HNUE JOURNAL OF SCIENCE
Natural Sciences 2026, Volume 71, Issue 1, pp. 122-132
This paper is available online at http://hnuejs.edu.vn/ns
DOI: 10.18173/2354-1059.2026-0011

ANTIOXIDANT ACTIVITY AND SELECTED METABOLIC EFFECTS OF ETHANOL EXTRACT FROM MANGOSTEEN (*Garcinia mangostana* L.) PERICARP IN HIGH-FAT DIET–INDUCED MICE: AN *IN VITRO* AND *IN VIVO* STUDY

Nguyen Thi Hien[1], Le Thi Tuoi[2], Tran Thu Ngan[2] and Nguyen Thi Hong Hanh[2,*]

[1]*Faculty of Food Technology, University of Economics - Technology for Industries, Hanoi, Vietnam*

[2]*Faculty of Biology, Hanoi National University of Education, Hanoi, Vietnam*

[*]Corresponding author: Nguyen Thi Hong Hanh, e-mail: hanhnth@hnue.edu.vn

Received January 1, 2026. Revised January 26, 2026. Accepted March 30, 2026.

Abstract. Mangosteen (*Garcinia mangostana* L.) pericarp is a rich source of polyphenolic xanthones and other bioactive compounds with potential antioxidant and metabolic regulatory properties. This study investigated the *in vitro* antioxidant activity and selected *in vivo* metabolic effects of ethanol extract from mangosteen pericarp. Mangosteen pericarp collected from Lam Dong province was extracted with 60% ethanol. The extract was characterized for total phenolic content by the Folin–Ciocalteu method. Antioxidant capacity was evaluated using the DPPH radical scavenging assay. For the *in vivo* study, male white mice (*Mus musculus*) were divided into four groups: a regular diet (RD), a high-fat diet (HFD), an HFD with extract at 300 mg/kg, and an HFD with extract at 400 mg/kg. Liver weight, spleen weight, and fasting blood glucose levels were measured after 8 weeks. The extract exhibited a high total phenolic content (200.16 ± 17.71 mg gallic acid equivalents/g extract) and showed dose-dependent DPPH radical scavenging activity with a half maximal inhibitory concentration (IC_{50}) value of 118.87 ± 13.56 µg/mL, indicating a moderate but reproducible antioxidant capacity. *In vivo*, the HFD group showed significantly increased blood glucose levels (10.38 ± 3.54 mmol/L) compared to RD controls (7.57 ± 3.45 mmol/L). Treatment with the extract at 400 mg/kg significantly reduced glucose levels (5.16 ± 0.93 mmol/L, $p < 0.05$) compared to the HFD group. The extract at 300 mg/kg showed intermediate effects (9.89 ± 2.77 mmol/L). No statistically significant differences were observed in liver or spleen weights among the groups. In summary, the mangosteen pericarp ethanol extract is rich in phenolics, exhibits moderate antioxidant activity *in vitro,* and demonstrates dose-dependent protective effects against HFD-induced hyperglycemia. While the *in vivo* metabolic assessment was limited to selected endpoints, these findings provide preliminary evidence supporting the potential of the mangosteen pericarp extract for further investigation in diet-induced metabolic dysfunction models.

Keywords: *Garcinia mangostana*, mangosteen pericarp, polyphenols, antioxidant activity, high-fat diet.

1. Introduction

Metabolic disorder represents a cluster of conditions, including obesity, insulin resistance, dyslipidemia, and hypertension, which collectively increase the risk of cardiovascular disease and type 2 diabetes mellitus [1]. The prevalence of metabolic syndrome has reached epidemic proportions globally, affecting approximately 25% of the adult population [2]. High-fat diet (HFD) consumption is a major contributing factor to the development of metabolic disorders through multiple mechanisms, including oxidative stress, chronic inflammation, and insulin resistance [3].

Oxidative stress, characterized by an imbalance between reactive oxygen species (ROS) production and antioxidant defense mechanisms, plays a crucial role in the pathogenesis of metabolic disorders [4]. Excessive ROS generation leads to lipid peroxidation, protein oxidation, and DNA damage, contributing to cellular dysfunction and tissue injury [5]. Therefore, compounds with antioxidant properties have garnered significant attention as potential therapeutic agents for the prevention and treatment of metabolic disorders.

Natural plant extracts have been extensively investigated for their health-promoting properties, particularly their antioxidant activities [6]. Many medicinal plants contain diverse phytochemical constituents, including polyphenols, flavonoids, and terpenoids, which exhibit potent free radical scavenging capabilities [7]. The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay is one of the most widely used methods for evaluating antioxidant capacity due to its simplicity, sensitivity, and reproducibility [8].

Mangosteen (*Garcinia mangostana* L.), a tropical fruit widely distributed in Southeast Asia, has long been used in traditional medicine for the management of metabolic and inflammatory disorders [9]. Its pericarp is particularly rich in xanthones, especially α-mangostin and γ-mangostin, which together can account for up to 30–40% of the dry weight [10], [11]. These bioactive compounds have demonstrated strong antioxidant, anti-inflammatory, and metabolic regulatory properties [12], [13]. Although previous *in vitro* studies have confirmed their potent antioxidant capacity [14], [15], evidence regarding their *in vivo* metabolic effects remains limited and warrants further investigation. The translation of antioxidant effects from *in vitro* to *in vivo* systems is complex due to factors such as bioavailability, metabolism, and distribution [16]. Furthermore, the relationship between antioxidant activity and metabolic outcomes in HFD-induced models requires comprehensive evaluation.

In this study, we characterized the total phenolic content of the mangosteen pericarp ethanol extract and evaluated its *in vitro* antioxidant activity using the DPPH radical scavenging assay. In addition, selected *in vivo* metabolic effects were assessed in mice fed an HFD. We hypothesized that the polyphenol-rich extract would exhibit measurable antioxidant capacity *in vitro* and exert dose-dependent effects on fasting glycemic status under HFD conditions. The findings of this study provide preliminary scientific support for the traditional use of mangosteen and offer a basis for further investigation of its bioactive constituents and their potential roles in diet-induced metabolic dysfunction.

2. Content

2.1. Materials and methods

2.1.1. Plant material and extraction

Mangosteen (*Garcinia mangostana* L.) was collected in Lam Dong province (2023). Pericarps were dried, avoiding direct sunlight, and stored at -21 °C. The dried material was crushed to a powder (100% passing a 1.0 mm sieve) and extracted with 60% ethanol (1 kg: 20 L ratio) in a thermal bath at 60 °C for 120 minutes. This process was repeated three times. The combined filtrates were concentrated under vacuum below 60 °C and freeze-dried. The extract yield was approximately 18 - 22% (w/w).

2.1.2. Total phenolic content determination

Total phenolic content (TPC) was determined using the Folin-Ciocalteu method [17]. Mangosteen pericarp extract (0.05 - 0.10 g) was dissolved in distilled water to make stock solutions. The extract solution was diluted 20-fold before analysis. In a test tube, 200 µL of diluted sample was mixed with 1.0 mL of Folin-Ciocalteu reagent (diluted 1:10 with distilled water) and allowed to stand for 5 minutes. Then, 0.8 mL of 7.5% sodium carbonate solution was added. The mixture was vortexed and incubated in the dark at room temperature for 30 minutes. Absorbance was measured at 750 nm using a UV-Vis spectrophotometer.

A calibration curve was prepared using gallic acid at concentrations of 0, 20, 60, 80, and 100 µg/mL. Total phenolic content was expressed as mg of gallic acid equivalents per gram of dry extract (mg GAE/g). All determinations were performed in triplicate.

2.1.3. DPPH radical scavenging assay

Antioxidant activity was evaluated using the DPPH assay. DPPH solution (0.1 mM in ethanol) was mixed with samples (20 µL sample + 230 µL DPPH) in 96-well plates and incubated for 30 minutes at room temperature in the dark. Absorbance was measured at 517 nm. The inhibition percentage was calculated as $[(A_0 - A_1) / A_0] \times 100$, where A_0 represents the absorbance of the control (DPPH solution without sample) and A_1 represents the absorbance in the presence of the sample. Half maximal inhibitory concentration (IC_{50}) values were determined by logarithmic regression analysis. Specifically, concentration values (in µg/mL) were natural log-transformed, and linear regression was performed with % inhibition as the dependent variable (y-axis) and ln(concentration) as the independent variable (x-axis), yielding equations of the form $y = a \cdot \ln(x) + b$. The IC_{50} was then calculated by solving for x when y = 50: $IC_{50} = \exp[(50 - b)/a]$. Ascorbic acid was used as the positive control. Experiments were performed in triplicate.

2.1.4. Animal models

Healthy male white mice (*Mus musculus*), aged 4-6 weeks, weighing 18 - 22 g, were sourced from the National Institute of Hygiene and Epidemiology, Vietnam. Mice were housed under controlled conditions (25 - 27 °C, 40-60% humidity, 12-hour light-dark cycle) with free access to food and water. After one week acclimatization, mice were randomly divided into four groups (n = 6): (1) Regular diet (RD, 100% standard

chow pellets; ≈ 360 kcal/100 g), (2) High-fat diet (HFD, consisting of 54% standard chow and 46% boiled pork fat; ≈ 600 kcal/100 g), (3) HFD + Extract 300 mg/kg, (4) HFD + Extract 400 mg/kg. The extracts were suspended in 5% (v/v) ethanol and administered at a dose volume of 0.5 mL per mouse. The extract was administered daily by oral gavage for 8 weeks. Mice in the RD group received an equivalent volume of 5% (v/v) ethanol following the same administration schedule. Body weight was measured every 7 days, and food intake was recorded daily using the same calibrated electronic balance with a precision of 0.001 g. All animal experimental procedures were approved by the University of Economics – Technology for Industries and were conducted in accordance with institutional guidelines for the care and use of laboratory animals. Mice were randomly assigned to experimental groups to minimize selection bias, with baseline body weights balanced across groups.

2.1.5. Sample collection and analysis

Mice were fasted for 12 hours prior to euthanasia. Euthanasia was performed by cervical dislocation (spinal cord separation). Animals were then placed in the dorsal recumbency, and a midline incision was made to expose the internal organs. The liver and pancreas were carefully excised and weighed.

2.1.6. Blood glucose measurement

Following the induction of anesthesia, blood samples were collected via cardiac puncture. Fasting blood glucose levels were analyzed by Medlatec Laboratory using standard clinical biochemical methods.

2.1.7. Statistical analysis

All experimental data were processed and analyzed using SPSS version 16.0 and Microsoft Excel (Microsoft 365) for preliminary data handling and graphical visualization. Results are expressed as mean ± standard deviation (SD). Comparisons among multiple experimental groups were performed using one-way analysis of variance (ANOVA). When a significant overall effect was detected, Tukey's HSD post hoc multiple comparison test was applied to identify pairwise differences between groups. A *p-value* < 0.05 was considered statistically significant.

For *in vitro* antioxidant assays, each experiment was conducted in triplicate (n = 3) using independently prepared samples. The DPPH radical scavenging activity was expressed as a percentage of inhibition relative to the control. The mean IC_{50} value was reported together with the SD to reflect inter-experimental variability. The coefficient of variation (CV) was calculated to assess the reproducibility of the assay using the formula:

$$\text{CV (\%)} = \frac{\text{SD}}{\text{Mean}} \times 100$$

2.2. Results and discussion

2.2.1. Total phenolic content

The total phenolic content of mangosteen pericarp extract was determined using the Folin-Ciocalteu assay. The gallic acid standard curve showed excellent linearity over the range of 0-100 µg/mL with regression equation y = 0.0231x + 0.1461 (R^2 = 0.9909)

(Figure 1). Across three independent analyses, the total phenolic content was 200.16 ± 17.71 mg GAE/g extract (Table 1), with a coefficient of variation of 8.9%, demonstrating good reproducibility of the extraction and analysis procedures. The result indicates that phenolic compounds constitute approximately 20% of the extract by dry weight.

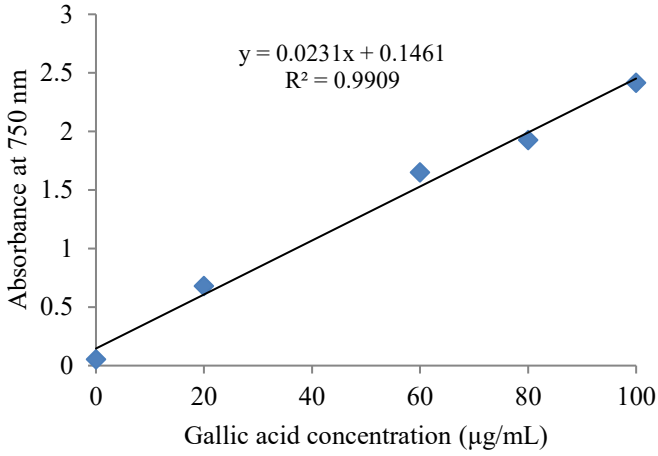

Figure 1. Gallic acid standard curve for total phenolic content determination

The total phenolic content observed in our extract (200.16 mg GAE/g) is within the reported range for mangosteen pericarp extracts, which typically contain 150 - 300 mg GAE/g depending on extraction solvent and conditions, with polyphenolic xanthones such as α-mangostin and γ-mangostin representing the major bioactive constituents [13], [15]. This substantial polyphenol content is comparable to other tropical fruit extracts known for antioxidant properties [7], [16]. This biochemical characterization provides important context for understanding both the *in vitro* and *in vivo* effects observed.

Table 1. Total phenolic content of mangosteen pericarp ethanol extract

Parameter	Value
Total phenolic content (mg GAE/g)	200.16 ± 17.71
CV (%)	8.9
Range (mg GAE/g)	182.20 - 217.62

Data are mean ± SD (n=3). GAE: gallic acid equivalents
CV: Coefficient of Variation. CV (%) = (SD / Mean) × 100. CV (%) = (SD / Mean) × 100

2.2.2. *In vitro* antioxidant activity of mangosteen pericarp ethanol extract

The DPPH radical scavenging activity of mangosteen pericarp ethanol extract is presented in Table 2. The extract exhibited a clear, dose-dependent increase in antioxidant activity over the tested concentration range. At the lowest tested concentration (115 - 116 µg/mL), the extract inhibited 46.42 ± 2.89% of DPPH radicals. Increasing the concentration to 230–232 µg/mL resulted in a marked increase in inhibition to 64.10 ± 1.16%. Further increases in concentration to 460 - 464 µg/mL and

920 - 928 μg/mL led to inhibition values of 76.87 ± 0.81% and 80.04 ± 0.64%, respectively.

Based on logarithmic regression analysis of the dose–response data, the mean IC_{50} value of the extract was calculated to be 118.87 ± 13.56 μg/mL, with a coefficient of variation of 11.4%, indicating acceptable reproducibility across three independent experiments.

Ascorbic acid, used as a positive control, showed stronger radical scavenging activity with an IC_{50} value of 0.177 mM (31.21 μg/mL). Accordingly, the antioxidant potency of the mangosteen pericarp extract was approximately 3.8-fold lower than that of ascorbic acid.

Table 2. DPPH radical scavenging activity of mangosteen pericarp ethanol extract compared with ascorbic acid

Sample	Dilution Factor	Concentration	Absorbance (517 nm)	Inhibition (%)
Mangosteen Pericarp Extract	80× dilution	115-116 μg/mL*	0.227 ± 0.012	46.42 ± 2.89
	40× dilution	230-232 μg/mL*	0.152 ± 0.005	64.10 ± 1.16
	20× dilution	460-464 μg/mL*	0.098 ± 0.003	76.87 ± 0.81
	10× dilution	920-928 μg/mL*	0.085 ± 0.003	80.04 ± 0.64
	Mean IC_{50} = 118.87 ± 13.56 μg/mL, CV = 11.4%			
Ascorbic Acid	-	0 (Control)	0.424 ± 0.006	0.00
	-	0.1 mM	0.279 ± 0.009	34.20 ± 2.04
	-	0.2 mM	0.196 ± 0.018	53.69 ± 4.29
	-	0.4 mM	0.112 ± 0.033	73.66 ± 7.75
	-	0.8 mM	0.063 ± 0.003	85.14 ± 0.71
	IC_{50} = 0.177 mM (31.21 μg/mL)			

Data are presented as mean ± SD (n = 3); IC_{50}: Half maximal inhibitory concentration
CV: Coefficient of variation. CV (%) = (SD / Mean) × 100
**Concentration ranges represent minor variation across three independent experiments due to differences in stock preparation (CV < 1%).*

The findings of this study indicate that mangosteen pericarp ethanol extract possesses moderate and reproducible *in vitro* antioxidant activity, consistent with its high total phenolic content. Polyphenolic compounds, particularly xanthones such as α-mangostin and γ-mangostin, which are well-established as the primary bioactive constituents in mangosteen pericarp [9], [11], possess multiple hydroxyl groups that enable efficient hydrogen donation for ROS neutralization, the mechanistic basis of the DPPH assay. While the DPPH IC_{50} was approximately 3.8-fold higher than pure ascorbic acid, this is expected given that the extract is a complex mixture rather than a purified compound. The relationship between total phenolic content and antioxidant activity is well-documented in the literature, with polyphenol-rich plant extracts

generally demonstrating proportional free radical scavenging abilities [13], [15], and our findings align with this established principle.

2.2.3. *In vivo* effects of mangosteen pericarp ethanol extract

The polyphenolic content and antioxidant capacity observed *in vitro* may partially explain the effects of mangosteen pericarp ethanol extract demonstrated *in vivo*.

**** Visual morphological assessment***

Representative images of mice from different experimental groups are shown in Figure 2A. After 8 weeks of HFD feeding, mice displayed visibly increased body size and abdominal adiposity compared to RD controls. Treatment with mangosteen pericarp extract at both doses appeared to attenuate these morphological changes, with the 400 mg/kg group showing a body habitus more similar to RD controls.

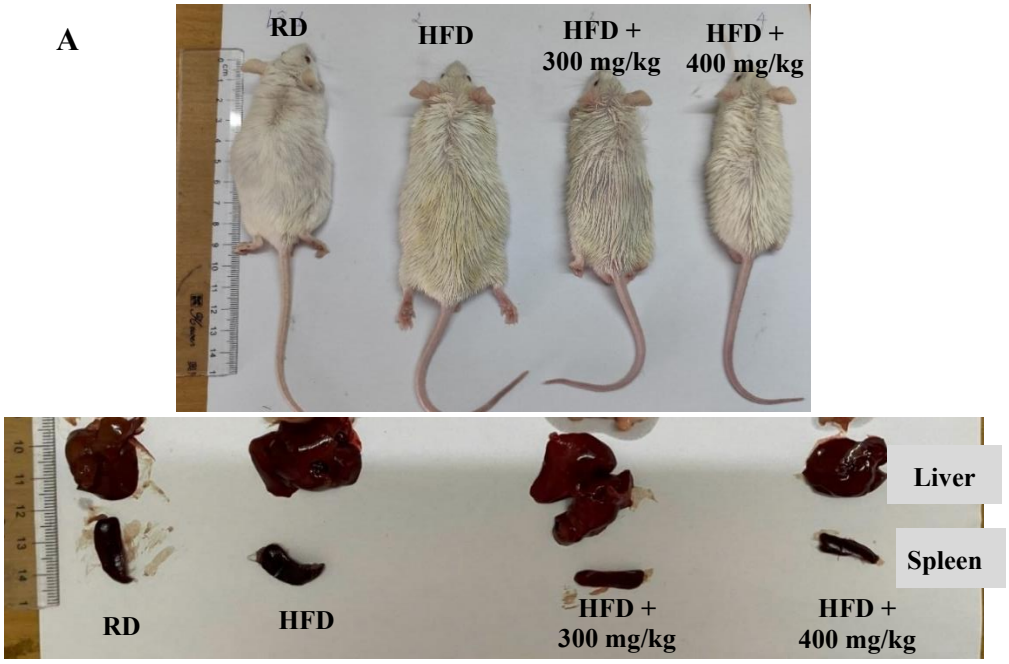

Figure 2. Effects of mangosteen pericarp ethanol extract on body morphology (A) and organ appearance (B) in mice

A metric ruler is shown for size reference. Images are representative of n = 6 animals per group. RD: Regular diet; HFD: High-fat diet

Macroscopic examination of organs revealed notable differences (Figure 2B). Following 8 weeks of HFD feeding, the liver of HFD-fed mice appeared enlarged and paler in color compared with RD controls, while the spleen appeared reduced in size. These macroscopic observations are indicative of diet-induced organ alterations but do not allow definitive conclusions regarding hepatic lipid accumulation. Treatment with mangosteen pericarp extract at both doses was associated with observable differences in liver appearance compared with the HFD group, with size and coloration closer to those of RD controls. Modest changes in spleen morphology were also noted following extract administration; however, these observations were not supported by statistically

significant differences in organ weights. These macroscopic observations are consistent with the quantitative organ weight measurements presented in Table 3.

**** Metabolic parameters***

After 8 weeks, significant alterations were observed in metabolic parameters (Table 3). Both doses appeared to stabilize liver weights and partially restore spleen weights.

Table 3. Effects of mangosteen extract on metabolic parameters in HFD-fed mice

Parameter	**RD (n = 6)**	**HFD (n = 6)**	**HFD + Extract 300 mg/kg (n = 6)**	**HFD + Extract 400 mg/kg (n = 6)**	***p***
Liver weight (g)	3.37 ± 1.08	3.48 ± 0.73	3.15 ± 0.33	3.23 ± 0.23	0.620
Spleen weight (g)	0.54 ± 0.34	0.28 ± 0.13	0.26 ± 0.10	0.22 ± 0.07	0.376
Glucose (mmol/L)	7.57 ± 3.45	10.38 ± 3.54$^{\#}$	9.89 ± 2.77	5.16 ± 0.93*	0.048

RD: Regular diet; HFD: High-fat diet. Data are mean ± SD.
$^{\#}$ $p < 0.05$ vs. RD; * $p < 0.05$ vs. HFD.

The liver weights showed minimal variation across all experimental groups. The RD control group exhibited a mean liver weight of 3.37 ± 1.08 g. HFD feeding resulted in a slight, non-significant increase in liver weight to 3.48 ± 0.73 g, which may reflect HDF-induced alterations in liver mass related to hepatic lipid accumulation [18]. Treatment with the ethanol extract at both dosages appeared to attenuate this increase. Animals receiving 300 mg/kg extract showed a liver weight of 3.15 ± 0.33 g, while those receiving 400 mg/kg exhibited 3.23 ± 0.23 g, but the difference was not significant ($p > 0.05$).

Spleen weight exhibited a decreasing trend in response to the HFD. The RD group showed a mean spleen weight of 0.54 ± 0.34 g, whereas HFD feeding reduced this value to 0.28 ± 0.13 g. This reduction may reflect immune dysregulation or altered splenic function associated with HFD-induced metabolic stress [19]. Administration of mangosteen pericarp extract at doses of 300 and 400 mg/kg resulted in spleen weights of 0.26 ± 0.10 g and 0.22 ± 0.07 g, respectively. However, these differences were not statistically significant among groups ($p = 0.376$). Although the extract did not significantly reverse HFD-induced changes in spleen weight, the observed trend may suggest a modest modulatory effect on splenic responses under metabolic stress.

The most striking and statistically significant findings were observed in fasting blood glucose levels. HFD increased glucose levels significantly (10.38 ± 3.54 vs. 7.57 ± 3.45 mmol/L in RD, $p < 0.05$). The 400 mg/kg dose dramatically reduced glucose (5.16 ± 0.93 mmol/L, $p < 0.05$ vs. HFD), representing 50% reduction. The 300 mg/kg dose showed moderate effects (9.89 ± 2.77 mmol/L).

The 50% glucose reduction with 400 mg/kg extract surpasses many reported plant extracts [20], [21] and likely involves multiple mechanisms. In support of this, the enzyme inhibition assays revealed that the extract exhibited moderate α-glucosidase inhibitory activity, with an IC_{50} value of 99.37 μg/mL, suggesting a potential role in delaying intestinal carbohydrate digestion and glucose absorption [22]. α-Mangostin has been shown to enhance GLUT4 translocation, activate AMPK signaling, and improve insulin sensitivity [23]. Additionally, mangosteen xanthones inhibit α-glucosidase and α-amylase, thereby reducing postprandial glucose spikes [24]. The antioxidant properties may also improve insulin signaling by reducing oxidative modification of insulin receptor substrates [25]. Furthermore, mangosteen xanthones have demonstrated hepatoprotective effects through modulation of lipid metabolism genes and reduction of hepatic triglyceride accumulation [23], [26]. The spleen weight findings, though modest, suggest potential immunomodulatory effects warranting further investigation, as metabolic syndrome is associated with immune dysregulation [19].

Study limitations include the 8-week duration and the lack of comprehensive lipid profiles, insulin levels, and histopathological examination. Future studies should identify specific bioactive compounds responsible for these effects, elucidate molecular mechanisms through gene and protein expression analysis, and evaluate long-term safety. Clinical translation requires pharmacokinetic studies and the standardization of xanthone content.

3. Conclusions

Mangosteen pericarp ethanol extract is enriched in phenolic compounds (200.16 ± 17.71 mg GAE/g) and exhibits moderate, reproducible *in vitro* antioxidant activity as determined by DPPH radical scavenging (IC_{50} = 118.87 μg/mL). The high total phenolic content of the extract likely contributes to this antioxidant capacity. In HFD-induced mice, the 400 mg/kg dose reduced fasting glucose by 50%, suggesting a marked reduction in fasting blood glucose levels mediated by phenolic compounds. However, changes in liver and spleen weights were not statistically significant. These findings provide preliminary scientific support for the traditional use of mangosteen and suggest its potential role in improving glycemic status. Future research should focus on phytochemical characterization, mechanistic studies, and clinical evaluation.

REFERENCES

[1] Alberti KG, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, Fruchart J-C, James WPT, Loria CM, Smith SC Jr, (2009). Harmonizing the metabolic syndrome: a joint interim statement of the international diabetes federation task force on epidemiology and prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of obesity. *Circulation*, 120(16), 1640-1645. doi: 10.1161/CIRCULATIONAHA.109.192644.

[2] Saklayen MG, (2018). The global epidemic of the metabolic syndrome. *Current Hypertension Reports*, 20(2), 1-8. doi: 10.1007/s11906-018-0812-z.

[3] Hariri N & Thibault L, (2010). High-fat diet-induced obesity in animal models. *Nutrition Research Reviews*, 23(2), 270-299. doi: 10.1017/S0954422410000168.

[4] Matsuda M & Shimomura I, (2013). Increased oxidative stress in obesity: implications for metabolic syndrome, diabetes, hypertension, dyslipidemia, atherosclerosis, and cancer. *Obesity Research & Clinical Practice*, 7(5), e330-e341. doi: 10.1016/j.orcp.2013.05.004.

[5] Newsholme P, Cruzat VF, Keane KN, Carlessi R & de Bittencourt Jr PIH, (2016). Molecular mechanisms of ROS production and oxidative stress in diabetes. *Biochemical Journal*, 473(24), 4527-4550. doi: 10.1042/BCJ20160503C.

[6] Newman DJ & Cragg GM, (2020). Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. *Journal of Natural Products*, 83(3), 770-803. doi: 10.1021/acs.jnatprod.9b01285.

[7] Panche AN, Diwan AD & Chandra SR, (2016). Flavonoids: an overview. *Journal of Nutritional Science*, 5, e47. doi: 10.1017/jns.2016.41.

[8] Kedare SB & Singh RP, (2011). Genesis and development of DPPH method of antioxidant assay. *Journal of Food Science and Technology*, 48(4), 412-422. doi: 10.1007/s13197-011-0251-1.

[9] Pedraza-Chaverri J, Cárdenas-Rodríguez N, Orozco-Ibarra M & Pérez-Rojas JM, (2008). Medicinal properties of mangosteen (*Garcinia mangostana*). *Food and Chemical Toxicology*, 46(10), 3227-3239. doi: 10.1016/j.fct.2008.07.024.

[10] Ovalle-Magallanes B, Eugenio-Pérez D & Pedraza-Chaverri J, (2017). Medicinal properties of mangosteen (*Garcinia mangostana* L.): A comprehensive update. *Food and Chemical Toxicology*, 109, 102-122. doi: 10.1016/j.fct.2017.08.021.

[11] Ibrahim MY, Hashim NM, Mariod AA, Mohan S, Abdulla MA, Abdelwahab SI & Arbab IA, (2016). *α*-Mangostin from *Garcinia mangostana* Linn.: An updated review of its pharmacological properties. *Arabian Journal of Chemistry*, 9(3), 317-329. doi: 10.1016/j.arabjc.2014.02.011.

[12] Akao Y, Nakagawa Y, Iinuma M & Nozawa Y, (2008). Anti-cancer effects of xanthones from pericarps of mangosteen. *International Journal of Molecular Sciences*, 9(3), 355-370. doi: 10.3390/ijms9030355.

[13] Jung HA, Su BN, Keller WJ, Mehta RG & Kinghorn AD, (2006). Antioxidant xanthones from the pericarp of *Garcinia mangostana* (Mangosteen). *Journal of Agricultural and Food Chemistry*, 54(6), 2077-2082. doi: 10.1021/jf052649z.

[14] Oh Y, Do HTT, Kim S, Kim YM, Chin YW & Cho J, (2020). Memory-enhancing effects of mangosteen pericarp water extract through antioxidative neuroprotection and anti-apoptotic action. *Antioxidants*, 10(1), 34. doi: 10.3390/antiox10010034.

[15] Zarena AS & Sankar KU, (2009). A study of antioxidant properties from *Garcinia mangostana* L. pericarp extract. *Acta Scientiarum Polonorum Technologia Alimentaria*, 8(1), 23-34.

[16] Noce A, Di Lauro M, Di Daniele F, Pietroboni Zaitseva A, Marrone G, Borboni P & Di Daniele N, (2021). Natural bioactive compounds useful in clinical management of metabolic syndrome. *Nutrients*, 13(2), 630. doi: 10.3390/nu13020630.

[17] Singleton VL, & Rossi Jr JA, (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16(3), 144-158. doi: 10.5344/ajev.1965.16.3.144

[18] Ipsen DH, Lykkesfeldt J & Tveden-Nyborg P, (2018). Molecular mechanisms of hepatic lipid accumulation in non-alcoholic fatty liver disease. *Cellular and Molecular Life Sciences,* 75(18), 3313-3327. doi: 10.1007/s00018-018-2860-6.

[19] Asghar A, Akhtar T, Batool T, Khawar MB, Nadeem S, Mehmood R & Sheikh N, (2021). High-fat diet-induced splenic, hepatic, and skeletal muscle architecture damage: cellular and molecular players. *Molecular and Cellular Biochemistry,* 476(10), 3671-3679. doi: 10.1007/s11010-021-04190-6.

[20] Fatoumata BA, Mohamet SENE & El Hadji Makhtar BA, (2020). Antidiabetic properties of *Moringa oleifera*: A review of the literature. *Journal of Diabetes and Endocrinology*, 11(1), 18-29. doi: 10.5897/JDE2019.0136.

[21] Deguchi Y & Miyazaki K, (2010). Anti-hyperglycemic and anti-hyperlipidemic effects of guava leaf extract. *Nutrition & Metabolism*, 7(1), 9. doi: 10.1186/1743-7075-7-9.

[22] Nguyen TH & Nguyen THH (2025). Antimicrobial, cytotoxic, and enzyme inhibitory activities of *Garcinia mangostana* L. pericarp extract relevant to diabetes and Alzheimer's disease: Findings from an *in vitro* study. *TNU Journal of Science and Technology*, 230(13), 478-485. doi:10.34238/tnu-jst.12780.

[23] Choi YH, Bae JK, Chae HS, Kim YM, Sreymom Y, Han L & et al, (2015). *α*-Mangostin regulates hepatic steatosis and obesity through SirT1-AMPK and PPARγ pathways in high-fat diet-induced obese mice. *Journal of Agricultural and Food Chemistry*, 63(38), 8399-8406. doi: 10.1021/acs.jafc.5b01637.

[24] Chatatikun M, Tedasen A, Phinyo P, Wongyikul P, Klangbud WK, Kawakami F & et al., (2024). Hypoglycemic activity of *Garcinia mangostana* L. extracts on diabetes rodent models: A systematic review and network meta-analysis. *Frontiers in Pharmacology*, 15, 1472419. doi: 10.3389/fphar.2024.1472419.

[25] Evans JL, Goldfine ID, Maddux BA & Grodsky GM, (2002). Oxidative stress and stress-activated signaling pathways: A unifying hypothesis of type 2 diabetes. *Endocrine Reviews*, 23(5), 599-622. doi: 10.1210/er.2001-0039.

[26] Majdalawieh AF, Khatib BK & Terro TM, (2025). *α*-Mangostin is a xanthone derivative from mangosteen with potent immunomodulatory and anti-inflammatory properties. *Biomolecules*, 15(5), 681. doi: 10.3390/biom15050681.