diabetic animal models have reported associations among hyperglycemia, lipid peroxidation, and antioxidant systems. Research on exercise and nutritional interventions has also found that MDA responses may vary according to the tissue examined and the duration of the intervention (Ryadinency et al., 2018; Ibuki et al., 2020; Viroel et al., 2022; Pourmousavi et al., 2023). Overall, the present findings are best described as differences in mean-value patterns among the interventions, with limited statistical evidence for changes in the lipid profile and MDA. Interpretation of treatment effectiveness would require complete reporting of p-values, effect sizes, and between-group comparisons.

These findings have several implications for the interpretation and design of future research. First, the observed glucose pattern in the swimming group may warrant further investigation with a larger sample size and a clearly specified exercise protocol, while avoiding conclusions about effectiveness based solely on mean values. Second, the absence of statistically significant changes in lipid profiles and MDA suggests that future studies could consider a longer intervention period, more frequent

measurements, and additional markers of oxidative status, provided the study objectives support these choices. Third, reporting effect sizes and confidence intervals alongside p-values would help readers assess the magnitude and precision of observed differences. Finally, future analyses should account for the non-normal distributions and unequal variances reported in this study, and should provide complete results for the statistical comparisons used.

4. CONCLUSION

This study found different patterns in fasting blood glucose levels among rats with type 2 diabetes mellitus (T2DM) receiving different interventions. The untreated group showed an increase from 104.40 to 430.80 mg/dL, whereas the swimming group showed a slight decrease from 106.80 to 105.20 mg/dL. In contrast, the metformin, steviol glycoside, and intermittent fasting groups showed increases in mean fasting blood glucose levels by the end of the observation period. These descriptive findings should be interpreted cautiously because changes in mean values alone do not establish intervention effectiveness, particularly given the non-normal distribution in four of the five groups and the lack of homogeneity of variance. The lipid profile changes were not statistically significant, and plasma malondialdehyde (MDA) levels increased across all groups, as observed descriptively ($p \geq 0.05$). Therefore, this study provides limited statistical evidence of changes in lipid profiles and MDA levels during the observation period and does not establish the superiority of any intervention. The findings imply that evaluating metabolic interventions in experimental T2DM requires comprehensive statistical comparisons alongside descriptive trends. Future studies should report complete p-values, effect sizes, and confidence intervals; use appropriate statistical methods for non-normally distributed and heterogeneous data; and consider larger sample sizes, standardized intervention protocols, and longer observation periods. Additional oxidative stress biomarkers and antioxidant parameters should also be assessed to clarify whether changes in blood glucose are associated with changes in oxidative status. These steps would support more robust conclusions regarding the potential metabolic effects of steviol glycosides, swimming, intermittent fasting, and metformin in experimental T2DM.

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