Original Article

Effect of *Solanum Melongena* Peel Extracts on Glucose Level and Biochemical Parameters in Alloxan-Diabetic Mice

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ABSTRACT

Background: Natural compounds are safe and commonly used in medicine. Diabetes is a chronic metabolic disease that is widely spread in the world. Natural products can decrease blood sugar levels. This effect controls the pancreas and metabolic pathways.

Objectives: The aim of this research is to extract effective compounds from eggplant peels and study their effects on blood glucose levels, lipid profiles, kidney function, and liver enzymes in diabetic mice.

Methods: In this study, crude extract and some natural products such as oils, polyphenols, and anthocyanins were isolated. These extracts were identified by gas chromatography (GC) and high-performance liquid chromatography (HPLC). Some parameters were measured, such as glucose, urea, creatinine, triglyceride (TG), high- and low-density lipoprotein cholesterol (LDL-c), very low-density lipoprotein cholesterol (VLDL-c), alanine transaminase, aspartate aminotransferase (AST), lipase, and atherogenic index in male diabetic mice.

Results: The results showed the presence of many fatty acids, polyphenols, and anthocyanin compounds in eggplant peels. A significant effect on lipid profiles, glucose, creatinine, and lipase was found after ten days of treatment in diabetic mice with the aforementioned extracts. In contrast, a nonsignificant effect was noted in HDL-c and urea levels with oil and polyphenol extracts. Nevertheless, these extracts had no effect on AST and ALT levels.

Conclusion: In this study, the effects of these extracts were found to be mixed. However, they demonstrated beneficial effects on blood glucose, creatinine levels, and lipid profiles. These extracts may help reduce the severity of diabetes or its complications. No clear effect was observed in liver function tests.

Keywords: Anthocyanin, Atherogenic index, diabetes mellitus, Fatty acids, Polyphenol.

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Introduction

Diabetes is a mainly unstable defect in carbohydrate metabolism due to partial or complete failure of pancreatic beta cells and decreased sensitivity of body tissues to insulin (Marchetti et al., 2023). Nephropathy, retinopathy, and neuropathies are caused by chronically high blood sugar in type II diabetics, which has an enormous impact on lifestyle and overall healthy life expectancy (Faselis et al., 2020). Approximately 60% of the world's population uses medicines derived from plants, and although there are several ways to mitigate the adverse effects of diabetes and its complications, herbal formulations may be somewhat better because they tend to be less expensive and have fewer if any, side effects (Modak et al., 2007). Several studies have investigated some diabetic complications, such as the relationship between gingivitis and these complications (Nguyen et al., 2020). A diet rich in natural products, such as polyphenol compounds can be used in treating, monitoring, or controlling type 2 diabetes and various other diseases because of their multiple vital properties. Flavanols, stilbene, curcuminoids, anthocyanins, naringenin, hesperidin, and phenolic acids are common polyphenols found in blueberries, turmeric, sea buckthorn, citrus fruits, cranberries, and grains (Naz et al., 2023). In recent years, there has been an increase in the number of scientific articles addressing oxidative stress, including the metabolism of reactive oxygen and nitrogen species; nonetheless, antioxidants in fruits and vegetables are responsible for many health advantages (Al-lehebe et al., 2022).

Plant polyphenols, which are aromatic compounds containing one or more hydroxyl groups, are mainly used by plants to prevent oxidative stress. Phenols are natural secondary metabolites derived from the shikimate/phenylpropanoid pathway or the polyketide acetate/malonate pathway (Naikoo et al., 2019). Anthocyanins are natural compounds that belong to the polyphenol family and can be found mainly in dark fruits (such as black currants, blueberries, and cranberries) and vegetables (such as eggplant, red cabbage, and radishes). These compounds play a major role in reducing the complications of type 2 diabetes and contribute to regulating carbohydrate metabolism in the body by controlling the transmission of insulin-regulated glucose transporter (GLUT4) and increasing the activation of peroxisome proliferator-activated receptor γ (PPARγ) in adipose tissue and skeletal muscle, in addition to increasing the secretion of adiponectin and leptin (Różańska & Regulska-Ilow, 2018). The eggplant fruit is characterized by its large content of antioxidants, such as phenolic compounds (Cao et al., 1996). Most of the anthocyanins in eggplant peel are derivatives of delphinidin, while some research has mentioned that nasunin is the main substance in the peel of Japanese eggplant. Nasunin was first isolated in 1933 by Kuroda Wada who found residues of delphinidin, glucose, and coumaric acid, at which time the structure was named delphinidin-3-diglucoside acylated with coumaric acid (Noda et al., 2000).

This research aimed to isolate and extract natural compounds, such as oils, polyphenols, and anthocyanin, and evaluate their effect on glucose and some biochemical parameters in alloxan-diabetic mice.

Materials and Methods

Plant collection, preparation, and separation

Eggplants were collected from the local market in Baghdad, Iraq. The rinds were separated from the pulp by a micro peeling machine (1 kg) and crushed in a blender (Magic Bullet 600-Watt).

Crude extraction: 500 g of the eggplant peel prepared above was mixed with distilled water in a 1:1 ratio. The mixture was frozen and thawed three times, then treated with ultrasound instruments for 30 minutes. It was then filtered and separated using a refrigerated centrifuge and finally dried using a lyophilizer to obtain the crude extract.

Oil extraction: 250 gr of eggplant peel prepared above was dried to obtain a powder. Lipid content was extracted from the eggplant peel powder using a Soxhlet extraction system with petroleum ether as the solvent at 60 ˚C for 12 hours. (Tibbetts et al., 2015). An analysis of the yield was done by capillary gas chromatography (GC) (Shimadzu 2010).

Polyphenol extraction: Polyphenol compounds were extracted from the remaining parts of the previous step using a Soxhlet extraction system with ethanol as the solvent at 70 ˚C for 12 hours (Sridhar et al., 2021).

Anthocyanin extraction: 250 gr of the eggplant peel prepared above was dried to obtain a powder. Neff and Chory (Neff & Chory, 1998) suggested chloroform and methanol for the extraction of anthocyanins, and therefore, for the second method, 15 mL methanol, 10 mL water, 0.15 mL HCL, and 25 mL chloroform were mixed thoroughly with the samples, incubated at 4 ˚C for 24 h in a dark shaker, and then centrifuged at 4 ˚C, 7000 rpm for 15 min.

Analysis of compounds in the extractions:

High-pressure liquid chromatography (HPLC) and GC were used to identify and estimate the concentration of compounds in the alcoholic, aqueous, and oil extracts.

Fatty acids: The sample was prepared based on the esterification of fats by reacting them with methanolic potassium hydroxide, which was prepared by dissolving 11.2 g of potassium hydroxide in 100 mL of methanol. Then, 1 g of fat was taken, and 8 mL of methanolic potassium hydroxide was added to it. Afterward, 5 mL of hexane was added, and the mixture was shaken vigorously for 30 seconds before being allowed to separate into two layers. The upper layer (the hexane layer), which contains the esterified fat, was collected and injected into the device. Fatty acid compounds were analyzed using a GC device (GC - 2010), a Shimadzu model of Japanese origin, which used a flame ionization detector (FID) and a capillary separation column (SE-30) with dimensions of 30 m × 0.25 mm (Lee et al., 2019).

Polyphenols: Quantification of individual phenolic compounds was performed by reversed-phase HPLC analysis using a SYKAM HPLC chromatographic system equipped with a UV detector. The column used was a C18-OSD (25 cm, 4.6 mm). The column temperature was maintained at 30 ˚C. A gradient elution method was employed, with eluent A (methanol) and eluent B (1% formic acid in water (v/v)), as follows: Initial 0-5 min, 40% B; 5-15 min, 50% B; with a flow rate of 0.9 mL/min. The injected volume of samples was 100 µL, and the standards were also 100 µL, which was done automatically using an autosampler. The spectra were acquired in the 280 nm (Radovanović et al., 2015).

Anthocyanin: An HPLC model SYKAM (Germany) was used to analyze and detect anthocyanin. The mobile phase consisted of an isocratic flow of a 95/5 (v/v) mixture of water (pH 7.0) and 2% formic acid, with a flow rate of 0.8 mL/min. The column used was C18 – ODS (25 cm × 4.6 mm) and the detector was a UV-Vis operating at 520 nm (Shim et al., 2014).

Experimental animals: Laboratory-bred Swiss albino male albino mice (5-6 months, 25-30 g) were used in the study. Animals were kept in standard cages with alternating 12-hour dark and 12-hour light cycles under a controlled temperature of 25 ˚C. Animals were fasted for 12 hours before alloxan-induced diabetes and were monitored for seven days to confirm the development of diabetes. They were fed a standard commercial diet of pellets and water, consisting of 71% carbohydrate, 18% protein, 7% fat, 4% salt mixture, and adequate minerals and vitamins.

Diabetes induction; Alloxan was obtained from Sigma Chemicals Co., St. Louis, MO, USA. It was dissolved in 0.05% normal saline and prepared fresh for use within 5 min. Alloxan was injected intraperitoneally at 120 mg/kg body weight (Anjum et al., 2021). The blood glucose concentration was measured daily after alloxan injection. The blood samples were collected from the orbital venous plexus (Sajid et al., 2020).

Experimental groups and protocol: The animals were distributed into six groups, each consisting of 7 mice at the beginning of the study. Group 1 was intraperitoneally administered normal saline (healthy control). Animals in groups 2 to 6 were diabetic. Alloxan doses were administered at a volume not exceeding 1 mL/100 g body weight of the mice. Group 2 received no treatments (diabetic control), while groups 3 to 6 were treated with crude, oil, polyphenol, and anthocyanin extracts at doses of 8.53, 103.6, and 79.26 mg/kg, respectively, for ten days.

Blood sample collection: At the end of the experiment, all animals were anesthetized with ether, and blood was drawn from the orbital sinus vein. The samples were centrifuged immediately after blood collection for 5 minutes at 6,000 rpm at 4 ˚C. The serum was stored frozen until analysis.

Parameter analysis

All the tests were conducted on mice blood sera using an analysis kit from Bio-France Company as part of an enzymatic procedure. Blood glucose, urea, creatinine, alanine aminotransferase (ALT), aspartate aminotransferase (AST), and lipid profile levels (total cholesterol [T-Cho], triglyceride [TG], and high-density lipoprotein cholesterol [HDL-c]) were calculated. Very low-density lipoprotein cholesterol (VLDL-c) was calculated using the equation T.G/5 (Niemi et al., 2009), and low-density lipoprotein-cholesterol (LDL-c) was calculated using the equation provided by Bairaktari et al. (2000).

Lipase was measured by following the procedure of Alabbas et al. (2022), which involved monitoring the degradation of p-nitrophenol acetate by lipase and measuring p-nitrophenol at 410 nm (Alabbas et al., 2022).

Statistical analysis

Data were analyzed by SPSS software, version and expressed as Mean±SD of three replicates. Analysis was performed using Duncan's multiple-range test and one-way analysis of variance (ANOVA). $P \leq 0.05$ were considered significant.

Table 1. The percentage of fatty acids in the eggplant peel oil extract

Fatty Acids	Arachidonic	Linolenic	Linoleic	Oleic	Palmitic	Stearic
% of fatty acids in the petroleum ether extract of eggplant peel	0.433	0.881	0.521	0.544	0.327	0.522

Table 2. Polyphenol compounds in eggplant peel extract

Polyphenol Compounds	Catechin	Ferulic Acid	Gallic Acid	Kaempferol	Quercetin	Rutin	Total
Alcoholic extract (µg/g)	8.9	25.8	41.5	17.8	33.9	16.9	144.8
Eggplant peel (µg/kg)	37.86	109.77	176.58	75.73	144.24	71.9	615.08

Results

The results of the petroleum ether extraction indicated the presence of certain fatty acids, and the important fatty acids were identified by GC, as illustrated in Figure 1.

Table 1 shows the percentage of fatty acids in the eggplant peel petroleum ether extract, where five fatty acids were detected.

Some polyphenol compounds from the eggplant peels were also extracted by ethanol, and more than one compound was found (Table 2).

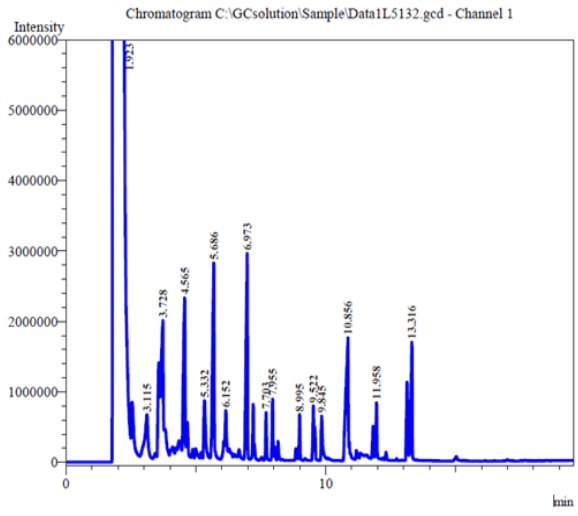
Two compounds were not detectable in the extracts and appeared at the retention times (RT) of 6.11 and 8.72 min. Polyphenol compounds may possess important antioxidant properties and anti-inflammatory actions, among other benefits (Urquiaga & Leighton, 2000). Quercetin and gallic acid were present in higher concentrations than the other polyphenols.

Anthocyanin compounds were found in the extracts, and cyanidin had a higher concentration than the other compounds, as shown in Table 3.

Biochemical parameters

Diabetes was induced in mice using alloxan at a dose of 120 mg/kg body weight. Alloxan acts as a selective destruction of the pancreas (Fajarwati et al., 2023). After ten days of treatment with the extracts, the effects of eggplant peel extracts on the lipid profile were investigated, as shown in Table 4. The best effects on VLDL-c, TG, and T-cho levels were observed with treatment using anthocyanin, while LDL-c was significantly decreased with treatment using the alcoholic extract. Additionally, HDL-c levels were improved with the oil extract.

Table 5 demonstrated a better effect on glucose levels when treating diabetic mice with the oil extract, on creatinine levels with the anthocyanin extract, on urea levels with the crude extract, and on lipase activity with the alcoholic extract. There were no significant effects on liver enzymes AST and ALT.



Peak Table - Channel 1

Peak#	Ret.Time	Area	Area%	Height	Name
1	1.923	2068829993	95.6793	85831909	
2	3.115	3542234	0.1638	500649	
3	3.728	18404107	0.8512	1830138	
4	4.565	7075301	0.3272	1725899	
5	5.332	2710991	0.1254	693327	
6	5.686	11780981	0.5448	2747326	
7	6.152	2837409	0.1312	598142	
8	6.973	11277625	0.5216	2881057	
9	7.703	1500876	0.0694	636223	
10	7.955	2707448	0.1252	858277	
11	8.995	1484656	0.0687	622788	
12	9.522	3168815	0.1466	765144	
13	9.845	2310939	0.1069	594684	
14	10.856	11304155	0.5228	1696404	
15	11.958	3799398	0.1757	784064	
16	13.316	9520452	0.4403	1646265	
Total		2162255380	100.0000	04412296	

Figure 1. The chromatogram of the GC chromatography of the oil (petroleum ether) extracts of eggplant peels

Table 3. The content of anthocyanidin compounds in eggplant peel

Anthocyanidin Compounds	Peonidin	Cyanidin	Malvidin	Delphinidin	Total
Aqueous extracts (µ/g)	19.8	66.2	24.6	21.8	132.4
Eggplant peel (µg/kg)	64.35	215.15	79.9	79.85	439.25

Finally, Table 6 shows that when compared to the positive controls, the TG/Glu index decreased dramatically in all groups. This could be due to the extracts acting on metabolism to utilize glucose rather than transferring or storing TG (Stinkens et al., 2015). Both the oil and alcoholic extracts demonstrated a positive effect on the LDL/HDL and CHO/HDL ratios, indicating that a higher level of HDL-c is associated with lower LDL-c, which leads to improved lipid metabolism and a decreased risk of atherosclerosis.

Discussion

In this study, the fatty acids were isolated from crude oil extracts, and the results showed beneficial effects, especially on lipid profiles and glucose in diabetic mice compared to the positive controls. Free fatty acids (FFAs) are thought to be essential for maintaining physiological glucose homeostasis, as they bind to orphan G protein-coupled receptors (GPCRs). Medium- and long-chain FFAs can activate GPR40 and GPR120, while short-chain FFAs can activate GPR41 and GPR43. The majority of the effects of FFAs on insulin production are mediated by GPR40, which is predominantly expressed in pancreatic β-cells. These findings, along with a critical examination of these GPCRs as potential new targets for diabetes treatment, are discussed (Rayasam et al., 2007). The alcoholic extracts containing polyphenols were analyzed by HPLC C-18, confirming the presence of more than one compound in the eggplant peel alcoholic extract.

Polyphenol compounds were also studied in this research; however, two compounds were not detectable in the extracts that appeared at the RT of 6.11 and 8.72 min. These compounds may play important antioxidant and anti-inflammatory roles (Urquiaga & Leighton, 2000). Quercetin and gallic acid were present in higher concentrations than other polyphenols.

Numerous studies attest to the ability of phenolic compounds to protect against the harmful consequences of diabetes mellitus. Their antidiabetic activity includes: i) control of glucose absorption; ii) protection of pancreatic β-cells; iii) improvement of insulin action; and iv) regulation of key signaling pathways for cell homeostasis. Dietary phenolic compounds provide a simple, safe, and economical means of preventing or reducing the complications associated with diabetes mellitus (R Dias et al., 2017).

Table 4. Effect of the eggplant peel extracts on lipid profile in alloxan-diabetic mice

Groups	Mean±SD				
	VLDL-C (mmol/dL)	LDL-C (mmol/dL)	HDL-C (mmol/dL)	TG (mmol/dL)	T-Cho (mmol/dL)
Healthy negative control	4.4±23.04^{ab}	7.1±40.3^{a}	8±102^{c}	17.3±107.7^{ab}	11.9±165^{c}
Diabetic positive control	4.5±36.4^{c}	9.4±101.3^{c}	13.3±68^{b}	22.8±182^{c}	201.5±14.6^{d}
Diabetic treated with crud extract at 250 mg/kg body weight	3.3±22.6^{ab}	21.05±81.6^{b}	14.5±48.4^{a}	21.6±99.2^{a}	31.9±143.4^{bc}
Diabetic treated with oil extract at 8.53 /mg/kg body weight	4.4±23.04^{ab}	7.1±40.3^{a}	8±102^{c}	22.4±115.2^{ab}	11.9±165.4^{c}
Diabetic treated with alcoholic extract at 103.6 mg/kg body weight	4.9±27.7^{b}	14.6±37.4^{a}	14.5±58.8^{ab}	24.6±138.8^{b}	13.8±127.7^{ab}
Diabetic treated with anthocyanin extract at 79.26 mg/kg body weight	7.7±16.4^{a}	21.5±49.1^{a}	18.5±48.4^{a}	38.9±82.4^{a}	25.8±107.1^{a}

Note: The vertical characters mean the significant deference at P≤0.05.

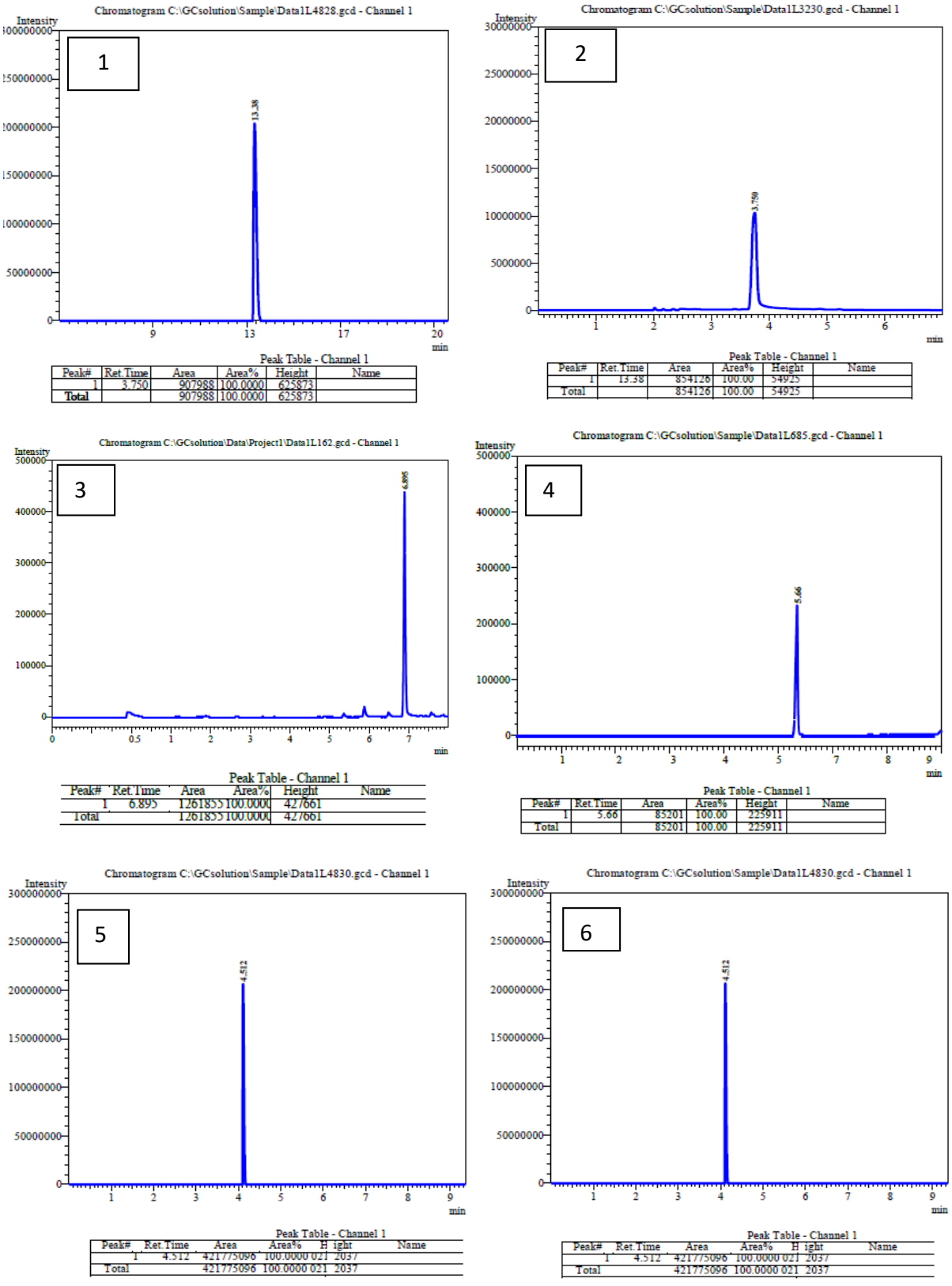
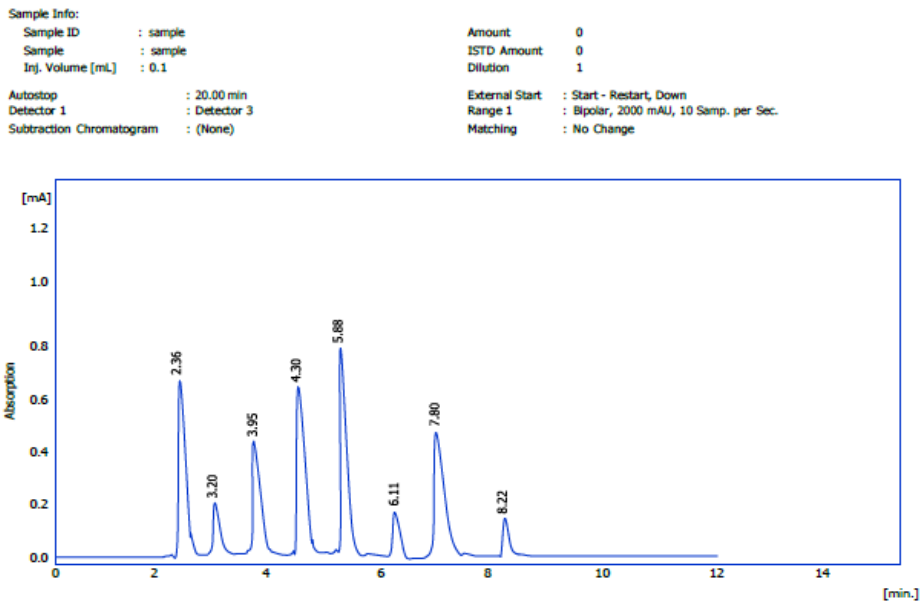


Figure 2. The chromatogram of the GC of the main standard fatty acids: 1 - arachidonic, 2 - linolenic, 3 - linoleic, 4 - oleic, 5 - palmitic, 6 – stearic



Result chromatography Table (Uncal - F:\ sample)

No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	2.36	180542.56	710.58	15.00	15.00	0.10	
2	3.20	20541.88	200.36	7.00	7.00	0.05	
3	3.95	80542.98	400.15	14.00	14.00	0.10	
4	4.30	120475.31	600.25	15.00	15.00	0.10	
5	5.88	245621.00	800.95	20.00	20.00	0.15	
6	6.11	15247.88	201.59	7.00	7.00	0.05	
7	7.80	60325.90	460.90	14.00	14.00	0.10	
8	8.22	15632.08	166.31	8.00	8.00	0.05	
	Total	782929.58	3451.92	100.00	100.00		

Figure 3. The chromatogram of HPLC analysis of the polyphenol compounds found in the alcoholic extraction of eggplant peels

The anthocyanin compounds found in the extracts indicated that cyanidin had a higher concentration than the other compounds.

The benefits of anthocyanin compound include protection against allergies and cardiovascular disease, enhancement of microcirculation, prevention of peripheral capillary fragility, prevention of diabetes, improvement of vision, and anti-allergic, anti-inflammatory, antiviral, antiproliferative, anti-mutagenic, anti-microbial, and anti-carcinogenic properties. Further studies on other physiological consequences are ongoing (Sivamaruthi et al., 2018).

Table 5. Effect of the eggplant peel extracts on glucose levels and kidney and liver function in alloxan-diabetic mice

Groups	Mean±SD					
	Glucose (mg/dL)	Creatinine (mg/dL)	Urea (mg/dL)	ALT (U/L)	AST (U/L)	Lipase (U/mL)
Healthy negative control	35.1±103.08^{a}	4.5±29.8^{ab}	0.3±1.01^{ab}	3.4±38.4^{a}	3.03±30.2^{a}	0.043±0.017^{a}
Diabetic positive control	244.3±43.8^{c}	6.1±44^{c}	0.8±1.37^{bc}	5.03±42.6^{a}	2.5±37.3^{ab}	0.070±0.03^{c}
Diabetic treated with crud extract at 250 mg/kg body weight	29.1±150.1^{b}	3.4±22.5^{a}	0.2±0.53^{a}	5.1±42.8^{a}	8.9 ±39.6^{b}	0.061±0.012^{bc}
Diabetic treated with oil extract at 8.53 mg/kg body weight	22.4±97.6^{a}	9.2±32.6^{b}	0.5±1.15^{abc}	4.6±43^{a}	6.8±38.7^{ab}	0.0674±0.031^{c}
Diabetic treated with alcoholic extract at 103.6 mg/kg body weight	39.7±172.9^{b}	5.2±27.8^{ab}	0.3±1.1^{ab}	4.5±41.8^{a}	3.8±39.6^{b}	0.0516±0.012^{ab}
Diabetic treated with anthocyanin extract at 79.26 mg/kg body weight	6.9±134.8^{ab}	3.1±22.1^{a}	0.7±1.9^{c}	3.5±38.6^{a}	4±34^{ab}	0.0586±0.0134^{bc}

Note: The vertical characters mean the significant difference at P≤0.05.

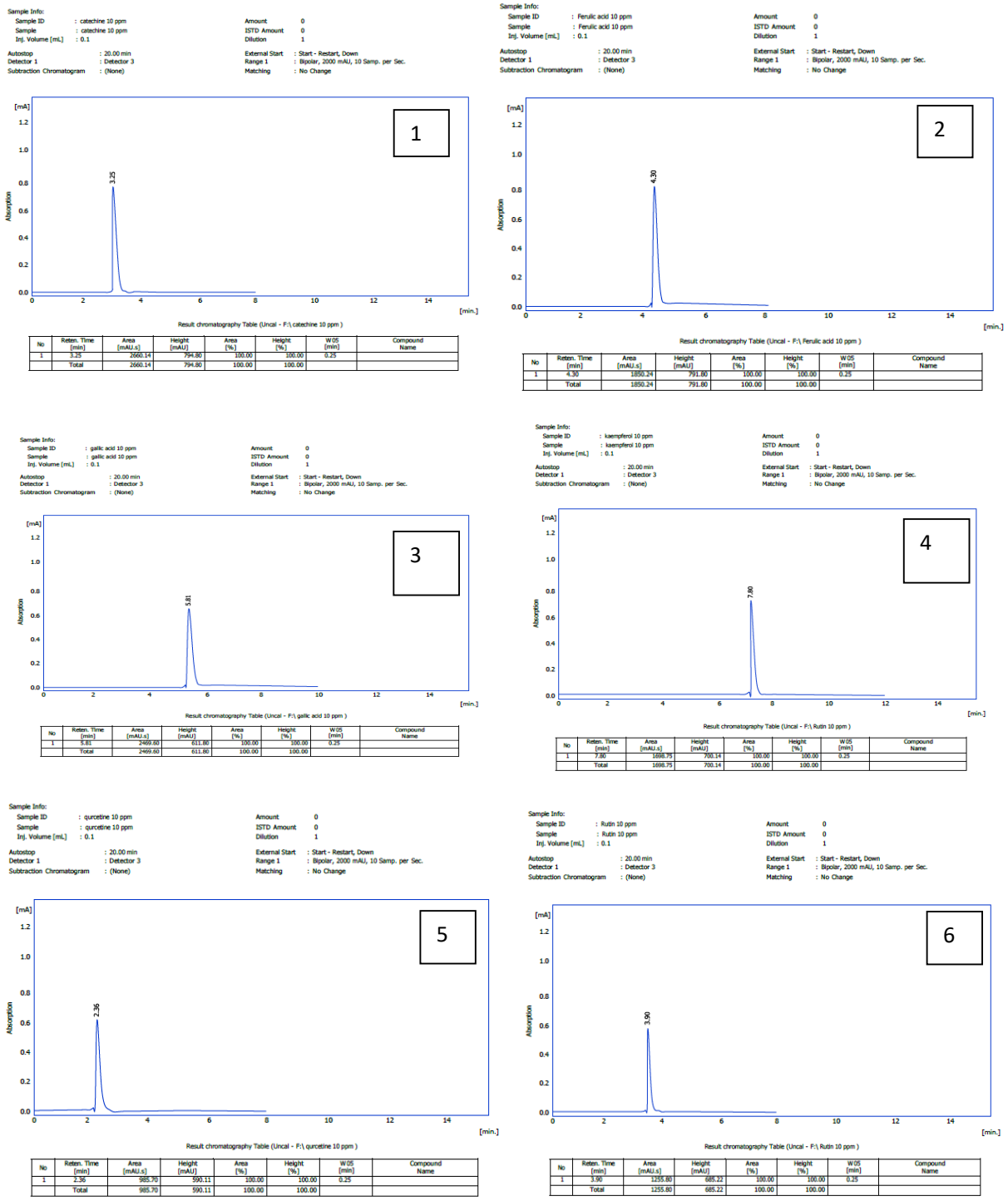
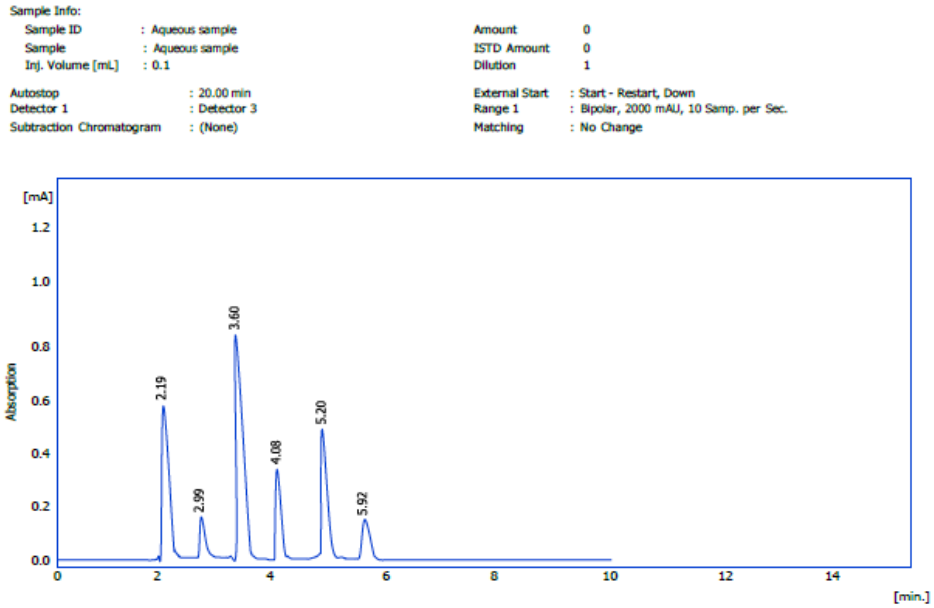


Figure 4. The chromatogram of HPLC analysis of the standard polyphenol compounds: 1-kaempferol, 2-catechin, 3-quercetin, 4-rutin, 5-ferulic acid, 6-gallic acid at 10 ppm

Diabetic Mice: Alloxan is a common compound with diabetogenic properties and is particularly toxic, especially to the beta cells in the pancreas (Solikhah et al, 2022). The effects of the crude extract were evident in all lipid profiles of the treated diabetic mice compared to the positive control untreated group; polyphenols may have a beneficial impact on disorders related to diabetes and obesity (Cory et al., 2018). Additional data points to the possibility of the benefits of phenolic compounds by interactions with gut microbiota, notably the bio-activation of phenolic compounds through gut bacterial metabolism (Marhuenda-Muñoz et al., 2019). Along with



Result chromatography Table (Uncal - F:\ Aqueous sample)

No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W 05 [min]	Compound Name
1	2.19	177854.08	590.25	26.00	26.00	0.20	
2	2.99	25414.15	180.99	9.00	9.00	0.10	
3	3.60	233952.40	860.22	27.00	27.00	0.30	
4	4.08	90652.14	362.81	11.00	11.00	0.15	
5	5.20	102632.00	492.10	16.00	16.00	0.20	
6	5.92	29654.11	178.99	11.00	11.00	0.10	
	Total	660158.79	2665.41	100.00	100.00		

Figure 5. The chromatogram of HPLC analysis of the anthocyanidin compounds found in the aqueous extract of eggplant peels

several other fruits and vegetables, eggplants have been found to contain high levels of dietary fiber (Adebawo et al., 2006), which can have a hypocholesterolemic effect. Studies have linked high insulin levels to aberrant clotting factors, hypertension, dyslipidemia, and atherosclerosis. It has been observed that dietary fiber reduces the body's insulinemic response to carbohydrates (Anderson et al., 1995).

In a different experiment, cyanidin and delphinidin, but not malvidin and peonidin, reduced the release of the risk factors for arteriosclerosis vascular endothelial (VEGF) in vascular smooth muscle cells upon stimulation by platelet-derived growth factor AB (PDGFAB)(Oak et al., 2006). Previous research on animals demonstrated that anthocyanin administration reduced serum lipid levels and fat formation. Acanthopanax senticosus activates 5′ adenosine monophosphate-activated protein kinase (AMPK) (Saito et al., 2016). Additionally, suppression

Table 6. Effect of the eggplant peel extracts on the atherogenic index in alloxan-diabetic mice

Groups	Mean±SD			
	TG/GLU	LDL/HDL	Cho/HDL	TG/HDL-C
Healthy negative control	0.21±4.68^{a}	0.07±0.39^{a}	0.101±1.62^{a}	0.24±1.13^{a}
Diabetic positive control	0.107±5.32^{b}	0.35±1.65^{b}	0.508±3.03^{b}	2.94±0.33^{b}
Diabetic treated with crud extract at 250 mg/kg body weight	0.34±4.59^{a}	0.97±2.15^{b}	1.24±2.47^{ab}	2.24±3.105^{b}
Diabetic treated with oil extract at 8.53 mg/kg body weight	0.06±4.62^{a}	0.25±0.65^{a}	0.11±1.88^{a}	0.34±2.08^{ab}
Diabetic treated with alcoholic extract at 103.6 mg/kg body weight	0.33±4.87^{a}	0.23±0.61^{a}	0.18±1.98^{a}	0.95±2.15^{ab}

Note: The vertical characters mean the significant difference at P≤0.05.

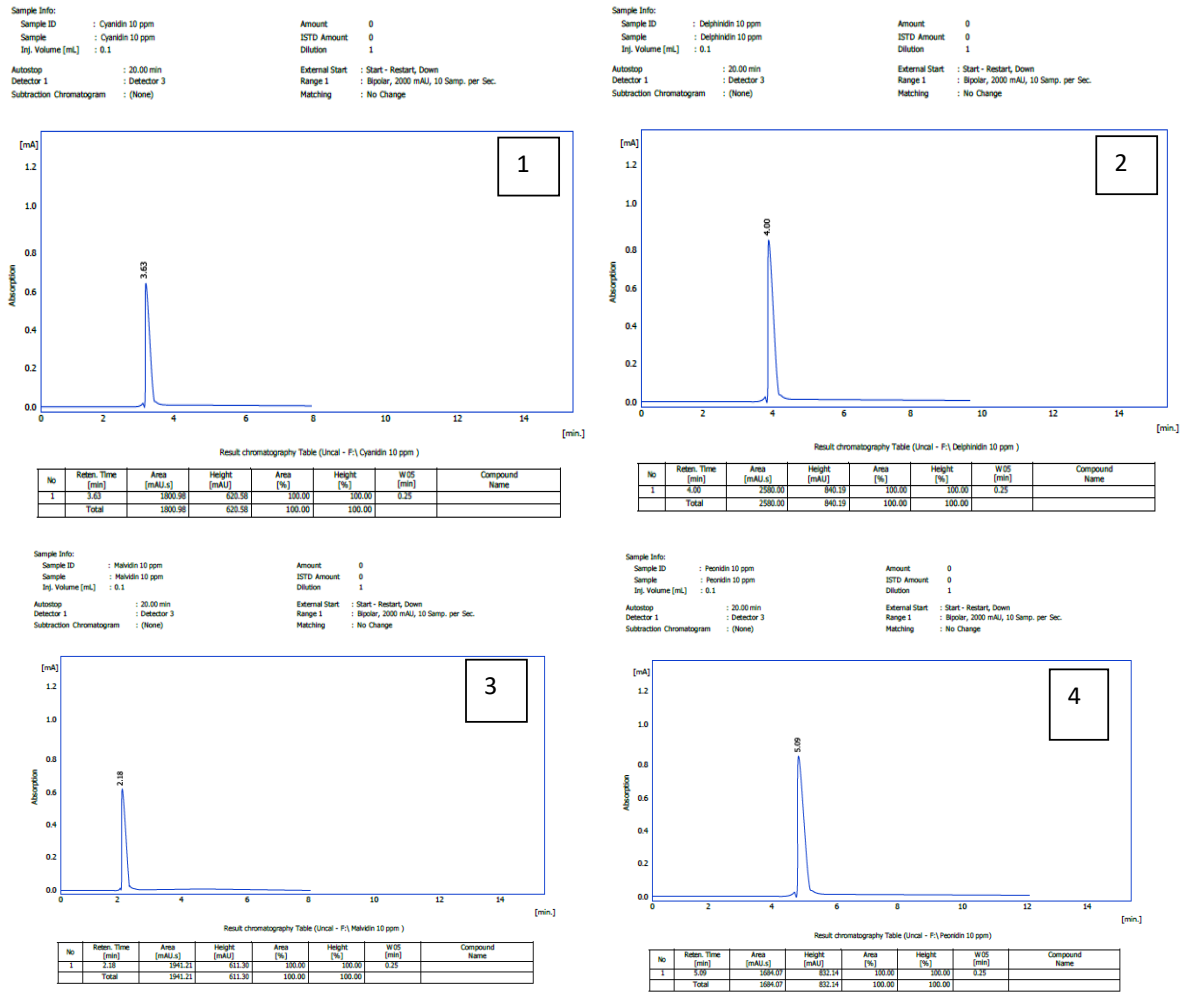


Figure 6. The chromatogram of HPLC analysis of the standard anthocyanin compounds: 1-delphinidin, 2-malvidin, 3-peonidin, 4-cyanidin at 10 ppm

of fatty acid synthase (FAS) and 3-hydroxy-3-methylglutaryl coenzyme A reductase expression by mulberry water extracts, as well as decreased expression of lipid metabolism-related genes such as *PPARγ* and sterol regulatory element-binding protein 1c (SREBP-1c) by Aronia melanocarpa extract, were observed. Similarly, in cell culture studies, an elevation of phosphorylated AMPK levels was noted (Lim et al., 2019).

In Table 5, we found beneficial effects of all the extracts on glucose levels when comparing the diabetic group positive control), with the alcoholic extracts illustrated the most significant effect. Some studies have demonstrated how plant extracts affect the activity of beta cells in the pancreas, enhance the inhibition of insulinase action, improve insulin sensitivity, or exhibit insulin-like activity. Additional mechanisms may be involved, including increased peripheral glucose consumption, increased hepatic glycogen synthesis, decreased glycogenolysis, suppression of intestinal glucose absorption, a reduced carbohydrate glycemic index, and decreased glutathione impact (Sharma et al., 2014).

Also, the anthocyanin extracts had a good hypoglycemic effect compared to the positive diabetic group. Antioxidant therapies (ANTs) can enhance insulin production and protect β cells by mitigating oxidative stress, leading to an improvement in insulin resistance and a reduction in postprandial glucose levels. Among the important compounds found in eggplant are polyamines, which play an important role as an antioxidant and improve insulin function (Rashan et al., 2023). While other parameters in the same table were not statistically and significantly affected by the treatment with extracts, this may be due to the experimental period being insufficient to reveal any effects.

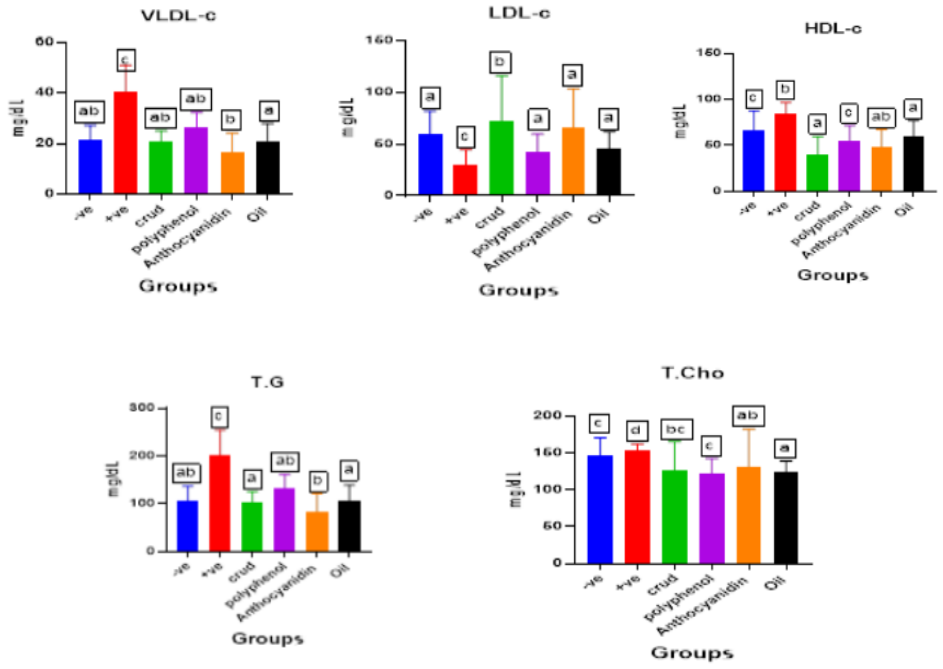


Figure 7. Different effects of eggplant extracts on the lipid profile

Lipoprotein lipase and lipase catalyze the hydrolysis of the TG component of circulating chylomicrons and VLDL-c (Mead et al., 2002). Patients with type 1 diabetes mellitus had higher HDL-C and lower VLDL-C and TG levels compared to healthy subjects, and these variations contributed to an increase in lipoprotein lipase activity (Nikkilä & Hormila, 1978). In this study, a significant increase in lipase activity was observed in diabetic mice compared to healthy controls, and treatment with

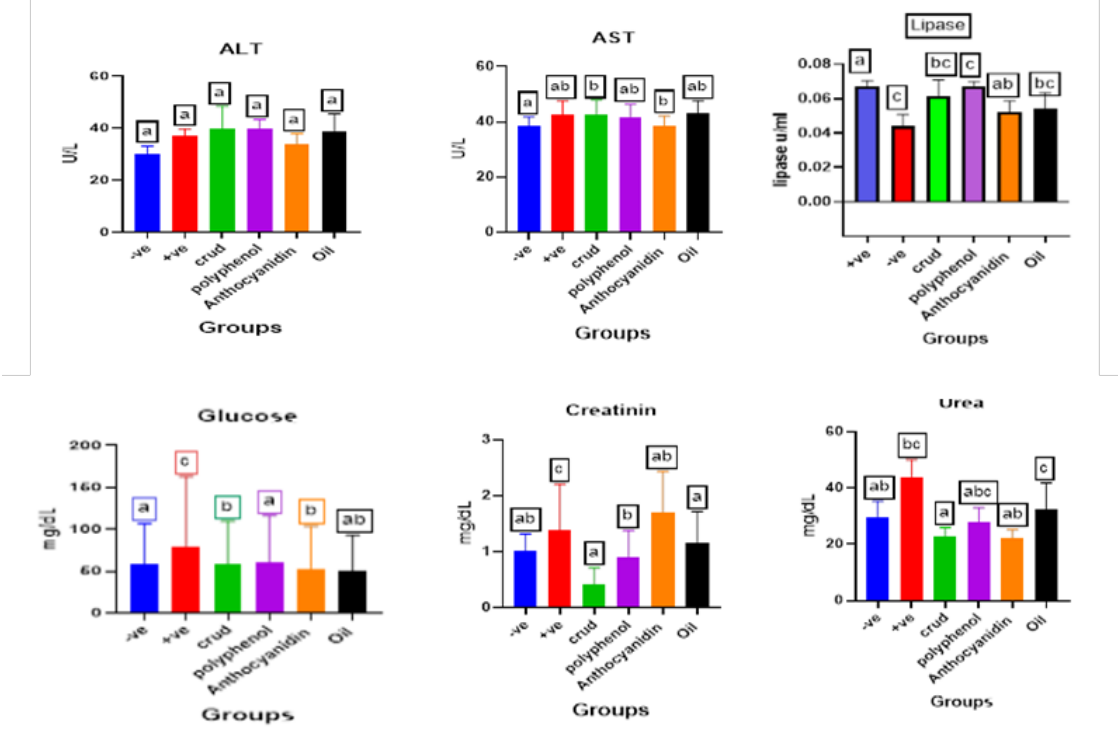


Figure 8. Different effects of eggplant extracts on glucose, renal, and liver function

extracts resulted in a notable decrease in lipase activity, with anthocyanins showing the most pronounced effect.

Table 6 shows that the atherogenic index decreased in all treated groups compared to the positive controls, and the TG/Glu index also decreased. This decrease may be due to the extracts' influence on the consumption of glucose rather than on the transfer or storage of TG (Stinkens et al., 2015). Both oil and alcoholic extracts demonstrated a beneficial effect on the LDL/HDL and total cholesterol/HDL ratios, indicating that a higher level of HDL-C is associated with lower LDL-C, leading to improved lipid metabolism and a decreased risk of atherosclerosis.

Conclusion

Diabetes mellitus has become one of the most hazardous diseases in the world, creating a demand for other therapy protocols. In this research, crude, alcoholic, oil, and anthocyanin extracts of eggplant peel showed significant effects on lipid profiles, atherogenic index, and glucose levels. The crude extract showed the most substantial effect on lowering the blood glucose levels, as well as on the levels of VLDL-c, and LDL-c, while the anthocyanins extract showed a better effect on HDL-C and TG, and T-Cholevels. Given that these extracts are derived from the peels of a safe food fruit, we recommend their use for regulating fat and sugar levels in individuals with diabetes.

Ethical Considerations

Compliance with ethical guidelines

The study protocol was approved by the Animal Ethics Committee of the University of Mosul, Mosul, Iraq.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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مقاله پژوهشی

تأثیر عصاره‌های پوست ملونژنا بر سطح گلوکز و پارامترهای بیوشیمیایی در موش‌های دیابتی آلوکسان

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چکیده

زمینه مطالعه: ترکیبات طبیعی بی خطر هستند و معمولاً در پزشکی استفاده می شوند. دیابت یک بیماری متابولیک مزمن است که به طور گسترده در جهان گسترش یافته است. بسیاری از مطالعات نشان داده اند که محصولات طبیعی می توانند سطح قند خون را کاهش دهند. این اثر پانکراس و مسیرهای متابولیک را کنترل می کند.

هدف: هدف از این تحقیق استخراج برخی از ترکیبات موثر از پوست بادمجان و بررسی تأثیر آن‌ها بر سطح گلوکز خون، پروفایل لیپیدی، عملکرد کلیه و آنزیم های کبدی در موش های دیابتی می‌باشد.

روش کار: این مطالعه برای جداسازی عصاره خام و برخی فرآورده های طبیعی مانند روغن ها، پلی فنل ها و آنتوسیانین ها مورد استفاده قرار گرفت. این عصاره ها به ترتیب با گاز کروماتوگرافی و کروماتوگرافی مایع با کارایی بالا شناسایی شدند. برخی از پارامترها مانند گلوکز، اوره، کراتینین، تری گلیسیرید، کلسترول لیپوپروتئین با چگالی بالا، کلسترول لیپوپروتئین با چگالی کم، کلسترول لیپوپروتئین با چگالی بسیار کم، آلانین ترانس آمیناز، آسپارتات آمینووژنپاسفراز دیابتی و لیپوپروتئین مالزی، و لیپوپروتئین با چگالی پایین، اندازه گیری شد.

نتایج: نتایج نشان داد که بسیاری از اسیدهای چرب، پلی فنل ها و ترکیبات آنتوسیانین در پوست بادمجان وجود دارد. پس از ۱۰ روز درمان در موش های دیابتی با عصاره های فوق، تأثیر معنی داری در پروفایل لیپیدی، گلوکز، کراتینین و لیپاز مشاهده شد. در حالی که اثر غیر قابل توجهی در HDL-c و اوره با عصاره روغن و پلی فنل به دست آمد. با این وجود، هیچ تاثیری بر سطوح AST و ALT با تمام عصاره ها وجود ندارد.

نتیجه‌گیری نهایی: در این مطالعه، اثرات این عصاره‌ها مخلوط شده است. با این حال، آنها اثرات خوبی بر گلوکز خون، سطح کراتینین و پروفایل لیپیدی داشتند. این عصاره ها ممکن است به کاهش شدت دیابت یا عوارض آن کمک کنند. هیچ اثر واضحی در آزمایشات عملکرد کبد نشان داده نشد.

کلیدواژه‌ها: آنتوسیانین، شاخص آتروژنیک، دیابت شیرین، اسیدهای چرب، پلی فنل.

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