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Research Article

Antioxidant Properties and Cardioprotective Mechanism of Malaysian Propolis in Rats

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Propolis contains high concentrations of polyphenols, flavonoids, tannins, ascorbic acid, and reducing sugars and proteins. Malaysian Propolis (MP) has been reported to exhibit high 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity and ferric reducing antioxidant power (FRAP) values. Herein, we report the antioxidant properties and cardioprotective properties of MP in isoproterenol- (ISO-) induced myocardial infarction in rats. Male Wistar rats ($n = 32$) were pretreated orally with an ethanol extract of MP (100 mg/kg/day) for 30 consecutive days. Subcutaneous injection of ISO (85 mg/kg in saline) for two consecutive days caused a significant increase in serum cardiac marker enzymes and cardiac troponin I levels and altered serum lipid profiles. In addition significantly increased lipid peroxides and decreased activities of cellular antioxidant defense enzymes were observed in the myocardium. However, pretreatment of ischemic rats with MP ameliorated the biochemical parameters, indicating the protective effect of MP against ISO-induced ischemia in rats. Histopathological findings obtained for the myocardium further confirmed the biochemical findings. It is concluded that MP exhibits cardioprotective activity against ISO-induced oxidative stress through its direct cytotoxic radical-scavenging activities. It is also plausible that MP contributed to endogenous antioxidant enzyme activity via inhibition of lipid peroxidation.

1. Introduction

Propolis, or bee glue, is a resinous product collected by bees from various plant sources, such as buds and exudates. The substance is sticky at and above room temperature (20°C), but at lower temperature it becomes hard and brittle [1–3]. Propolis is used as a sealant by bees to seal cracks in hives, encapsulate invader carcasses, repair combs, and strengthen thin borders [1, 2, 4]. Depending on its source, geographical climate, and age, propolis varies greatly; it possesses a pleasant aromatic odor and occurs in different colors, such as yellow, cream, green, and light or dark brown [5].

Propolis is mainly composed of resins, polyphenols, flavonoids, fatty acids, essential oils, wax, pollen, and other organics and minerals. Propolis contains at least 38 flavonoids [6]. It also contains vitamin B complexes; vitamins C and E; important minerals such as Zn, Mg, Cu, Fe, Mn, Ni, and Ca; and some trace elements [7]. Due to the presence of compounds such as flavonoids, phenolic acids, and their esters, propolis exhibits anti-inflammatory, antibacterial, antiviral, immunomodulatory, antioxidant, and antiproliferative properties [8]. Reactive oxygen species (ROS) such as superoxide anions and hydroxyl radicals are scavenged by antioxidants present in propolis [9, 10]. In addition, the extreme reactivity

of ROS toward lipids and proteins contributes to their rapid damaging capacity [11].

Myocardial infarction (MI), commonly known as “heart attack,” occurs due to an interruption in the supply of blood to heart tissue. As a result of coronary artery occlusion, necrosis of part of the myocardium occurs [12]. In fact, an imbalance between coronary blood supply and myocardial demand is the main cause of myocardium necrosis resulting from MI [13]. MI is a common presentation of ischemic heart disease (IHD) and is followed by numerous pathophysiological and biochemical changes, including lipid peroxidation (LPO), hyperglycemia, and hyperlipidemia [14]. In the developed world and most developing countries, MI is one of the main causes of mortality and morbidity [12, 15].

At low concentration, catecholamines exert a positive inotropic effect and are beneficial in regulating heart function. However, when present in high doses (administered or released in excess from the endogenous stores), catecholamines can deplete the reserved energy of cardiomyocytes, resulting in structural and biochemical changes leading to irreversible damage. Isoproterenol 4-[1-hydroxy-2-(isopropylamino)ethyl] benzene-1,2-diol hydrochloride (ISO) is a synthetic catecholamine and β -adrenergic agonist that causes severe stress to the myocardium, resulting in an infarct-like necrosis of the heart muscle [16]. Free radicals thus produced may attack polyunsaturated fatty acids (PUFAs) within membranes, forming peroxy radicals. These radicals then attack adjacent fatty acids, causing a chain reaction of LPO. Lipid hydroperoxide end products are harmful and may be responsible for the disruption of the integrity of the myocardial membrane [17, 18].

Recently, a number of Malaysian agro-food-based research institutes and local beekeepers have collected the bee propolis of different species to analyze its composition as well as its health benefits [19, 20]. Propolis from the *Trigona itama* species of Malaysia has been reported to contain a number of bioactive compounds with biological activities. The major phytochemicals identified in MP are hexadecanoic acid, which acts as an antioxidant; phenylethyl alcohol and dodecanoic acid, which act as antimicrobial agents; and norolean-12-ene, ethyl octadecanoate, 8-octadecanoic acid, and 9-octadecanoic acid, which serve as anti-inflammatory agents [19]. A previous study demonstrated that propolis contains remarkable antioxidant properties, mainly attributed to its phenolic and flavonoid contents [21]. The aim of this study was to investigate the antioxidant properties of Malaysian Propolis (MP) and its cardioprotective effect, elucidating the mechanism that occurs in ISO-induced MI in rats.

2. Materials and Methods

2.1. Chemicals and Drugs. Gallic acid, catechin, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical, and 2,4,6-tris(2-pyridyl)-1,3,5-triazine (TPTZ) standards were purchased from Sigma-Aldrich (St. Louis, MO). Tannic acid, L-ascorbic acid, and Folin-Ciocalteu's phenol reagent were purchased from Merck Co. (Darmstadt, Germany). ISO and 1,1,3,3-tetraethoxypropane were purchased from Nacalai Tesque,

Inc. Kyoto, Japan. All chemicals and reagents used in this study were of analytical grade.

2.2. Propolis Sample. Stingless bee propolis of *Tetratrigona* subgenus (genus: *Trigona*) was collected from the Min House Camp, Kubang Kerian, Kelantan, Malaysia in June 2013.

2.3. Extract Preparation. Propolis extract (20%) was prepared according to the method described by Laskar et al. [22]. Solid propolis samples (200 g) were first cut into small pieces using a sterile, smooth steel knife. The samples were soaked with ethanol (70%) for 48 hours and then shaken (150 rpm) at 30°C for 72 hours. The extract solution was filtered with Whatman number 1 filter paper and dried in a rotary evaporator (Buchi, Tokyo, Japan) under a reduced pressure (100 psi) and at a controlled temperature (40°C). The dried extract was collected and finally preserved at -20°C for subsequent *in vitro* and *in vivo* studies.

2.4. Phytochemical Analysis

2.5. Estimation of Total Polyphenols. The total polyphenol content of the propolis extract was estimated by spectrometric determination based on Folin-Ciocalteu's method [23] using a PD-303S spectrophotometer (APEL, Japan). Briefly, 0.4 mL of sample extract (10 mg/mL) was mixed with 1.6 mL of 7.5% sodium carbonate solution. Then, 2 mL of 10-fold diluted Folin-Ciocalteu's reagent was added, and the final reaction mixture was incubated for 1 hour in the dark. Total polyphenol content was determined as gallic acid equivalent (GAE) (6.25–100.00 μ g/mL) and expressed as mg of GAEs/g of propolis. The color intensity of the blue complex was measured at 765 nm.

2.6. Estimation of Total Flavonoids. The total flavonoid content was estimated using an aluminum chloride colorimetric assay [24]. First, 1 mL of sample (10 mg/mL) was mixed with 0.3 mL of 5% sodium nitrite and added to the reaction mixture; after approximately 5 min, 0.3 mL of 10% aluminum chloride was added. Subsequently, another 2 mL of 1 M sodium hydroxide (NaOH) was added after 6 min, followed by the immediate addition of 2.4 mL of distilled water to produce a total volume of 10 mL. The color intensity of the flavonoid-aluminum complex was measured at 510 nm. Total flavonoid content was determined as catechin equivalent (CE) (6.25–100.00 μ g/mL) and expressed as mg of CE/g of propolis.

2.7. Determination of Ascorbic Acid Content. The ascorbic acid content in the propolis was estimated by a method established by Omaye et al. [25], with slight modifications. Briefly, 1 mL of extract (10 mg/mL) was mixed with 1 mL of a 5% trichloroacetic acid (TCA) solution and centrifuged for 15 min at 3500 rpm. Then, 0.5 mL of the supernatant was mixed with 0.1 mL of DTC (2,4-dinitrophenylhydrazine/thiourea/copper) solution and incubated for 3 hours at 37°C. To the mixture was added 0.75 mL of ice-cold 65% H₂SO₄. The solution was allowed to stand for an

additional 30 min at room temperature. The colored complex that developed was monitored at 520 nm. The ascorbic acid concentration was determined as ascorbate equivalent (AEs) (1–10 $\mu\text{g}/\text{mL}$) and expressed as mg of ascorbate equivalents (AEs) per g of sample.

2.8. Estimation of Reducing Sugar Content. The content of reducing sugars in the propolis was estimated according to the Nelson-Somogyi method [26]. Briefly, 2 mL of propolis extract (10 $\mu\text{g}/\text{mL}$) and standards (made in 0.2% of benzoic acid) were transferred into two different test tubes, followed by the addition of 2 mL of copper reagent to each tube. The tubes were heated for 15 min in a 100°C water bath and then cooled. Finally, 1 mL of arsenomolybdate color reagent was added to the reaction mixture. The absorbance was measured at 520 nm. Dextrose was used as a standard for the preparation of the calibration curve (10–100 $\mu\text{g}/\text{mL}$), and the reducing sugar content was expressed as mg of D-glucose per g of propolis.

2.9. Estimation of Total Protein Content. The total protein content in the propolis was estimated using Lowry's method [27]. Bovine serum albumin (BSA) (12.5–100.0 $\mu\text{g}/\text{mL}$) was used as a standard to prepare a calibration curve. The final results are expressed as mg of BSA equivalent per g of propolis.

2.10. Analysis of Antioxidant Properties. To investigate the antioxidant potential of the propolis extracts, DPPH radical-scavenging and FRAP assays were performed.

2.11. DPPH Free Radical-Scavenging Activity. The antioxidant potential of the propolis was determined according to the DPPH radical-scavenging activity based on a method established by Braca et al. [28]. Briefly, 1 mL of the extract was mixed with 1.2 mL of 0.003% DPPH in methanol at varying concentrations (2.5–80.0 $\mu\text{g}/\text{mL}$). The percentage of DPPH inhibition was calculated using the following equation:

$$\% \text{ of DPPH inhibition} = \left[\left(\frac{A_{\text{DPPH}} - A_{\text{S}}}{A_{\text{DPPH}}} \right) \right] \times 100, \quad (1)$$

where A_{DPPH} is the absorbance of DPPH in the absence of a sample and A_{S} is the absorbance of DPPH in the presence of either the sample or the standard.

DPPH scavenging activity is expressed as the concentration of sample that is required to decrease DPPH absorbance by 50% (IC_{50}). The value can be graphically determined by plotting the absorbance (the percentage of inhibition of DPPH radicals) against the log concentration of DPPH and determining the slope of the nonlinear regression.

2.12. Ferric Reducing Antioxidant Power (FRAP) Assay. The FRAP assay was performed according to a method established by Benzie and Strain [29]. The reduction of a ferric tripyridyltriazine complex into its ferrous form produces an intense blue color at low pH that can be monitored by measuring absorbance at 593 nm. Briefly, 200 μL of the

solution at different concentrations (62.5–1000.0 $\mu\text{g}/\text{mL}$) was mixed with 1.5 mL of the FRAP reagent, and the reaction mixture was incubated at 37°C for 4 min. The change in absorbance was monitored at 593 nm against a distilled water blank. The FRAP reagent was prepared by mixing 10 volumes of 300 mM acetate buffer (pH 3.6) with 1 volume of 10 mM TPTZ solution in 40 mM hydrochloric acid and 1 volume of 20 mM ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$). The FRAP reagent was prewarmed to 37°C and was always freshly prepared. A standard curve was plotted using an aqueous solution of ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) (100–1000 μmol), with FRAP values expressed as micromoles of ferrous equivalent ($\mu\text{M Fe [II]}$) per kg of sample).

2.13. Experimental Animals. Adult male Wistar Albino rats ranging from 140 to 160 g were used. The animals were maintained under standard conditions of ventilation, temperature ($23 \pm 2^\circ\text{C}$), humidity (40–70%), and light/dark condition (12/12 h) in the animal house facility of the Department of Biochemistry and Molecular Biology, Jahangirnagar University, Savar, Dhaka. The rats were housed in polypropylene cages with soft wood-chip bedding. They were provided with a standard laboratory pellet diet and water *ad libitum*. The experiments were conducted according to the ethical guidelines as approved by Bangladesh Association for Laboratory Animal Science. The experiment protocol was approved by the Biosafety, Biosecurity, and Ethical Committee of Jahangirnagar University [Approval number BBEC, JU/M2014 (3)].

2.14. Induction of Experimental MI. MI was induced by subcutaneous injection of ISO (85 mg/kg). ISO was dissolved in normal saline and administered twice at an interval of 24 h for two consecutive days. The ISO dose was established based on a pilot study for ISO dose fixation and the results of previous studies [12, 18]. Animals were sacrificed (as below) 48 h after first ISO administration.

2.15. Experimental Design. Following one week of acclimation, the animals were randomly divided into four groups (8 rats in each group) and were treated as follows.

Group 1 (Control). Animals were given standard laboratory diet and water *ad libitum*.

Group 2 (MP). Animals were given propolis (100 mg/kg) for four weeks but were not given ISO.

Group 3 (ISO). Animals were injected with ISO (85 mg/kg) on the 29th and 30th days.

Group 4 (MP + ISO). Animals received MP (100 mg/kg) for 4 weeks prior to ISO (85 mg/kg) administration on the 29th and 30th days.

During the experimental period, the rats' body weights were recorded regularly and the doses modulated accordingly. Propolis dosage administered at 100 mg/kg was based on that reported in a previous study [30]. One day after the second ISO injection, the animals were anesthetized with

ketamine hydrochloride injection (100 mg/kg) for sacrifice prior to dissection. Blood samples (5 mL) were collected from the inferior vena cava of the rats. In addition, heart tissue was excised immediately from the surrounding tissues and was washed twice with ice-cold phosphate buffer saline (PBS), followed by storage at -20°C prior to analysis. Some of the heart samples were stored in 10% formalin for histopathological examination.

2.16. Serum Collection for Further Study. Blood samples (3 mL) were transferred to clean dry centrifuge tubes to allow for coagulation at an ambient temperature. The serum was separated by centrifugation at 2000 rpm for 10 min. The serum was kept at -20°C for subsequent biochemical analyses. The heart samples were homogenized in phosphate buffer (25 mM, pH 7.4) using a tissue homogenizer (F 12520121, Omni International, Kennesaw, USA) to make an approximately 10% w/v homogenate. This homogenate was centrifuged at 1700 rpm for 10 min. The supernatant was collected and stored at -20°C for biochemical analyses.

2.17. Estimation of Cardiac Troponin I (cTn I). The heart-specific troponin I (cTn I) level in the sera was estimated via enzyme immunoassay kits (JAJ International Inc., USA) using an ELISA reader (Digital and Analog System RS232, Das, Italy).

2.18. Assay of Cardiac Marker Enzymes. The serum activities of creatinine kinase-MB (CK-MB), aspartate transaminase (AST), lactate dehydrogenase (LDH), and alanine transaminase (ALT) were estimated via commercially available standard assay kits (Stanbio Laboratory, USA) using a PD-303S spectrophotometer (APEL, Japan).

2.19. Analyses of Lipid Profiles. The serum levels of total cholesterol (TC), triglycerides (TGs), and high-density lipoprotein-cholesterol (HDL-C) were estimated using commercially available standard assay kits (Stanbio Laboratory, USA). Serum VLDL-C levels were calculated by a formula provided by Friedewald et al. [31]:

$$\text{VLDL-C} = \frac{\text{TG}}{5}. \quad (2)$$

2.20. Estimation of LPO Products. Malondialdehyde (MDA) levels were assayed for LPO products in heart tissues according to the method described by Ohkawa et al. [32]. Briefly, tissue homogenate (0.2 mL) was mixed with 8.1% sodium dodecyl sulfate (0.2 mL), 20% acetic acid (1.5 mL), and 8% thiobarbituric acid (1.5 mL). The mixture was supplemented up to 4 mL with distilled water and was heated at 95°C in a water bath for 60 min. After incubation, the tubes were cooled to room temperature, and the final volume was increased to 5 mL. A butanol:pyridine (15:1) mixture (5 mL) was added, and the contents were vortexed thoroughly for 2 min. After centrifugation at 3,000 rpm for 10 min, the upper organic layer was aspirated and its absorbance was read at 532 nm against a blank. The levels of MDA were expressed as nmol

of thiobarbituric acid reactive substances (TBARS) per mg of protein.

2.21. Estimation of Antioxidant Enzymes. The levels of endogenous antioxidant or antiperoxidative enzymes, such as superoxide dismutase (SOD), glutathione peroxidase (GPx), glutathione reductase (GRx), and glutathione-S-transferase (GST), in the rats' heart tissues were estimated using standard assay kits (Abnova Corporation, Taiwan). To this end, the heart tissue homogenates were recentrifuged at 12,000 rpm for 10 min at 4°C using Eppendorf 5415D centrifuges (Hamburg, Germany). The resulting clean supernatants of tissue homogenates were fed into the assays. The SOD activity was expressed as units/mg of protein, GPx and GRx activities were expressed as nmol NADPH oxidized/min/mg of protein, and GST activity was expressed as nmol CDNB conjugated/min/mg of protein.

The total protein content in the recentrifuged tissue homogenates was estimated by the method described by Lowry et al. [27]. Briefly, 0.2 mL of sample (digested with 0.1 N NaOH) was mixed with 2 mL of working reagent (a mixture of 2% sodium carbonate, 0.1 N NaOH, 1.56% copper sulfate, and 2.37% sodium-potassium tartrate), and the reaction mixture was incubated for 10 min at room temperature. The addition of 1 N Folin-Ciocalteu's phenol reagent (0.2 mL) was followed by 30 min of incubation at room temperature. Finally, the absorbance was measured at 660 nm using a spectrophotometer (APEL, Japan). BSA was used as the standard.

2.22. Histopathological Examination. The heart was rapidly dissected out and washed immediately with saline after sacrifice. It was then fixed in 10% formalin. The fixed tissues were then embedded in paraffin. The tissues were sectioned into $5\ \mu\text{m}$ slices using a rotary microtome and then stained with hematoxylin and eosin dye for observation under a light microscope (MZ3000 Micros, St Veit/Glan, Austria) at 40x magnification. The pathologist performing the histopathological evaluation was blinded to the treatment assignment of the different study groups.

2.23. Statistical Analysis. All analyses were conducted in triplicate and the data are expressed as the mean \pm standard deviation (SD). The data were analyzed using GraphPad PRISM (version 6.05; GraphPad software Inc., San Diego, CA, USA), Microsoft Excel 2007 (Redmond, Washington, USA), and SPSS (Statistical Packages for Social Science, version 20.0, IBM Corporation, New York, USA). The mean values of different groups were compared using one-way analysis of variance (ANOVA). Statistical analyses of biochemical data were conducted using Tukey's test. The minimum level of significance was set to <0.05 .

3. Results

3.1. Antioxidant Constituents. The bioactive polyphenols, flavonoids, tannin and ascorbate, protein, and reducing sugar contents in MP are presented in Table 1.

TABLE 1: Total polyphenols, flavonoids, tannins, protein, ascorbic acid, and reducing sugar contents in MP.

Phytochemicals	Amount present in propolis (mg/g)
Total polyphenols (GAEs)	15.93 ± 0.18
Total flavonoids (CEs)	1.65 ± 0.10
Total tannins (TEs)	5.81 ± 1.65
Ascorbic acid (AEs)	0.91 ± 0.02
Total protein (BSA)	24.54 ± 0.26
Reducing sugar (D-glucose)	38.22 ± 3.22

Data are presented as means ± SD.

GAE: gallic acid equivalents; CE: catechin equivalents; TE: tannic acid equivalent; AE: ascorbate equivalent; BSA: bovine serum albumin.

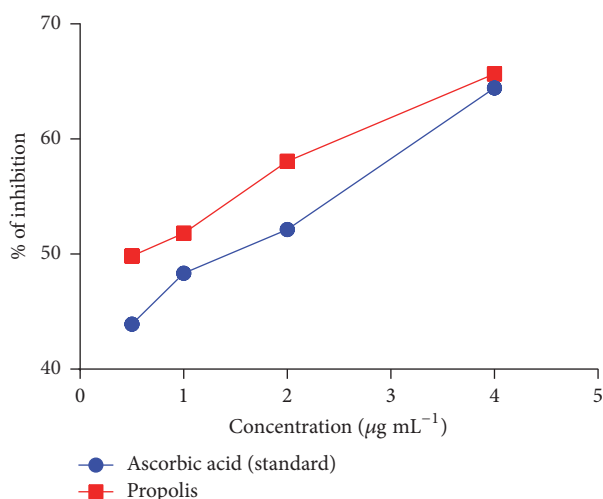


FIGURE 1: Percentage of DPPH inhibition of propolis against an ascorbic acid standard showing a dose-dependent inhibition potential.

3.2. Antioxidant Activity Assay. The antioxidant potential of MP was determined by both DPPH scavenging activity and the FRAP assay. The estimated IC_{50} value of DPPH scavenging activity was 1.08 µg/mL (Figure 1), and the FRAP value was 954.29 ± 3.40 [µM Fe(II)]/kg.

3.3. The Effects of Propolis on Biochemical Parameters. During the treatment period (4 weeks), no death was observed in any of the experimental groups, and no significant difference in body weight was observed between different groups (Table 2). The heart weight increased significantly in ISO-administered rats compared with that of normal control rats. However, a significant reduction in heart weight was observed in the propolis treatment (MP + ISO) group compared with that of the rats treated with ISO alone.

Serum cTn I levels were significantly increased in ISO-administered rats compared with those of the normal controls (Figure 2). However, a significant reduction in serum cTn I levels was observed in animals receiving prior treatment with propolis compared with those of ISO-treated rats.

A marked increase in serum cardiac enzyme activities was observed in ISO-induced myocardial ischemic rats. Again,

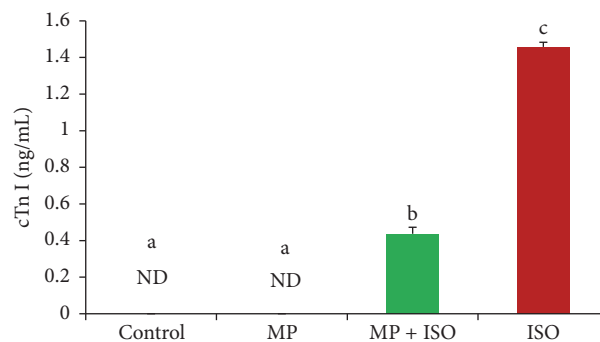


FIGURE 2: Effect of MP on serum cTn I in normal and treated rats. The bars represent means ± SD ($n = 8$); bars with different letters (a, b, c) indicate significantly different mean values at $p < 0.05$. ND: not detected.

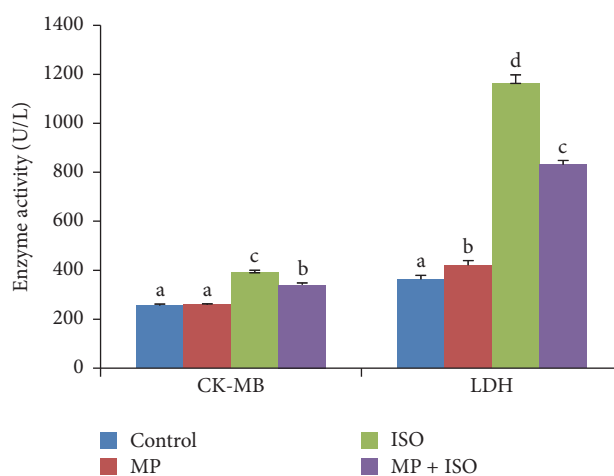


FIGURE 3: Effects of MP and ISO on serum CK-MB and LDH levels in normal and different treated rats. The bars represent means ± SD ($n = 8$); bars with different letters (a, b, c, d) indicate significantly different mean values at $p < 0.05$. MP: Malaysian Propolis. ISO: isoproterenol.

pretreatment with propolis significantly decreased the levels of CK-MB, LDH, AST, and ALT in rats challenged with ISO (Figures 3 and 4).

A marked increase in circulating levels of TC, TGs, and VLDL-C and a corresponding decrease in HDL-C level were observed in ISO-treated rats (Figure 5). Again, pretreatment with propolis was observed to significantly reduce the levels of TC, TGs, and VLDL-C while increasing the HDL-C level compared with the levels measured for the ISO-challenged group. Administration of MP alone did not significantly affect the lipid profile compared with that of normal control group.

ISO-induced rats exhibited a significant increase in MDA levels compared with the levels measured for the normal control group. Propolis pretreatment, however, significantly ameliorated the increase (Figure 6).

Table 3 presents the effects of propolis on the activities of antioxidant enzymes such as SOD, GRx, GPx, and GST in the heart tissue. Rats induced with ISO exhibited a significant decrease in the level of antioxidant enzymes compared with

TABLE 2: Effect of MP on body weights (BW) and absolute and relative heart weights.

Parameters	Treatment			
	Control	MP	ISO	MP + ISO
Initial BW (g)	133.25 ± 9.66 ^a	148.62 ± 10.07 ^a	139.75 ± 13.76 ^a	135.12 ± 7.86 ^a
Final BW (g)	162.37 ± 4.62 ^a	176.25 ± 16.61 ^a	169.25 ± 16.61 ^a	167.87 ± 7.69 ^a
BW gain (%)	17.98 ± 4.49 ^a	16.76 ± 2.32 ^a	17.39 ± 2.28 ^a	19.54 ± 1.24 ^a
Absolute heart weight (g)	0.67 ± 0.08 ^a	0.68 ± 0.04 ^a	0.92 ± 0.05 ^c	0.75 ± 0.02 ^b
Relative heart weight (g/100 g)	0.41 ± 0.05 ^a	0.41 ± 0.02 ^a	0.54 ± 0.02 ^b	0.45 ± 0.02 ^a

Data are presented as means ± SD, $n = 8$.

^{a,b,c} Values in the same row that do not share superscript letters (a, b, and c) differ significantly at $p < 0.05$; % of body weight (BW) gain = [(final BW – initial BW)/ initial BW] × 100.

MP: Malaysian Propolis. ISO: Isoproterenol.

TABLE 3: Effects of MP and ISO on the activities of superoxide dismutase (SOD), glutathione reductase (GRx), glutathione peroxidase (GPx), and glutathione-S-transferase (GST) in the heart tissue of normal and treated rats.

Parameters	Treatment			
	Control	MP	ISO	MP + ISO
SOD (units/mg of protein)	1.53 ± 0.15 ^a	1.96 ± 0.04 ^a	0.13 ± 0.02 ^c	0.31 ± 0.05 ^b
GRx (nmol NADPH oxidized/min/mg of protein)	96.23 ± 6.70 ^a	94.32 ± 1.74 ^a	71.07 ± 4.78 ^b	89.13 ± 9.28 ^a
GPx (nmol NADPH oxidized/min/mg of protein)	2.95 ± 0.57 ^a	2.27 ± 0.52 ^a	0.90 ± 0.02 ^b	1.98 ± 0.51 ^a
GST (nmol CDNB conjugated/min/mg of protein)	2.08 ± 0.20 ^a	2.55 ± 0.43 ^a	1.29 ± 0.18 ^b	2.13 ± 0.63 ^a

Data are presented as means ± SD, $n = 8$.

^{a,b,c} Values in the same row that do not share superscript letters (a, b, and c) indicate significant difference at $p < 0.05$.

MP: Malaysian Propolis. ISO: isoproterenol.

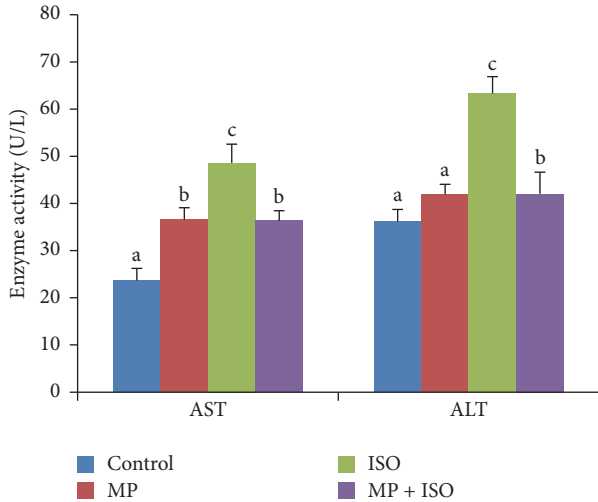


FIGURE 4: Effects of MP and ISO on serum AST and ALT levels in normal and different treated rats. The bars represent means ± SD ($n = 8$); bars with different letters (a, b, c) indicate significantly different mean values at $p < 0.05$. MP: Malaysian Propolis. ISO: isoproterenol.

the level measured for the control group. However, pretreatment with propolis significantly ameliorated the levels of SOD, GRx, GPx, and GST enzymes compared with the levels measured for the rats treated with ISO alone.

Normal cardiac muscle fibers without any infarction were observed in normal control rats (Figure 7(a)). Rats

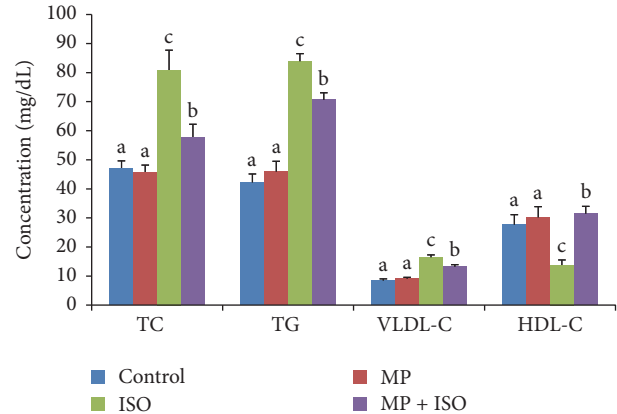


FIGURE 5: Effects of MP and ISO on serum lipid profile in normal and different treated rats. The bars represent means ± SD ($n = 8$); bars with different letters (a, b, c) indicate significantly different mean values at $p < 0.05$. MP: Malaysian Propolis. ISO: isoproterenol.

treated with propolis alone also showed normal cardiac muscle bundles without any infarction or tissue damage (Figure 7(b)). ISO-treated rats showed myocardial structural changes, including coagulative necrosis, separation of cardiac muscle fibers, and infiltration of inflammatory cells (Figure 7(c)). Pretreatment with propolis decreased the degree of infiltration of inflammatory cells (Figure 7(d)).

Histological changes in the heart in the various groups are presented in Table 4.

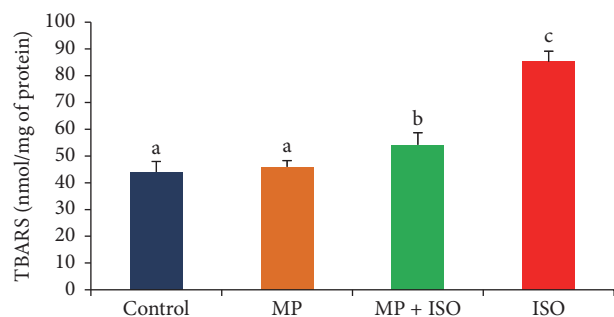


FIGURE 6: Effects of MP and ISO on cardiac LPO levels in normal and different treated rats. The bars represent means \pm SD ($n = 8$); bars with different letters (a, b, c) indicate significantly different mean values at $p < 0.05$.

TABLE 4: Semiquantitative scoring of the architectural changes evidenced by histopathological examination of rat myocardial tissues.

Parameters	Treatment			
	Control	MP	ISO	MP + ISO
Muscle separation	–	–	+++	+
Cellular necrosis	–	–	+++	+
Inflammatory cells infiltration	–	–	+++	+
Edematous intramuscular space	–	–	+++	++

Scoring was performed as follows: none (–), mild (+), moderate (++), and severe (+++).

4. Discussion

To the best of our knowledge, our study is the first to determine the antioxidant potentials of Malaysian bee propolis and to investigate the effects of a propolis extract on myocardial ischemia based on the findings of several biochemical markers in addition to histopathological findings in a rat model.

Polyphenols and flavonoids are important constituents that contribute to the functional quality, color, and flavor of bee products and serve as powerful antioxidants due to the hydrogen-donating ability of their hydroxyl groups as well as their ability to donate electrons to arrest the production of free radicals as a result of oxidative stress [33]. Tannins are another important subclass of water-soluble phenolic compounds. They have been reported to exhibit significant astringent, antimicrobial, and antioxidant properties [34, 35]. Our findings indicate that MP serves as a reserve source of phenolics, flavonoids, and tannins and may therefore play a significant role as a singlet oxygen quencher and free radical scavenger to minimize molecular damage of the cell.

Ascorbic acid is a small antioxidant molecule that directly interacts with a broad spectrum of ROS, terminating the chain reaction initiated by free radicals via electron transfer as well as participating in the regeneration of vitamin E [33]. To the best of our knowledge, our study is the first to report on the ascorbic acid content of MP, which, when coupled with the presence of other antioxidants, can be used as a natural source of antioxidants. Our study also confirms that MP is a rich source of reducing sugars with a significant amount of protein.

The antioxidant activities of MP were evaluated by FRAP and DPPH assays. FRAP assays primarily measure the abilities of antioxidants to reduce ferric tripyridyltriazine (Fe^{3+}) to their ferrous form (Fe^{2+}), whereas DPPH assays measure percentages of radical-scavenging activity [35]. The FRAP and DPPH assays confirmed the high antioxidant potential of MP, as previously reported [9].

MI is a clinical syndrome arising from sudden and persistent curtailment of myocardial blood supply, resulting in the necrosis of myocardium [36]. Administration of ISO contributes to the release of cellular enzymes in the circulation due to irreversible cardiac damage, which leads to an alteration in the integrity of the plasma membrane as a response to β -adrenergic stimulation. The stimulation generates ROS and downregulates copper-zinc superoxide dismutase activity, reduces glutathione levels (which leads to the loss of membrane integrity), induces heart contractile dysfunction and myocyte toxicity, and finally produces myocardial necrosis [37]. In the present study, the heart weights increased significantly with relatively no change in body weight following ISO administration, which contributed to the increased heart weight to body weight ratio. The increased heart weights may be attributed to increased water content and edematous intramuscular space [38], which was confirmed by our histopathological findings. Pretreatment with propolis, however, helped to maintain near-normal heart weights, indicating the therapeutic benefits of the substance.

Cardiac troponin I (cTn I) is a contractile protein that is a highly sensitive and specific marker of myocardial cell injury; it is normally absent in serum and released only following myocardial necrosis [39]. Our study confirmed that serum cTn I levels were significantly higher in ISO-treated rats than in the normal control group, which may be attributed to ISO-induced cardiac damage. The results are consistent with those reported by Afroz et al. [12]. Animals challenged with ISO after pretreatment with propolis, however, showed significantly lower cTn I levels compared with those of rats treated with ISO alone. This phenomenon may be attributed to the protective effect of phenolics in propolis on the myocardium by preserving the structural and functional integrity of the contractile apparatus and thus preventing oxidative injury of cardiac muscles.

An insufficient supply of oxygen or nutrients to cardiac tissues or chemically induced cardiac damage may increase the permeability or even rupture the cardiac membrane, resulting in leakage of cytosolic enzymes, including CK-MB, AST, LDH, and ALT (diagnostic markers of MI), into the bloodstream and a subsequent increase in their serum concentrations [12, 40]. The CK-MB activity assay is an important and reliable diagnostic index for MI because of the marked abundance of CK-MB in the myocardium and its virtual absence in most other tissues and consequent sensitivity [41]. In the present study, ISO administration in rats caused a marked elevation in the activities of all the cardiac marker enzymes in the serum, in accord with previously reported studies [12, 18], an important indication of ISO-induced necrotic damage of the myocardium and leakiness of the plasma membrane. Pretreatment with MP,

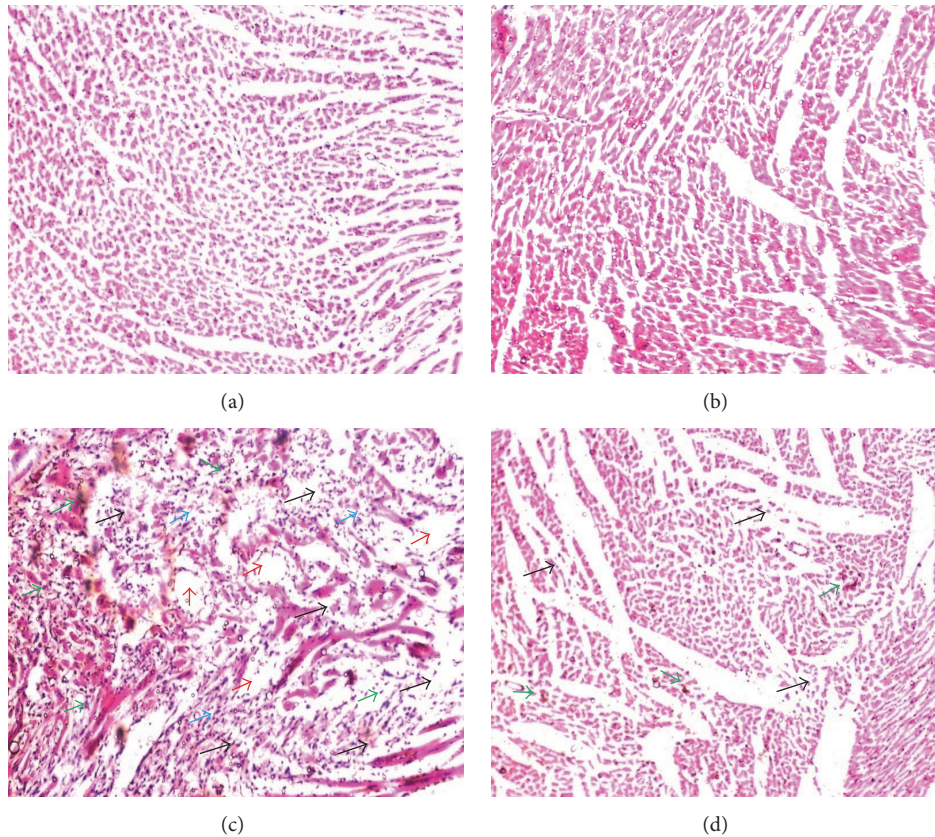


FIGURE 7: (a) Group I: H & E stained myocardial tissue section from normal control heart showing normal cardiac muscle fibers. (b) Group II: pretreatment with MP (100 mg/kg) showing normal muscle fibers without any pathological changes. (c) Group III: ISO (85 mg/kg) treated heart showing cardiac muscle fibers with muscle separation (black arrows), edematous intramuscular space (red arrows), cellular necrosis (blue arrows), and infiltration of inflammatory cells (green arrows). (d) MP (100 mg/kg) + ISO (85 mg/kg) treated heart showing lowered inflammatory cells (green arrows) and reduced muscle fibrous separation with edematous intramuscular space.

however, significantly ameliorated the activities of all marker enzymes in the serum, indicating that propolis helps maintain membrane integrity, thereby limiting the leakage of the enzymes. Polyphenols such as tannic acid, ascorbic acid, flavonoids, and reducing sugars confirmed to be present in MP are important constitutive antioxidants that may confer a protective effect against oxidative cardiac injury, thus restricting the leakage of these enzymes from the myocardium.

Plasma cholesterol and triglycerides play a key role in the pathogenesis of cardiovascular disease not only due to the development of atherosclerosis but also due to the modification of the composition, structure, and stability of cellular membranes [42]. A significant increase in the levels of TC, TG, and VLDL-C along with a decrease in HDL-C levels was observed in ISO-treated rats, as previously reported [40]. There are a positive correlation between high levels of LDL-C and VLDL-C with MI and a negative correlation between high levels of HDL-C and MI. HDL-C inhibits the uptake of LDL-C by the arterial walls and facilitates the transport of cholesterol from peripheral tissues to the liver and is catabolized and excreted from the body [43]. Administration of MP significantly restored these alterations, thereby maintaining the normal fluidity and function of the myocardial

membrane. The improvement in lipoprotein status has been due to the polyphenols in MP, which are responsible for the upregulation of proinflammatory cytokines, chemokines, and angiogenic factors and consequent inhibition of progression of atherosclerosis [44].

Propolis is also reported to downregulate the mRNA expression of key genes, including monocyte chemoattractant protein (MCP)-1, interferon gamma, interleukin-6, cluster of differentiation (CD) 36, and transforming growth factor beta (TGF- β), which have been associated with the atherosclerotic process [44, 45]. Moreover, MP lowered TC levels and elevated HDL-C levels, as also reported by Daleprane et al. [45], which may contribute to the upregulation of ABCA 1 gene expression associated with increased HDL-C levels and restoration of lipid profiles in animals [44].

LPO, a type of oxidative deterioration of PUFAs, has been linked to pathogenic events in MI [14, 40]. The myocardial necrosis observed in the rats receiving ISO can be attributed to peroxidative damage because it has been previously reported that ISO generates lipid peroxides [46]. Increased LPO appears to be the initial stage of the pathogenesis, making heart tissue more susceptible to oxidative damage [18]. ISO administration caused a marked elevation in LPO, which

was expressed as MDA content, in line with previous reports [14, 40]. Oral pretreatment with MP led to a significant reduction in myocardial MDA content. This result can be attributed to the presence of flavonoids in MP, which can scavenge LPO products generated excessively by ISO, thus conferring protection to the cardiac tissue [47]. It has been reported that the synergistic scavenging effects of bee products may be due to both enzymatic and nonenzymatic antioxidants involved in cardiovascular defense mechanisms [48, 49].

The oxidative stress may be exerted through quinone metabolites of ISO that react with molecular oxygen to produce superoxide anions and other ROS, which may interfere with cellular antioxidant enzymes [18]. Endogenous antioxidant enzymatic defense plays a key role in neutralizing oxygen free radical-mediated tissue injury [50]. SOD, catalase, and GPx are the primary free radical-scavenging enzymes involved in the first line of cellular defense against oxidative injury, removing both oxygen (O_2) and hydrogen peroxide (H_2O_2) before they can interact to form more reactive hydroxyl radicals [51, 52].

In our study, significantly reduced activities of SOD and GPx and GRx and GST were observed in the heart tissues of ISO-treated rats compared with the activities observed in control rats. The observed decreases in the activities of these enzymes are in accord with findings reported in previous studies [12, 53]; such decreases may be due to the increased utilization of these enzymes for scavenging ROS and their inactivation by excessive ISO oxidants [52]. Pretreatment with MP, however, improved the activities of cellular antiperoxidative enzymes. The findings could be due to the direct free radical-scavenging potency of phenolics in propolis [47]. It is also plausible that MP restores antioxidant enzyme function via upregulation of the activity or expression of Nrf2, an important intracellular transcription factor, released from its repressor (Keap1) under oxidative or xenobiotic stress [46]. The released Nrf2 binds to the antioxidant response element (ARE) in the promoter region of cytoprotective genes and induces their expression. The transcribed genes subsequently induce the expression of free radical-scavenging enzymes to neutralize, detoxify, and eliminate the cytotoxic oxidants [46, 54, 55].

The biochemical improvements reported in the current study are consistent with the histopathological findings, in which the heart tissues of normal control rats and rats treated with MP alone clearly illustrated the integrity of the myocardial cell membrane. The tissue of rats treated with ISO alone showed widespread myofibrillar disorder, necrosis of myocytes, inflammatory cell infiltration, and cardiac muscle fiber separation. However, MP-pretreated hearts showed a near-normal morphology of cardiac muscle with the absence of necrosis and reduced inflammatory cells compared with the hearts of rats treated with ISO alone. Similar histopathological findings were obtained in ISO-treated rats with respect to gallic acid, a phenolic acid also present in honey [56], which also showed remarkable antioxidant properties, further supporting the antioxidant potential of MP as a cardioprotectant. Nevertheless, further research must be undertaken to investigate the active constituents present in MP to confirm the cardioprotective mechanism.

5. Conclusion

MP is a promising source of natural antioxidants, as confirmed by its high polyphenols, flavonoids, tannins, ascorbic acid, and reducing sugar contents, as well as its considerably high DPPH free radical-scavenging activities and FRAP values. Our *in vivo* study confirmed that MP significantly altered nearly all biochemical parameters associated with ISO-induced myocardial injury, as further supported by histopathological findings. MP may have antilipoperoxidative and antioxidant effects that confer these cardioprotective effects.

Disclosure

Romana Ahmed and E. M. Tanvir are joint first authors.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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